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MILITARY HANDBOOK

FUZES

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FOREWORD

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LIST OF ABBREVIATIONS AND ACRONYMS

AA = antiaircraft
ac = alternating current
Acc = accumulator
ADAM = area-denial artillery munition
ADPA = American Defense Preparedness Association
AGC = automatic gain control
AISI = American Iron and Steel Institute
ALU = arithmetic logic unit
AMC = US Army Materiel Command
AMRAD = Joint-Services Fuze Management Board Armament/Munitions Requirements, Acquisition, and Development
AMSAA = US Army Materiel Systems Analysis Activity
ANSI = American National Standards Institute
AP = armor-piercing
APA = Army Procurement Appropriation
APC = armored personnel carrier
APERS = antipersonnel
AQL = acceptable quality level
ARDEC = US Army Research, Development, and Engineering Center
AT = antitank
AT/AV = antitank-antivehicular
BCD = Binary Coded Decimal
BD = base detonating
CAD = computer-aided design
CAE = computer-aided engineering
CB = chemical and biological
C^2E = continuous comprehensive evaluation
CEP = Concept Evaluation Program
CG = center of gravity
CKT = circuit
CL = clock
CLGP = cannon-launched guided projectiles
CMOS = complementary metal oxide semiconductor
CP = concrete-piercing
CPU = central processing unit
CTE = coefficient of thermal expansion
CVT = controlled variable time
CW = continuous wave
dc = direct current
diff-amp = differential-amplifier
DIP = dual in-line package
DLY = delay
DoD = Department of Defense
DTUPC = design to unit production cost
EBW = exploding bridgewire
ECCM = electronic counter countermeasures
ECL = emitter-coupled logic
ECM = electronic countermeasure
ED = energy density
EED = electroexplosive device
EEPROM = electrically erasable programmable ROM
EFI = exploding foil initiator
E-head = electronic head
EM = electromagnetic
EMC = electromagnetic compatibility
EME = electromagnetic effects
emf = electromotive force
EMI = electromagnetic interference
EMP = electromagnetic pulse
EMR = electromagnetic radiation
EO = electro-optical
EOD = explosive ordnance disposal
ESD = electrostatic discharge
ESR = effective series resistance
ET = electronic time
ETF = electronic time fuzes
EUTE = Early User Test and Evaluation
FAE = fuel-air-explosive
FASCAM = family of scatterable mines
FAST = Fairchild advanced Schottky TTL
FASTS = fuze arm spin test system
FDM = force discriminating mechanism
FF = flip-flop
FFAR = folding-fin aircraft rocket
FM = flight motor
FMEA = failure mode and effects analysis
FMECA = failure mode, effects, and criticality analysis
FMU = fuze munition unit
FOGM = fiber-optic guided missile
FOT = follow-on tests
FOTE = follow-on operational test and evaluation
FOV = field of view
FTA = fault tree analysis
GaAs = gallium arsenide
GATOR = ground laid interdiction minefield
GEMSS = ground-emplaced mine scattering system
GM = guided missile
GND = ground
GP = general-purpose
HCMOS = high-speed CMOS
HDL = Harry Diamond Laboratory
HE = high explosive
HE-AP = high-explosive armor-piercing
HEAT = high-explosive antitank
HEAT-MP-T = high-explosive antitank, multipurpose, tracer
HE-CP = high-explosive concrete-piercing

HEDP = high-explosive dual purpose
HEI = high-explosive incendiary
HEI-T = high-explosive incendiary, tracer
HEP = high-explosive plastic
HE-T = high-explosive, tracer
IC = integrated circuit
ICM = improved conventional munitions
ICOMS = improved conventional mine system
IDM = impact delay module
IEEE = Institute of Electrical and Electronics Engineers
IEP = independent evaluation plan
IER = independent evaluation report
I^2L = integrated injection logic
IMPATT = impact avalanche and transit time
Int = interrupt
INV = inverter
IOT = initial operational test
IPR = in-process review
IQR = interrupt request
IR = infrared
IR&D = independent research and development
IRQ = interrupt request
ITL = intent to launch
JOCG/FSG = Joint Ordnance Commanders' Group/Fuse Sub-Group
JSOR = Joint Service Ordnance Requirement
KE = kinetic energy
LAOD = liquid annular-orifice dashpot
Laser = light amplification by stimulated emission of radiation
LAW = Light Antitank Weapon
LCC = life cycle cost
LCD = liquid crystal display
LLNL = Lawrence Livermore National Laboratory
LRIP = Low-Rate Initial Production
LSI = large scale integration
LSTTL = low-power Schottky TTL
MANPRINT = manpower and personnel integration
MCD = magnetic coupling device
MDF = mild detonating fuse
MIL-SPEC = military specification
MIL-STD = military standard
MLRS = multiple launch rocket system
mmw = millimeter wave
MNOS = metal nitride oxide semiconductor
MOPMS = modular pack mine system
MOPP = Mission-Oriented Protective Posture
MOS = metal oxide semiconductor
MOSFET = metal oxide semiconductor field-effect transistor
MT = mechanical time
MTBF = mean time before failure
MTF = mechanical time fuze
MTSQ = mechanical time superquick
mv = muzzle velocity
NATO = North Atlantic Treaty Organization
NBC = nuclear, biological, and chemical
NC = no change
NSB = near-surface burst
NSWC = Naval Surface Warfare Center
OMA = Operations and Maintenance, Army
OMEW = Office of Missile Electronic Warfare
OpAmp = operational amplifier
ORATMS = off-route antitank mine system
ORD = Operational Requirements Document
OSC = oscillator
OSC = oscillator controlled timer
OSC-AMP = oscillator-amplifier
OSTR = one shot transformed response
OT&E = operational test and evaluation
OTEA = US Army Operational Test and Evaluation Agency
PA = Picatinny Arsenal
PAOD = pneumatic annular-orifice dashpot
PCB = printed circuit board
PD = point detonating
PDSD = point-detonating, self-destruct
PDSQ = point-detonating, superquick
PHA = preliminary hazard analysis
PIBD = point-initiating, base-detonating
PIP = product improvement program
Pla = programmable logic array
PLL = phase lock loop
PPT = Production Proveout Test
PROX = proximity
PS = power supply
PT = pyrotechnic time
PUT = programmable unijunction transistor
PYROTIME = pyrotechnic time
QAP = quality assurance provision
QT = Qualification Test
R = reset
RAAM = remote antiarmor mine
RAM = random access memory
RAP = rocket-assisted projectile
RC = resistor-capacitor
RCR = rotation counterrotation
R-C-R = resistance-capacitance-resistance
RDTE = research, development, test, and evaluation
RF = radio frequency
ROM = read-only memory
ROTAC = rotary actuator
rpm = revolutions per minute
rps = revolutions per second
S&A = safety and arming

SAD = safety and arming device
SADARM = search and destroy armor projectile
SAM = surface-to-air missile
SCR = silicon-controlled rectifier
SD = self-destruct
SES = second environment sensor
SESE = secure echo-sounding equipment
SHA = system hazard analysis
SIP = single in-line package
SLUFAE = Surface-Launched Unit Fuel-Air-Explosive
SNORT = Supersonic Naval Ordnance Research Track
SOIC = small outline integrated circuits
SOP = standard operating procedure
SOS = silicon-on-sapphire
SOT = small outline transistors
SPST = single-pole, single-throw
SQ = superquick
SQ-DLY = selectable superquick delay action
SW = switch
TDD = target-detecting device
TDP = technical data package
TDP = test design plan
T&E = test and evaluation
TECOM = US Army Test and Evaluation Command
TEMP = test and evaluation master plan
TEMPEST = electromagnetic fields inadvertently emanating from operating equipment
TIWG = Test Integration Working Group
TOW = tube-launched, optically tracked, wire-guided antitank missile
TRADOC = US Army Training and Doctrine Command
TT&E = technical testing and evaluation
TTL = transistor transistor logic
UMIDS = universal mine dispensing system
US = United States
VARICOMP = variation of explosive composition
VCO = voltage-controlled oscillator
VT = variable time
WP = white phosphorus
WSESRB = Navy Weapon System Explosives Safety Review Board
WSMR = White Sands Missile Range
WW = World War

PART ONE
FUNDAMENTAL PRINCIPLES OF FUZES

Part One presents the fundamental principles of fuzes. The discussion includes the purpose and operation of a fuze, design considerations, principles of fuze initiation and explosive train design. Chapter 1 provides a comprehensive discussion of all types of fuzes for the various types of ammunition used by the services. Chapter 2 discusses the philosophy of fuze design and general guidelines on the conduct of a fuze development program. Chapter 3 describes the methods of target sensing and fuze initiation. Chapter 4 provides information on the design of components which make up the fuze explosive train.

CHAPTER 1
INTRODUCTION

This chapter begins with the definition of a fuze in terms of its application to munitions of providing safety during the factory-to-function sequence and its final mission of effecting initiation at the required time and place to optimize damage to the target.

The wide variety and intended use of munitions, which control the design and configuration of fuzes, are explained along with the gradation in complexity from the very simple fuze used in small caliber rounds to the highly sophisticated radar fuze of the guided missile.

Components related to fuzes, such as power sources, explosive items, timing, and safety and arming devices (SAD), are covered in some detail.

Fuze action is described in terms of the functioning of its explosive train beginning with the initiating stimulus and proceeding by explosive amplification stages to final detonation of the munition. The rationale for isolating the initiating element (detonator) until arming is described.

Fuze design philosophy employed by the United States as a means to attain the required safety level is discussed along with the balance required between safety and reliability. The arming process is shown in graphical form.

Beginning with artillery ammunition, typical ammunition items in stockpile and under development by the Army are listed and described. Rifled and smooth bore guns, guns of small through large caliber, automatic and single fire systems, high-angle fire guns (such as howitzers and mortars), and long-range rifles are discussed.

A specific munition used as tank main armament is described in some detail to illuminate such highlights as the use of a shaped charge for armor penetration, requirement of a nonspin projectile, and the use of a combustible cartridge case to reduce clutter within the tank.

Rocket ammunition, which has the unique characteristic of low launch setback (acceleration), or recoil, relative to the launch platform, is discussed. Artillery rockets, aircraft-delivered rockets, and man-portable rockets are explained as they relate to fuzing requirements.

Guided missiles, although for the most part rocket propelled, are a separate category that places high demands on fuze design. Categories covered are surface-to-surface, surface-to-air, and air-to-surface. Guidance by laser, infrared (IR), radar, and wire is explained.

Requirements placed on fuzes by the stationary munitions, e.g., mines and boobytraps, which must wait for the target to come to them and which have little or no environment to arm a fuze, are also covered. The emergence of the mine as a vitally important and flexible weapon of modern battlefield warfare is described. The radical changes in conventional mine design as effected under the family of scatterable mines (FASCAM) are explained as a quick strike emplacement capability through air, artillery, and special purpose ground delivery techniques. Since this system offers a usable arming environment, fuzes for such mines have taken on greater capabilities, and they are covered herein. Target sensing by seismic, acoustic, radio frequency (RF), and magnetic influences is described.

Like mines, the hand grenade—originating in its present form in World War I—has been vastly expanded to include propellant-launched grenades with greater range than the obsolete rifle grenade and delivery of antitank and antipersonnel grenades by cargo-carrying rounds. In the latter capacity the grenade is classified as a submunition.

A fuel-air-explosive (FAE) weapon capable of detonating minefields and incapacitating enemy troops who are under cover of foxholes and bunkers is also discussed. This weapon consists of a flammable gas contained as a liquid and mixed with air to form an explosive mixture. The intricate fuzing system needed to effect use of this weapon is described and illustrated.

The categorization of fuzes is discussed by end-item, by purpose, by tactical application, by functioning action, and by location in the munition. Detailed description of fuzes is given by functioning action, such as impact, time, proximity, command, and combination. Fuze nomenclature for the Army, Navy, and Air Force is described and examples are given.

The remainder of the chapter is devoted to a detailed description and illustration of representative fuzes for such functioning modes as impact; time, i.e., mechanical, electronic, and pyrotechnic; and proximity in artillery weapons, aircraft-delivered weapons, and guided missiles.

1-1 DEFINITION AND PURPOSE OF A FUZE

The word fuze is used to describe a wide variety of devices used with munitions to provide basically the functions of (1) safety, i.e., keeping the munition safe for storing, handling (including accidental mishandling), transportation, and launching or emplacing, (2) arming, i.e., sensing the environment(s) associated with actual use including safe separation and, thereupon, aligning explosive trains, closing switches and/or establishing other links or logic to prepare the munition for functioning, and (3) firing, i.e., sensing the point in space or time at which initiation is to occur and effecting such initiation. See Ref. 1 for nomenclature and definitions in the ammunition area. Distinct fuze terms are defined in the glossary.

There is a very wide variety of munitions in existence, and new ones are continually being developed. They include artillery ammunition (nuclear and nonnuclear), tank ammunition, mortar ammunition, mines, grenades, pyrotechnics, rockets, missile warheads (nuclear and nonnuclear), and other munition items. Because of the variety of types and the wide range of sizes, weights, yields, and intended uses, it is natural that the configuration, size, and complexity of fuzes also vary over a wide range (Refs. 2 and 3). Fuzes extend from a relatively simple device such as a grenade fuze to a highly sophisticated system or subsystem such as a radio frequency (RF) proximity fuze for a missile warhead. In many instances the fuze is a single physical entity, such as a grenade fuze, whereas in other instances two or more interconnected components placed in various locations within or even outside the munition make up the fuze or fuzing system.

There is also a wide variety of fuze-related components, such as power sources, explosive initiators, timers, safety and arming devices (SAD), cables, and control boxes. These components are sometimes developed, stocked, and issued as individual end-items but in the overall picture comprise a part of the fuzing system.

Leading nations employ the most advanced technology available in the design of modern weapons and are constantly advancing the state of the art. This fact is particularly true of fuzes because of their important and exacting role, which in effect is to constitute the brain of the munition. This handbook is concerned with some of the basic principles underlying the design of fuzes. The final design of any fuze will depend upon the role and performance required of it and upon the ingenuity of the designer; thus attention in this handbook is focused on basic principles. Illustrations of applications are purposely kept as simple as possible in order to leave the final design approaches, as they must be, to the fuze designer.

1-2 FUZE ACTION

Inherent to the understanding of fuze design is the concept of the progression of the action of the explosive train (Ref. 4), which begins with initiation and progresses to the functioning of the main charge in the warhead. Initiation, as the word implies, starts with an input "signal", such as target sensing, impact, or other stimulus. This "signal" then must be amplified by such devices as a detonator (first stage of amplification), a lead (second stage of amplification), and a booster (third stage of amplification). The booster has an explosive output of sufficient force to function the main charge. The detonator contains explosives that are very sensitive because it is required to respond to the initial weak signals. The basic role of the fuze is not only to indicate the presence of the target and to initiate the explosive train but also to provide safety by separating the detonator from the remainder of the explosive train until arming is acceptable. Significant casualties to property and life in the past have been directly traceable to inadequate built-in fuze safety.

As an approach to providing adequate safety, present design philosophy calls for a fuze to have at least two independent safety features wherever possible, each of which is capable of preventing an unintended detonation. At least one of these features must provide delayed arming (safe separation). This and other aspects of safety are discussed in detail in Chapter 9. Reliability of functioning is also a primary concern of the fuze designer, details of which are covered in par. 2-3.

Fig. 1-1 is a diagram of the steps involved in a typical arming process. At the left the fuze is represented as unarmed so that it may be stored, transported, handled, and

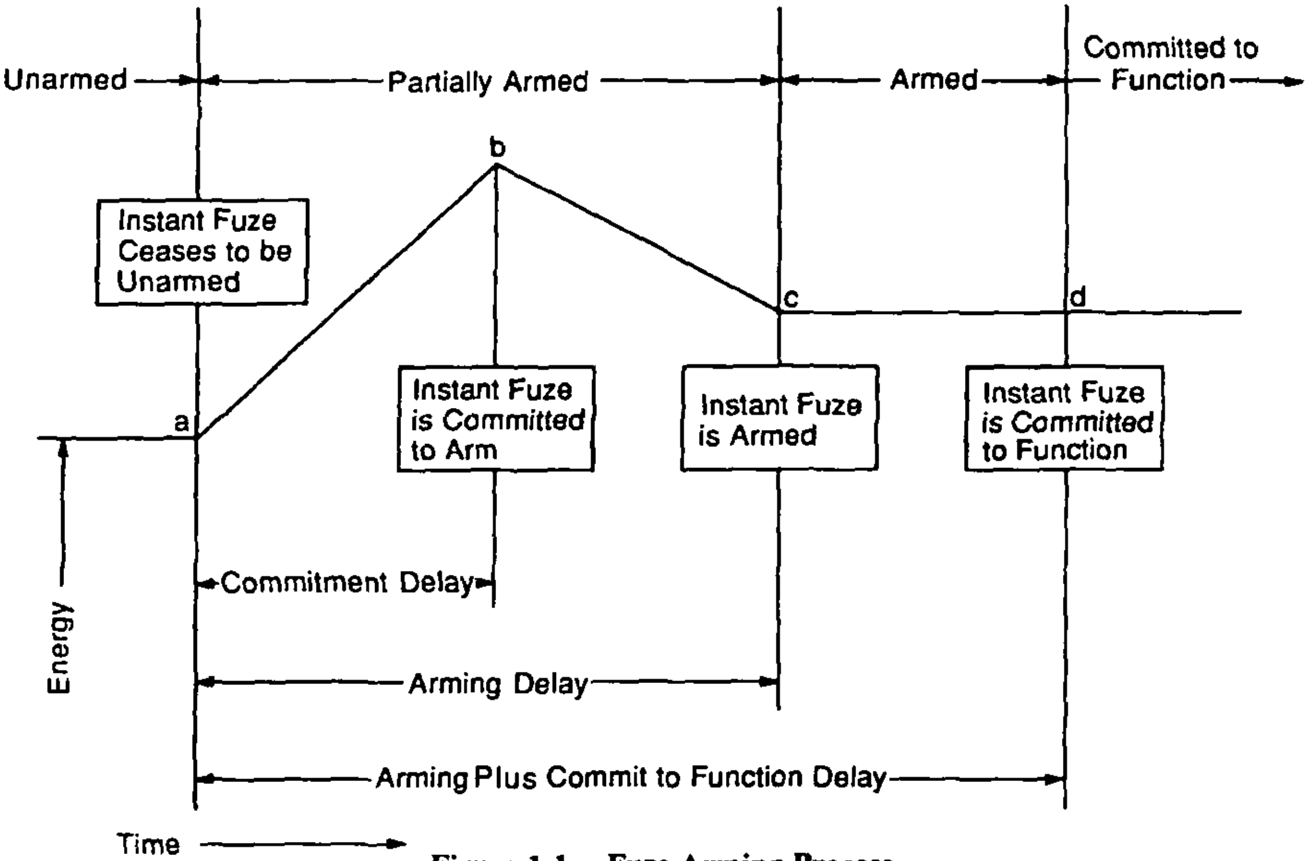


Figure 1-1. Fuze Arming Process

safely launched. The arming process starts at "a" by adding energy to the system in a proper manner. At "b" enough energy has been added so that the device will continue to completion of the arming cycle. At any time between "a" and "b" the device will return to or remain in the unarmed condition if the energy is removed or the threshold level is insufficient to sustain arming. After "b" the fuze is committed to continue the arming process; therefore, "b" is termed the commitment point. The explosive train is aligned at "c", and the fuze is considered armed. In some fuze designs, however, other functions, such as switch closure, must occur before the fuze can function as intended. In these cases the fuze is said to be explosively and electrically committed to function after switch closure is completed at "d".

1-3 TYPICAL ARMY AMMUNITION ITEMS

Depending upon its tactical purpose, ammunition can carry a fuze in its nose, its base, or any interior location. To illustrate this versatility, several common fuze carriers are described.

1-3.1 PROJECTILES

Artillery munitions can be classified according to the payload carried, such as high explosive (HE), high-explosive incendiary (HEI), high-explosive armor-piercing (HE-AP), high-explosive concrete-piercing (HE-CP), high-explosive plastic (HEP), high-explosive antitank (HEAT), improved conventional munitions (ICM), illuminating, smoke, and chemical (Refs. 5 and 6). By and large these munitions follow a ballistic trajectory although guided projectiles now exist in the inventory.

Another classification is according to usage, such as antiaircraft (AA), antitank (AT), antipersonnel (APERS), and armor-piercing (AP).

Some projectile launch platforms induce spin (rifled bore), whereas others do not (smooth bore). The nonspin types usually require fins for flight stabilization; however, tank main armament can be smooth bore and not require fin stabilization. Rifled launchers are cannon (automatic), howitzers, and rifles. The mortar generally is launched from a smooth bore platform. Some fin-stabilized rounds are adaptable to a rifled barrel.

1-3.1.1 Artillery

Artillery ammunition is classified according to form as fixed, semifixed, separated, and separate loading. In fixed ammunition, as shown in Fig. 1-2, the cartridge case is rigidly attached to the projectile and the propelling charge is nonadjustable (Refs. 5 and 6). In semifixed ammunition, as shown in Fig. 1-3, the increment-sectioned cartridge case—which contains the propelling charge—is not permanently fixed to the projectile so that the charge is accessible for adjustment for zone firing. In separated ammunition, as shown in Fig. 1-4(A), the propelling charge is sealed in a metal cartridge case by a closing plug and is nonadjustable. Separated ammunition is used when the ammunition is too large to handle as fixed ammunition. All of the previously discussed types are loaded into the gun in one operation, and the cartridge case is fitted with a primer. In separate loading ammunition—as shown in Fig. 1-4(B)—the projectile, propelling charge, and primer are loaded into the weapon separately. The projectile is inserted into the breech and

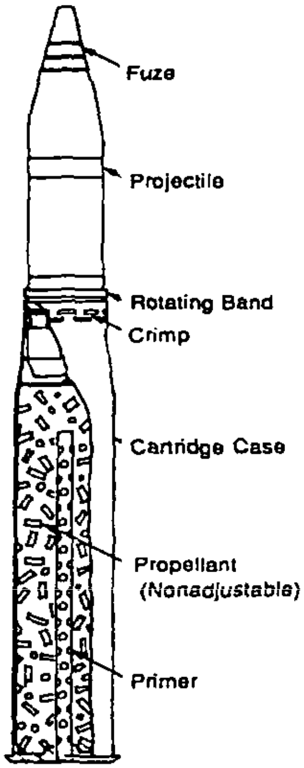


Figure 1-2. APERS-T, Fixed Artillery Round, 105 mm, M494

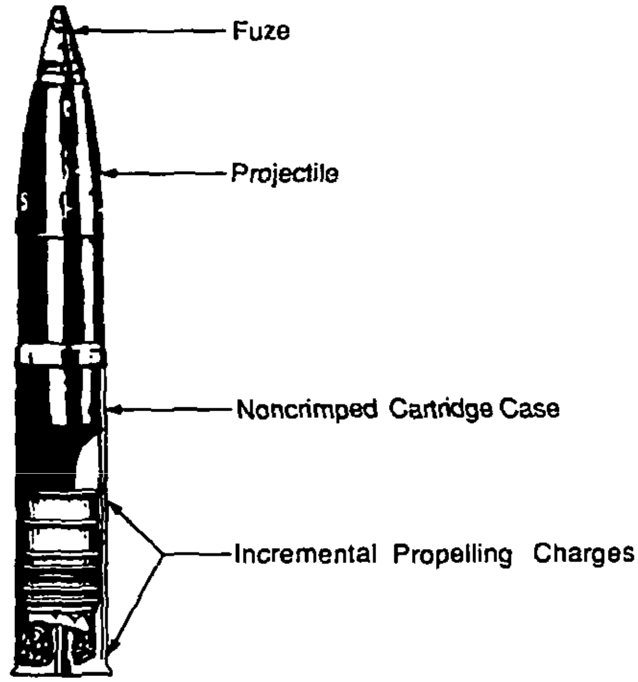


Figure 1-3. Semifixed Ammunition

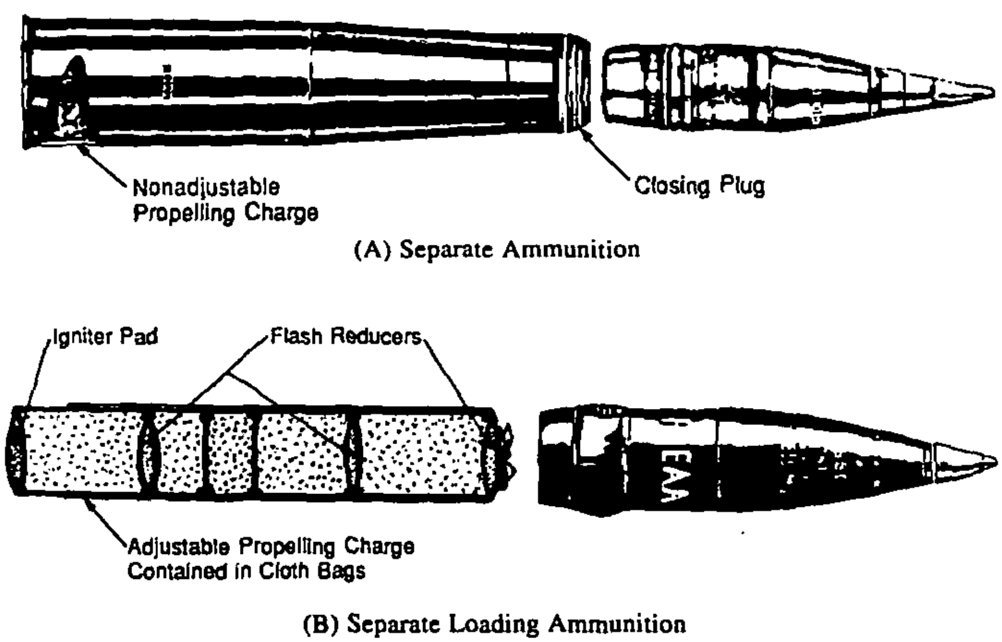


Figure 1-4. Separate Ammunition

rammed so that the rotating band seats, and the propelling charge, which is adjustable, is placed in the chamber immediately to the rear of the projectile. The primer is inserted into the breechblock after it has been closed.

The cartridge case primer consists of an electric percussion primer and a black powder igniter charge, which ignites the propellant directly or by means of a black powder igniter bag fixed to the propellant envelope. The resulting gases propel the projectile out of the gun tube.

Most projectiles are equipped with a rotating band that, when rammed into the gun barrel, centers the base of the projectile in the bore and helps prevent escape of propellant gases. As the projectile moves forward, rifling in the bore of the gun barrel (Ref. 7), which is helical, engraves the band and imparts spin to the projectile. This rotation stabilizes the projectile in flight.

Although they differ in characteristic details, artillery projectiles are of the same general shape, i.e., they have a cylindrical body and generally an ogival or conical head. Some special purpose projectiles (Ref. 8), such as armor piercing, have a hardened steel penetrator encased in an aluminum and magnesium sabot. These projectiles contain no explosives and use kinetic energy as the principal means of defeating an armored target.

Other AP projectiles use a shaped charge (See Refs. 9 and 10 for detailed discussions of shaped charges.), as shown in Fig. 1-5, which, when detonated, produces a jet of high-velocity metal. The energy of the jet causes failure of the armor, and metal particles penetrate the interior of the target.

A new family of improved conventional munitions has been developed to deliver submunitions. These projectiles contain a payload of either dual-purpose grenades or antitank or antipersonnel mines, as illustrated in Fig. 1-21. An expulsion charge is contained in the nose of the projectile to eject the payload, and the payload is dispersed over a wide area by centrifugal force induced by the spinning projectile.

Both the Army and the Navy have fielded a new generation of "smart weapons" (Ref. 11) designed to permit highly accurate delivery of artillery projectiles. The Army's COPPERHEAD, shown in Fig. 1-6, and the Navy's 5-in./54

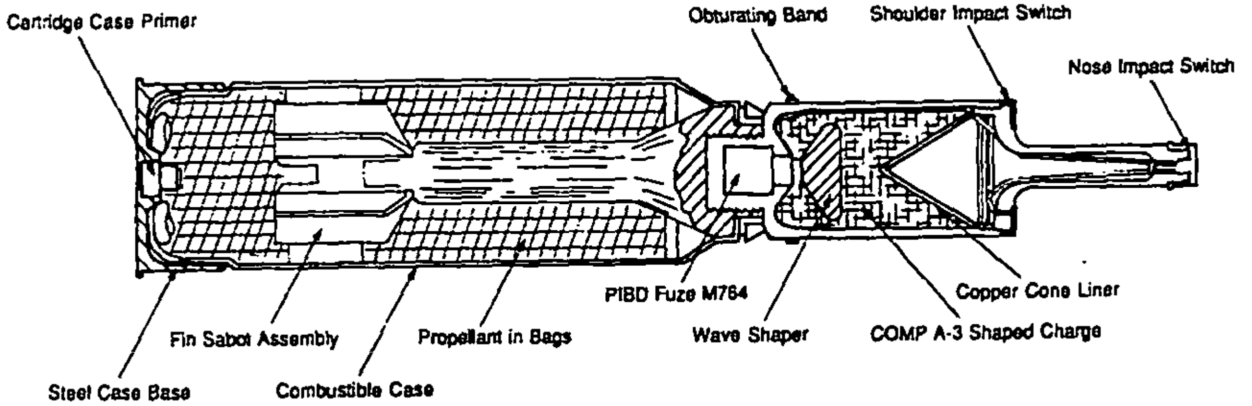


Figure 1-5. Cartridge, 120 mm, HEAT-MP-T, M830

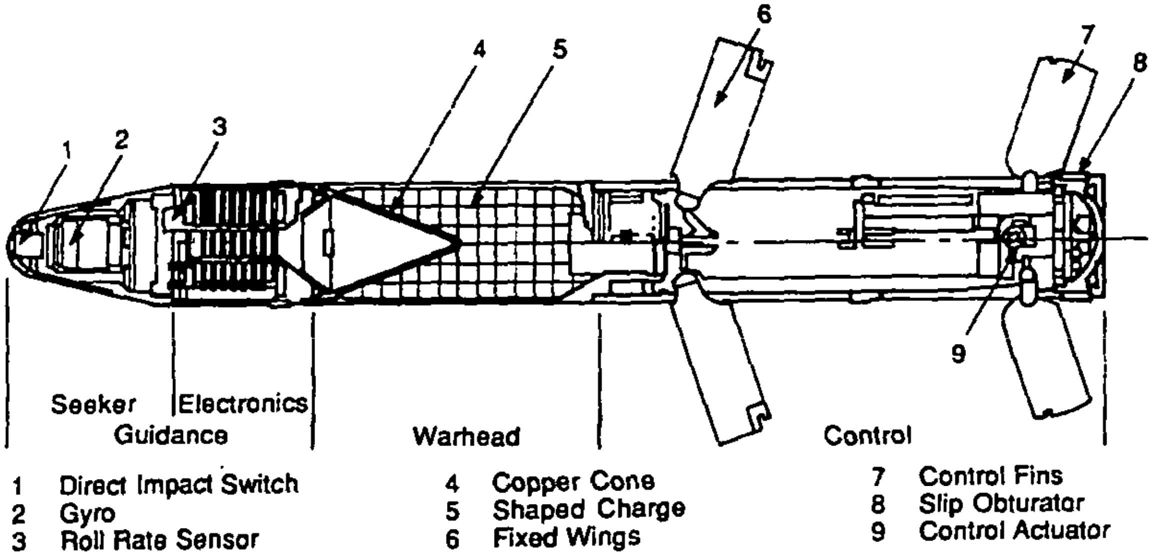


Figure 1-6. 155-mm Cannon-Launched Guided Projectile (CLGP) COPPERHEAD

Guided Projectile contain a seeker and electronic package in the forward section; the warhead and fuze in the midsection; and the guidance and control section, power supply, and control fins in the rear section. These munitions contain guidance and fuzing elements that can be activated by target signatures which are passive infrared (IR) or externally induced (laser designated).

An extension of the major thrust of the Army toward development of smart weapons is the search and destroy armor (SADARM) projectile (Ref. 11) for the 155-mm howitzer. When fielded, the SADARM projectile will give the Army a fire-and-forget capability against moving and stationary targets. The SADARM projectile, shown in Fig. 1-7, contains two submunitions, each equipped with a millimeter wave and/or IR sensor, a drogue, a SAD, and an explosive charge with a self-forging fragment lens. Upon expulsion from the projectile, the submunitions are deployed and stabilized by the drogues. The submunitions scan the target area and, upon sensing the location of a target, detonate their warheads. A self-forging fragment forms, which impacts and destroys the target. The SADARM projectile is one of several smart projectile weapon systems that are in development.

Three types of fuzing are used with artillery projectiles. They are direct target impact, proximity to the target, and time preset prior to launch. Multioption fuzing concepts (par. 1-6.3) combining all of these methods of initiation into a single fuze are under development.

1-3.1.2 Mortars

Mortars (Ref. 6) are generally smooth bore, muzzle loaded, high-angle fire weapons. The 81-mm round shown in Fig. 1-8 has a nose fuze, a high-explosive payload, and

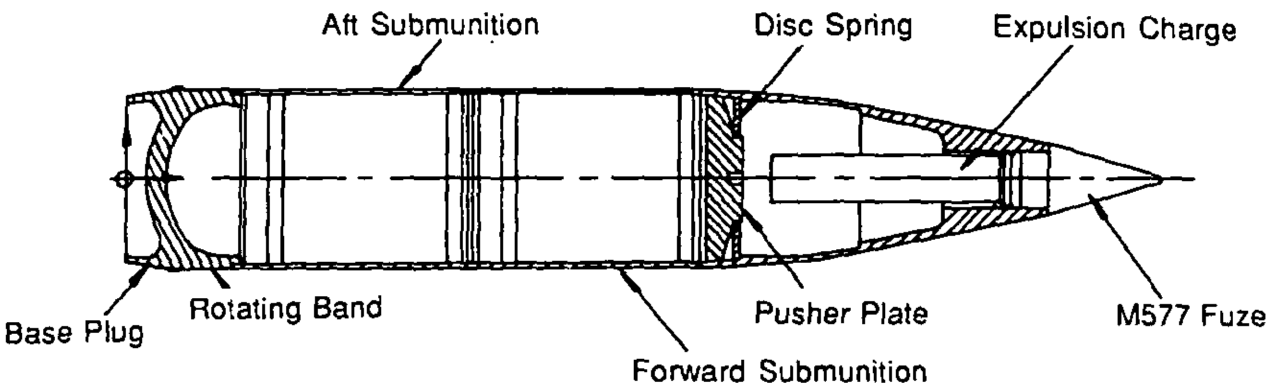


Figure 1-7. 155-mm SADARM, XM898 Projectile

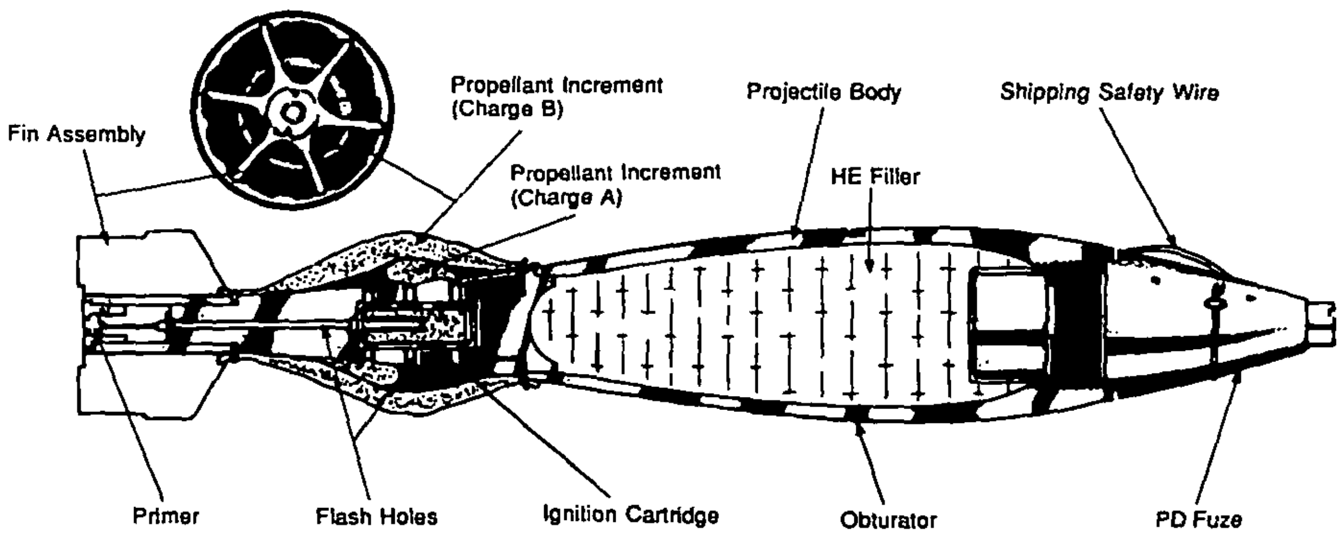


Figure 1-8. Mortar Cartridge, 81mm, M374A2

a tail-fin assembly with ignition and propellant charges attached. As the cartridge slides down the mortar tube, a percussion primer in the fin assembly is initiated by striking a fixed firing pin in the base cap of the mortar tube. The burning primer flashes through a hole in the cartridge housing to ignite the ignition cartridge. This in turn ignites the propellant charge, which propels the cartridge toward the target under fin stabilization. Range is controlled by the angle of elevation and/or the number of propellant increment charges used.

Ammunition for mortars is classified as HE, illuminating, white phosphorus (WP) smoke, and training or target practice. HE cartridges are used mainly against light materiel and personnel and function with both fragmentation and blast effects. Smoke cartridges contain a WP filler and are used to provide a screening smoke or as an incendiary device against personnel and materiel. Illuminating cartridges contain a parachute and an illuminant charge capable of burning up to 60 s with a minimum of 500,000 candlepower. They are used at night to illuminate a desired point or area.

A maximum fire rate of 30 rounds/min is allowable for a 1-min period, 18 rounds/min for periods not exceeding 4 min, and 8 rounds/min indefinitely.

Mortar sizes are 60 mm, 81 mm, 4.2 in., and 120 mm. 4.2-in. mortars do not have fins, but they are fired from rifled tubes and are therefore spin stabilized. To permit free-fall in the tube, the rotating band is recessed and then expanded by the propellant pressure to engage the rifling.

Mortars use point-detonating, time, and multioption (proximity, near-surface burst, instantaneous, and delay) fuzes. Arming delay is achieved by clock mechanisms, air bleeds, pyrotechnic delay, or air vane and gear reduction systems. Setback forces range from 300 to 10,000 g and muzzle velocities (mv) from 47 to 302 m/s (156 to 990 ft/s) with ranges from 274 to 5669 m (300 to 6200 yd). Range is controlled by tube elevation and by increments of propellant that are attached to the fin assembly.

1-3.1.3 Tank Main Armament

A typical projectile for tank main armament is the High-Explosive Antitank, Multipurpose, Tracer (HEAT-MP-T) M830 cartridge shown in Fig. 1-5. This round is fired from the 120-mm smooth bore cannon M256. It is nonspin to prevent degradation in performance of the shaped charge (Refs. 5, 9, and 10) and has a combustible cartridge case to minimize clutter within the tank. The complete round consists of a projectile fixed to the cartridge case. This configuration is different from earlier tank ammunition, which used separate cartridge cases. The projectile contains a shaped charge; a spike nose; a point-initiating, base-detonating fuze; a tracer element (located at the base of the projectile and not shown in the figure); and fins. Although used primarily as an armor-defeating round, the M830 possesses effective fragmentation capability and is, therefore, a multipurpose projectile. A contact switch, contained in the nose spike, acts as one of three means of triggering initiation of the fuze explosive train. Located in the shoulder is another contact switch that, combined with the nose switch, provides a good frontal area impact sensor system. The third impact sensor is located in the base fuze, and it consists of an inertia spring mass, which triggers fuze initiation on graze impacts. A detailed description of the fuze is in par. 1-7.

1-3.1.4 Automatic Cannon

Automatic cannons are rifled guns that are noted for their severe environments of loading forces, spin, and launch acceleration. The ammunition is essentially all HE and fitted with nose fuzes (Ref. 12); however, some foreign rounds have base fuzes. The main uses of these cannons are for antiaircraft, antivehicle, and air-to-air and air-to-ground targets. The airborne cannons do not generally exceed 30 mm because the airframe is normally limited to the recoil of this caliber.

Launch platforms for this class of ammunition consist of helicopter, high-speed jet aircraft, and towed and tracked armored gun systems. A development effort is ongoing to provide a hybrid gun system consisting of an automatic cannon combined with a ground-to-air missile to engage air targets. This combination will provide extended range and a high degree of lethality to the system, and the cannon will provide quick reaction time, countermeasure immunity, and close-in encounter capabilities.

Fuzes for automatic cannon-launched rounds generally use disc or ball rotor mechanisms—to be discussed later—which arm relatively close to the launch vehicle—10 to 100 m. A self-destruct feature usually is employed in ground-launched, small-caliber rounds for antiaircraft use to preclude hazards to friendly troops and materiel deployed nearby from armed rounds that miss the target.

1-3.1.4.1 20 Through 40 mm

A typical 25-mm round is shown in Fig. 1-9. The round is used in the M242 BUSHMASTER gun against ground and air targets. The fuze provides superquick, graze, and self-destruct modes of function. The gun environments are setback, 104,000 g; spin, 1734 revolutions per second (rps); muzzle velocity, 1097 m/s (3599 ft/s), and creep 63 g.

Functioning occurs at target impact by means of a stab firing pin driven into the detonator or on graze by means of an inertia plunger, which drives the detonator onto the firing pin. Self-destruction occurs at a predetermined range if no target is encountered and thus protects friendly troops and/or installations. A detailed description of the M758 fuze used with this round is contained in par. 1-8.1.

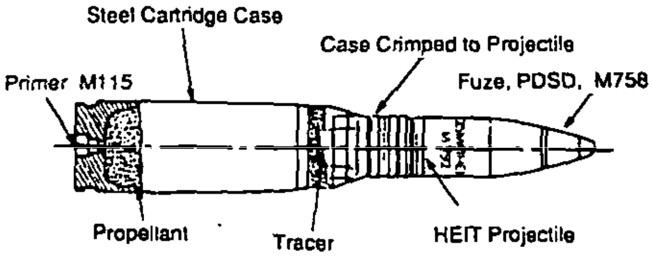


Figure 1-9. Typical 25-mm Round, M792

1-3.1.4.2 Larger Than 40 mm

A medium caliber (75-mm), automatic rapid-fire cannon mounted in a tracked armored gun carrier is designed to defeat medium- and heavy-armor threats. Two types of ammunition have been developed; a telescoped kinetic energy round, XM885, shown in Fig. 1-10(A) and an HE round, XM884, with a multipurpose fuze. The XM884 round is intended for use against light armor, buildings, and bunkers.

The Navy uses the 76-mm "Oto-Melara" automatic rapid-fire cannon mounted on hydrofoil craft designed for high-speed torpedo attack on unarmored or lightly armored surface ships. The HE round shown in Fig. 1-10(B) is nose fuzed and has superquick and delay function options. The fuze, MK 407 Mod 1, shown in Fig. 1-43 and described in par. 1-8.2, differs from the conventional Army point-detonating (PD) fuze in that it has a hardened steel penetrating body to enhance target penetration.

1-3.2 ROCKETS

Rocket ammunition (Ref. 13) has the unique advantage of zero setback or recoil relative to the launcher. This permits the launching of large warheads from light structures, such as fixed and rotary wing aircraft, trucks, and from the shoulders of troops. Rockets range in caliber from 66 to 345 mm (2.6 to 13.58 in.) and can deliver a large variety of payloads including HE, shaped charge, flechette, grenade, smoke, incendiary, illuminating, and fuel-air-explosive (Refs. 14 and 15).

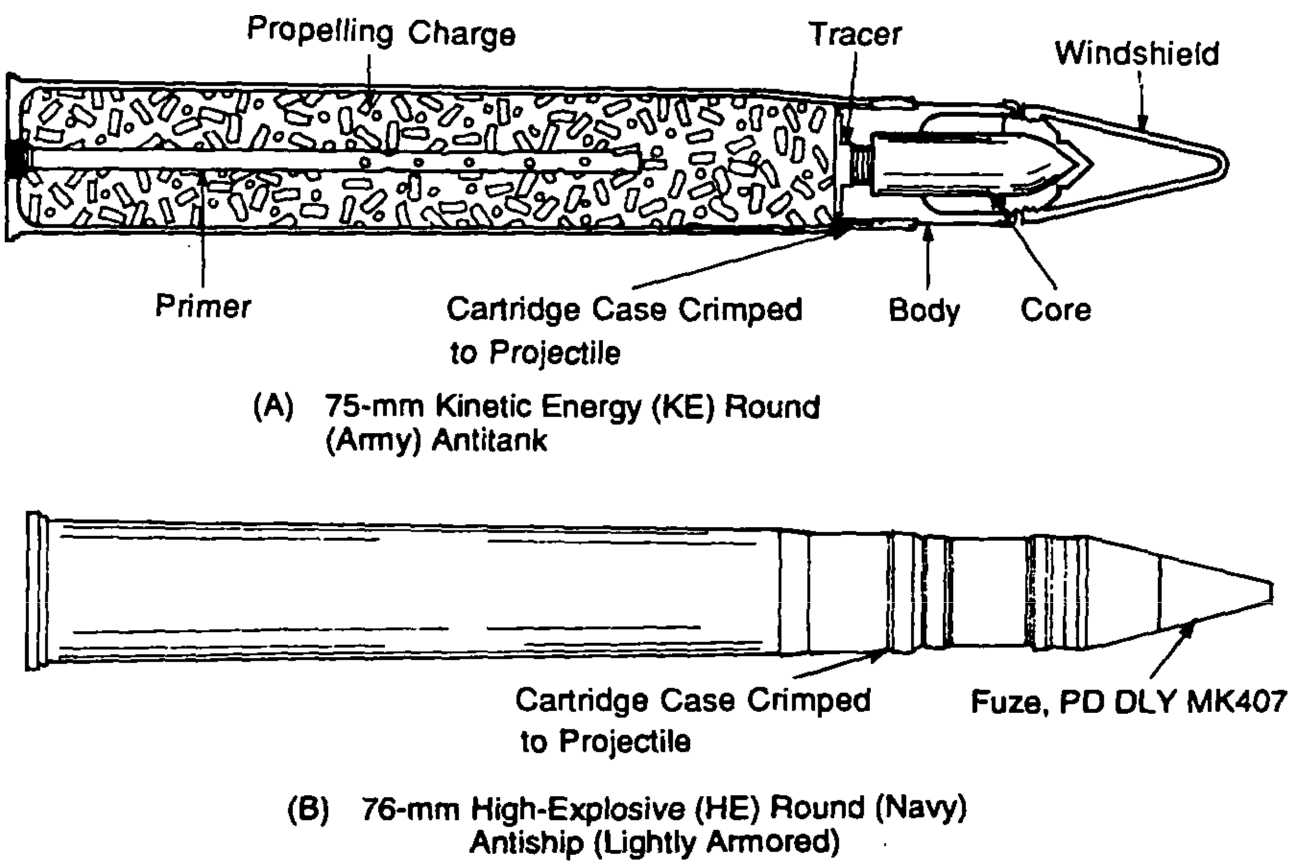


Figure 1-10. Ammunition, Automatic Cannon, 75 mm and 76 mm

Essentially all rockets are fin stabilized, provide thrust for only a short period of time, and by comparison are less accurate than tube-fired ammunition. For these reasons, most rockets are fired from relatively short ranges. The only notable exception is the Multiple Launch Rocket System (MLRS), shown in Fig. 1-11, which is used for long-range area coverage missions.

Most rocket fuzes use acceleration as one environment to remove a lock from the out-of-line explosive train and an acceleration-integrating device to achieve safe separation from the launch platform. Current rocket fuze designs use ram air, air drag, or electroexplosive devices to activate a second independent lock on the out-of-line explosive train in order to comply with MIL-STD-1316, *Safety Criteria for Fuze Design*.

1-3.2.1 Artillery Rockets

Rockets used as artillery are launched from multiple launchers mounted on vehicles. One such system is the 228-mm cargo-carrying rocket. The M42 submunitions with shaped charge and fragmenting case are dispensed from the warhead shown in Fig. 1-12 by an electronic time fuze (par. 1-9.2) against ground personnel and light materiel.

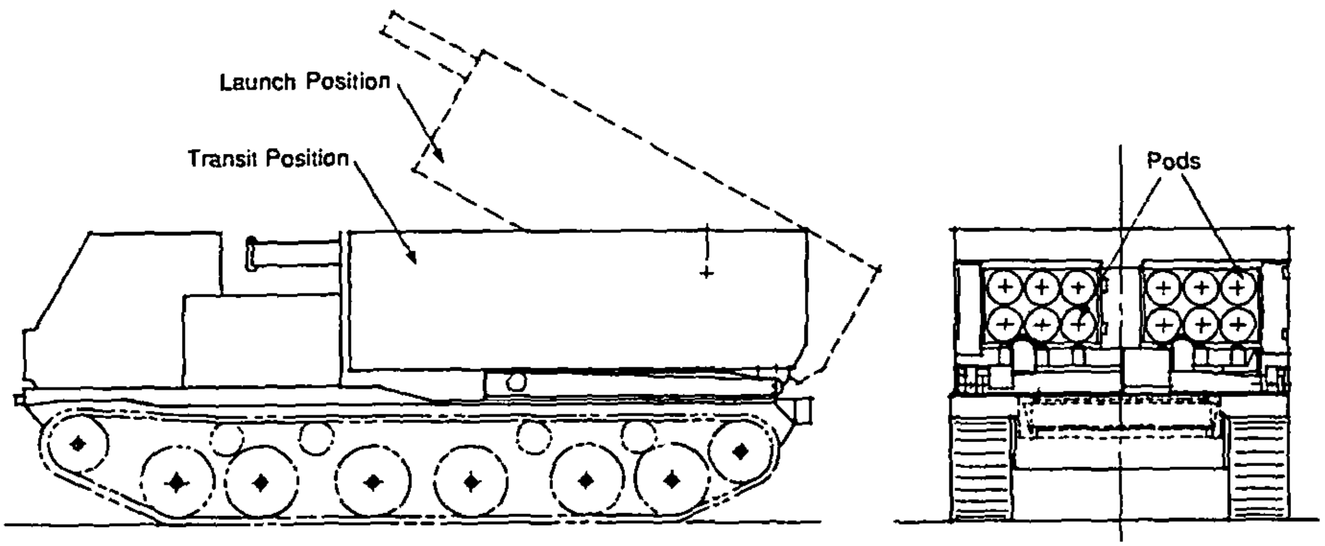


Figure 1-11. 228-mm (9-in.) Multiple Launch Rocket System

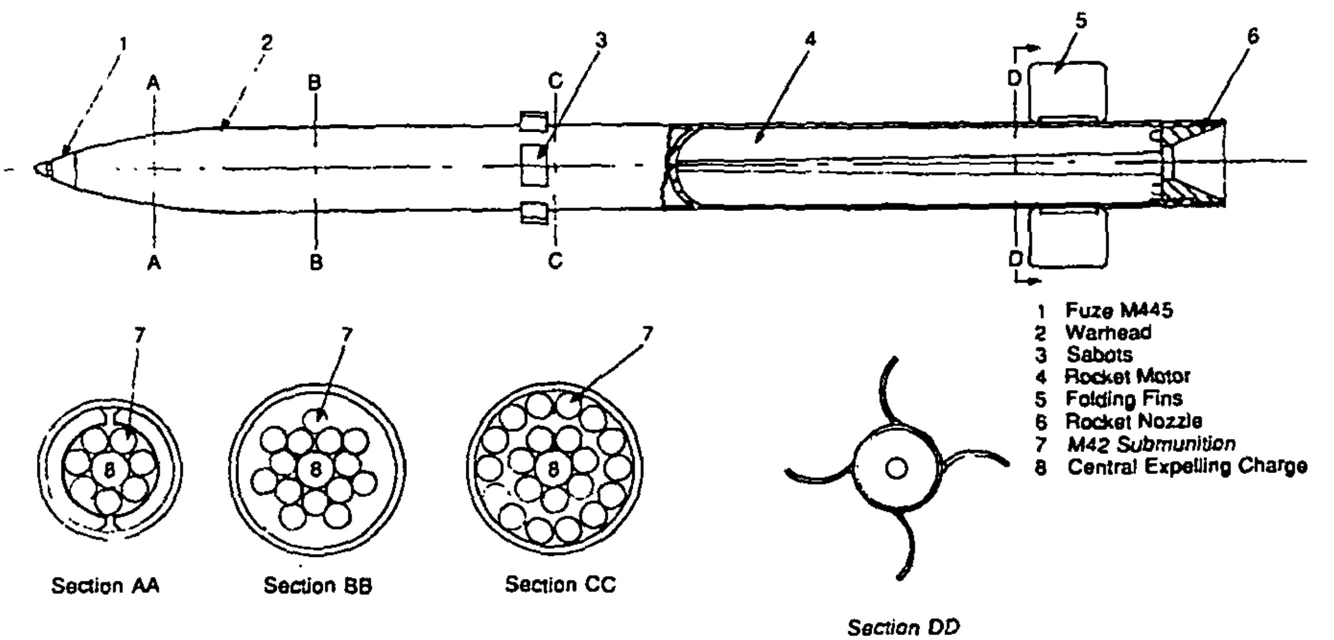


Figure 1-12. Rocket-Launched Submunition Dispensing Warhead

The fuze for the submunition (par. 1-13) is a simple, mechanical, inertia-fired, impact fuze armed by the restraint of a trailing ribbon. The dispensing fuze M445 (par. 1-9.2) is an electronic time fuze located in the nose of the rocket.

This munition rotates at 12 rps, experiences 100 g acceleration, and has a velocity of 1000 m/s (3281 ft/s). To achieve fuze arming, the rocket must sustain motor boost for 1.25 s at 31 g minimum. A second safety environment used for arming of the M445 fuze is sustained airflow of 70 m/s (230 ft/s).

The purpose of the cargo rocket is to maximize the area of coverage.

1-3.2.2 Aircraft Rockets

The 70-mm (2.75-in.) folding-fin aircraft rocket (FFAR) (Ref. 13) is the smallest rocket carried by high-speed, fixed-wing aircraft and rotary-wing aircraft. It is carried in quantities in jettisonable pods, which are usually fixed to standard bomb racks or special attachments. A number of launched rocket payloads—such as HE, smoke, flechette, and illuminating—can be delivered by aircraft. Most aircraft rockets are composed of four major assemblies: the fuze (may be nose or base), the warhead, rocket motor, and a folding-fin assembly, as shown in Fig. 1-13. The rocket

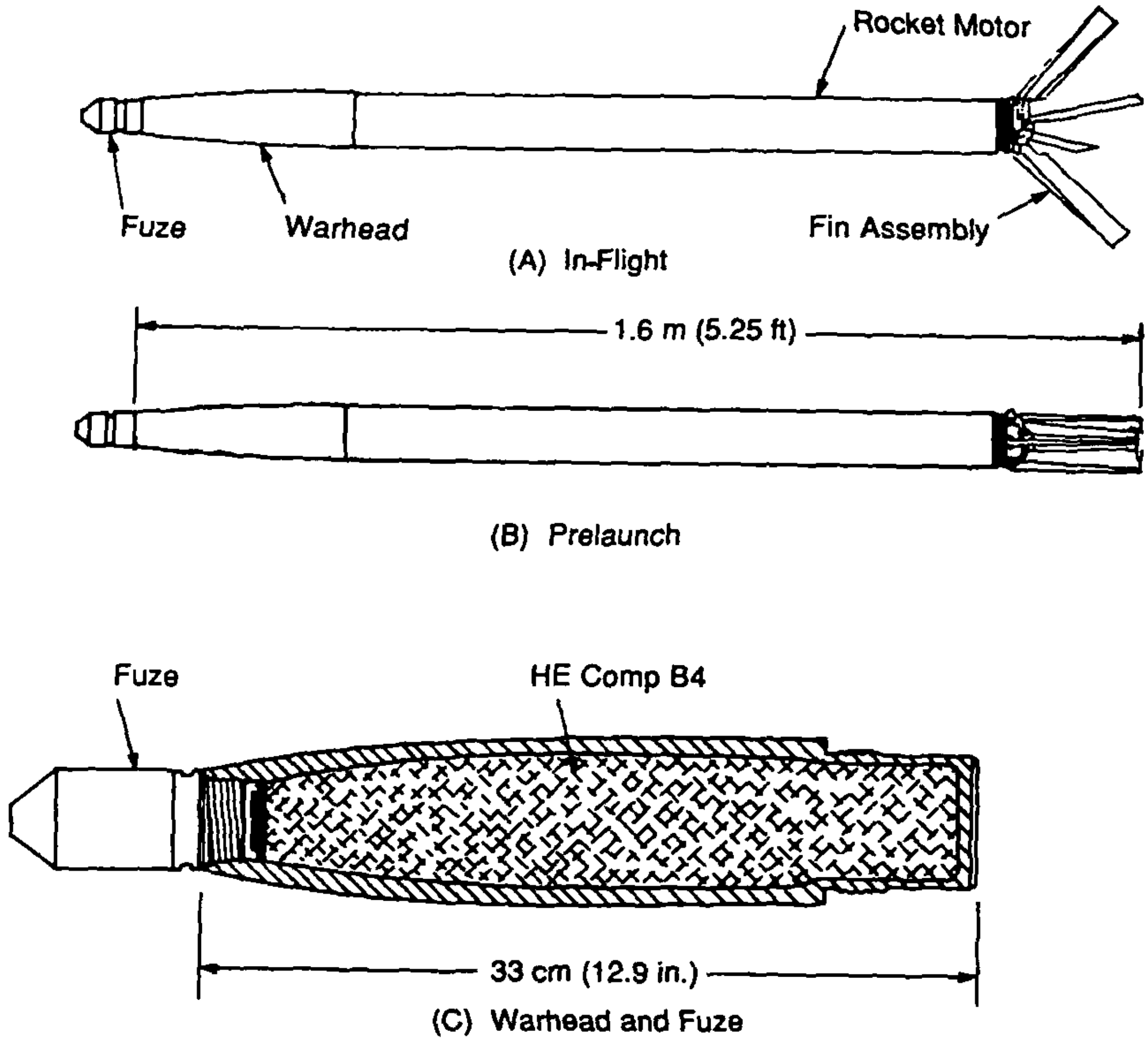


Figure 1-13. 70-mm (2.75-in.) Folding-Fin Aircraft Rocket (FFAR) With M151 Warhead

motor is ignited by an electric igniter that uses on-board aircraft power. Aircraft rocket fuzes can be of the following types: PD, time (electric or pyrotechnic), proximity, and combinations of these. Par. 1-9.1 provides a detailed description of a typical mechanical fuze used with an aircraft-launched HE warhead.

1-3.2.3 Man-Portable Rocket

The 66-mm (2.60-in.) rocket Light Antitank Weapon (LAW) (Fig. 1-14), M72A3 HEAT with electromechanical fuze M412E1 is a means available to the individual foot soldier to attack armored vehicles. The weapon is shoulder fired. The principle evolved from the World War II "BAZOOKA" weapons. Improved fuze and improved accuracy in target acquisition have been introduced along with a significant increase in target damage. The round consists of a light case shaped-charge warhead with an armor-penetrating capability of 230 to 280 mm (9 to 11 in.) and a single-stage motor that produces 283 m/s (928 ft/s) velocity at 8000 g setback. The round is packaged in a telescoped launcher tube, which can be considered expendable.

The fuze is point initiating with a nose piezo crystal power source and is base detonating. An inertia trigger weight provides graze sensitivity. Arming is controlled by setback action on a falling leaf mechanism, which is described in par. 6-5.3.

1-3.3 GUIDED MISSILES

Guided missiles as a class are rocket powered with the exception of the Cruise missile, which is powered by a jet engine. Guidance is necessary to provide a high probability of one-shot kill against fast-moving targets (aircraft), erratically moving targets (vehicles and helicopters), radiating targets, and under conditions of poor visibility, e.g., clouds, fog, smoke, and darkness.

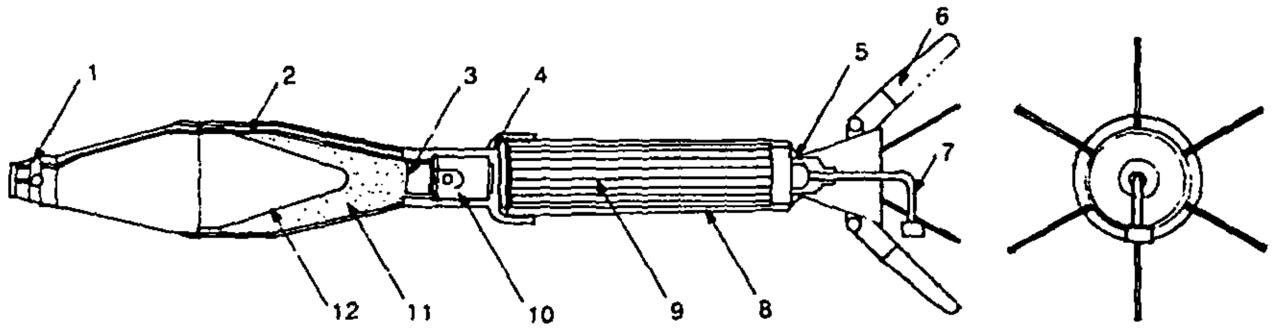
There is a large variety of guidance systems, and in some cases they are used in combination. Wire guidance is used in surface-to-surface and air-to-surface (from helicopters) applications, laser guidance is used in surface-to-surface and air-to-surface applications, and heat-seeking IR guidance is used on targets with heat-emitting signatures. Some heat seekers are used against tanks, but their effectiveness is degraded after one tank is hit and burning because other missiles may home-in on the burning tank. Other methods are used in missiles that home-in on the electronic emissions from the target, e.g., an enemy radar complex. Some long-range surface-to-air missiles (SAMs) have ground control guidance with the missile picking up the target and supplying data to ground control for final run-in.

Fuzing systems for guided missiles are sophisticated and comparatively complex and provide redundancy to improve the reliability of costly and important weapons. As previously noted, decoys, such as heat, fire, aluminum chaff, and metallic-coated fiberglass needles, can sometimes be used effectively against these missiles. The wire and fiber-optic guidance method is immune to decoys and electronic countermeasures (ECM).

1-3.3.1 Surface-to-Surface

The TOW, M207E2, as shown in Fig. 1-15, is a fielded, wire-guided, fin-stabilized, heavy antitank missile. The shaped-charge warhead, 152 mm (6.0 in.) in diameter, is point initiated (crush switch) and base detonated. Launch can be from a tube mounted on the M113 Armored Personnel Carrier (APC), on a vehicle with a pop-up turret, or from a ground-mounted tripod manned by a crew of four.

Standoff initiation is accomplished by a spring-extended, 0.41-m (16.0-in.) probe containing a crush switch, and deployment is triggered by a bore rider pin in the fuze. The TOW missile uses the M114 Safety and Arming Device



1 Piezoelectric Element
2 Lead Wire Conduit
3 HE Booster
4 Closure
5 Igniter
6 Folding Fin
7 Flash Tube
8 Motor Body
9 Propellant Grains
10 Fuze
11 HE Charge
12 Copper Cone

Figure 1-14. 66-mm (2.60-in.) Light Antitank Weapon Rocket

(par. 1-10.1). Fuze safety is achieved by an electroexplosive piston that locks an acceleration-sensing leaf mechanism. This locked mechanism in turn keeps the out-of-line explosive train in the safe position. Final arming and safe separation are achieved by an acceleration-integrating device, which requires sustained rocket boost.

Ballistic data for the TOW missile are 390-g launch and 21-g boost acceleration. Velocity at the end of boost is 330 m/s (1083 ft/s).

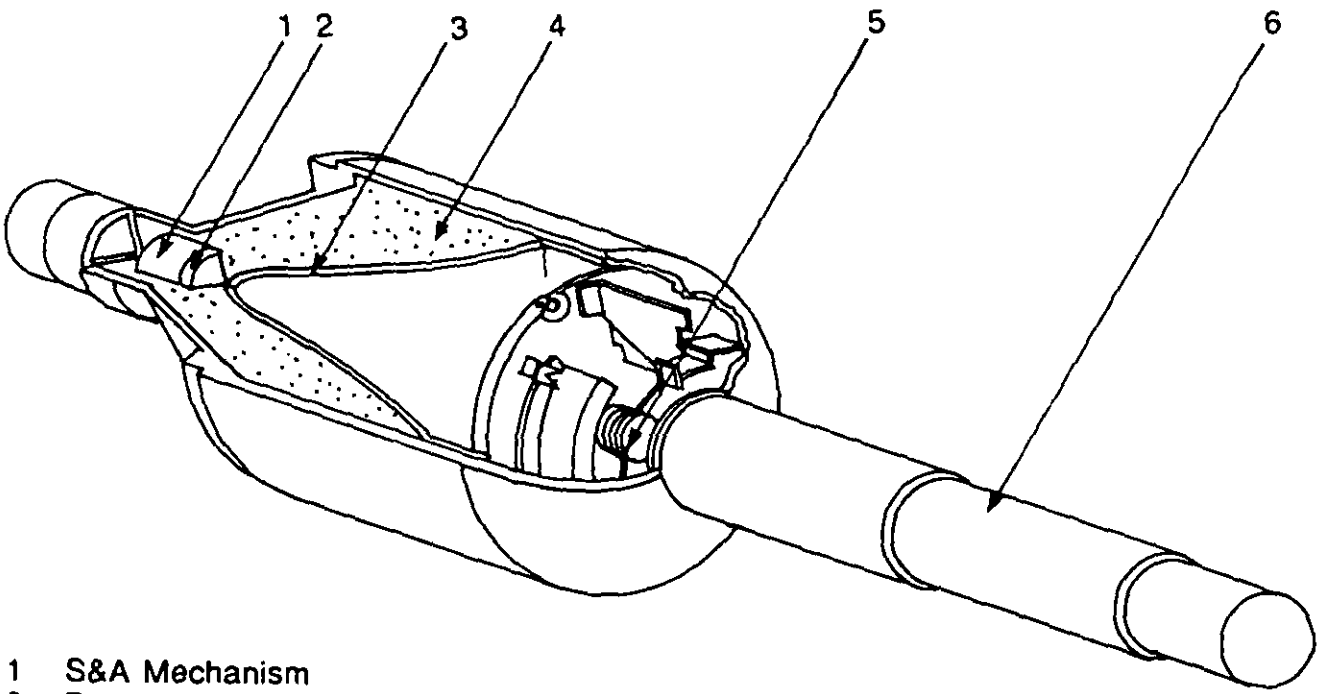
1-3.3.2 Surface-to-Air

The STINGER is a shoulder-launched, forward air defense, IR-homing, two-stage, rocket-propelled, antiaircraft missile. The titanium-cased M258E5 warhead, as shown in Fig. 1-16(A), contains the M934 electromechanical fuze and uses blast as the predominant damage mechanism.

The safety and arming (S&A) mechanism contains an unbalanced rotor, which is spring biased away from the armed position. The rotor position is monitored by an electronic interrogating system that allows the rotor to arm if proper g conditions exist or locks it in a safe position if improper signals are received. The system is time gated by using digital timer systems. (See Figs. 1-16(B) and 1-17.)

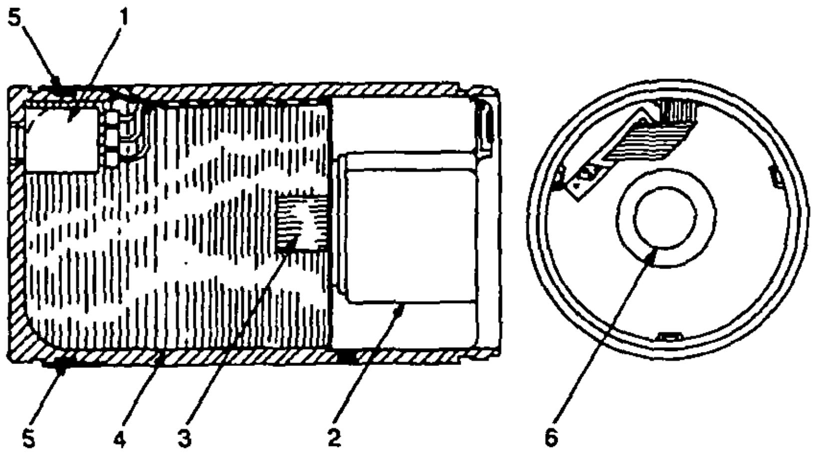
A delayed arming distance of 305 m (1000 ft) is provided. The first safety is a launch signal from umbilical retraction. The second safety is based on a 30-g setback acceleration from the launch motor. The final safety uses launch motor separation and a 22-g (minimum) acceleration boost from the flight motor for 22 ms (minimum). The missile power supply is a thermal battery.

The rotor is secured in the armed position by hardened, spring-powered, detent pins to avert misalignment during target penetration. The penetration delay is electronically determined by flight time, which roughly determines the impact velocity. The fuze has an instantaneous override to protect against warhead breakup if the missile strikes a hard structural member. A tension band sensor switch around the warhead opens on warhead deformation. Target impact is sensed by a mechanical inertia switch that is capable of initiating the warhead at angles of obliquity up to 80 deg. A self-destruct circuit destroys the warhead in 15 ± 2 s if a target is not engaged.



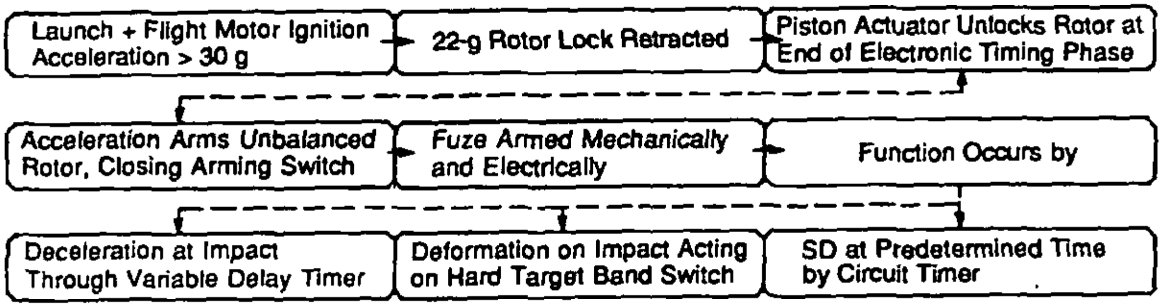
1 S&A Mechanism
2 Booster Pellet
3 Copper Cone, Trumpet Shape
4 Shaped Charge
5 Probe Extension Springs (3)
6 Extendible Probe

Figure 1-15. 152-mm (6-in.) TOW Warhead, HEAT, M207E2



1 Connector
2 Fuze GM 934E5
3 PBX Booster Pellet
4 Main Charge
5 Hard Target Sensor, Printed Wiring
6 Safe/Arm Viewing Window

(A) 70-mm (2.75-in.) Warhead



(B) Fuze Function Schematic

Figure 1-16. STINGER Warhead, HE, M258E5 Mod 1

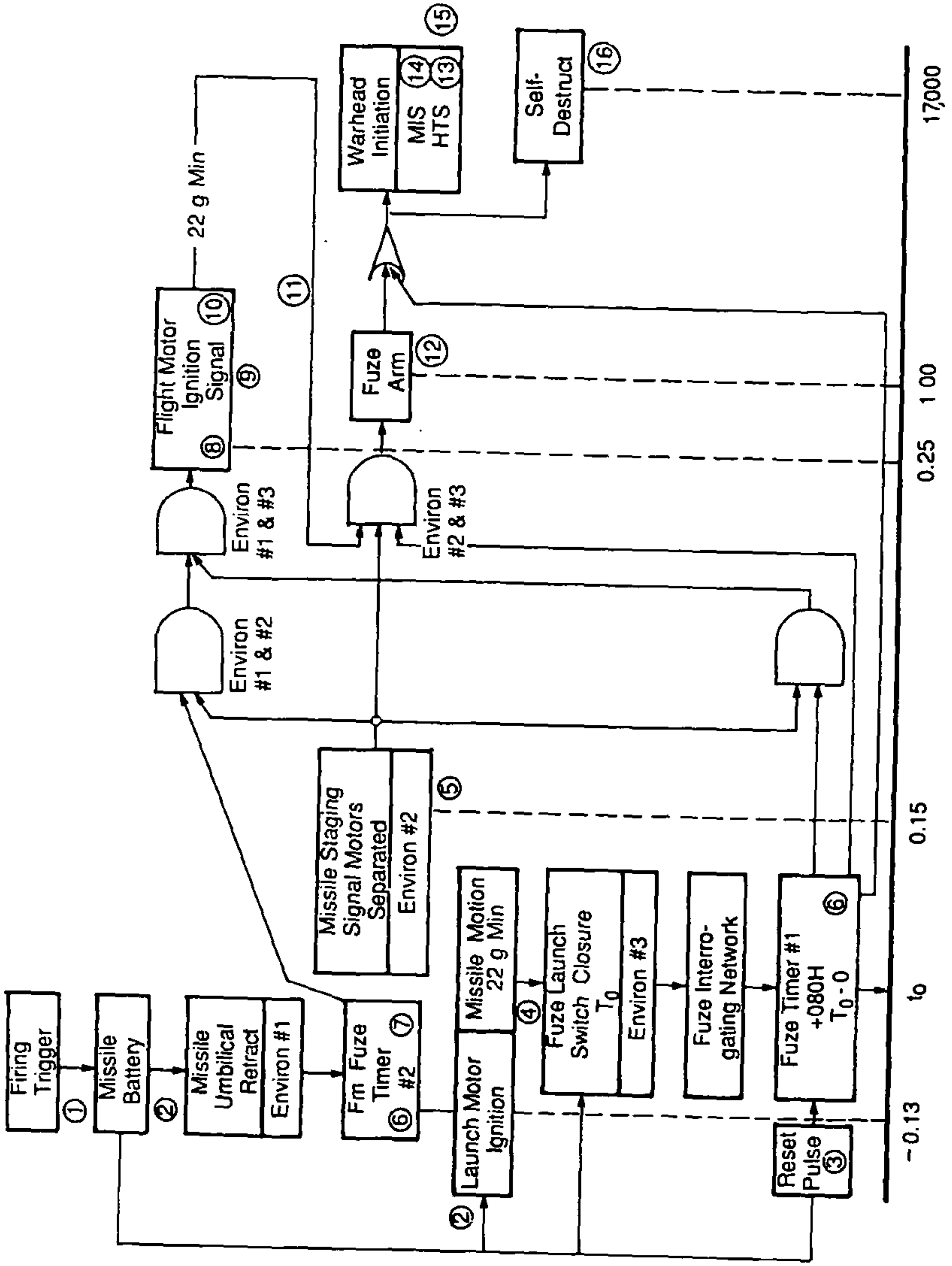


Figure 1-17. Function Diagram for STINGER Missile

1-3.3.3 Air-to-Surface

The HELLFIRE missile, shown in Fig. 1-18(A), is used on advanced attack helicopters. It is a heavy antitank weapon of a 178-mm (7-in.) diameter with a shaped-charge warhead and an electromechanical fuzing system, as shown in Fig. 1-18(B). Initiation is by contact through a crush switch at the end of a fixed standoff probe. The sensitivity of this switch is such that the warhead can penetrate light foliage without being initiated. In this respect, no-fire on 3.2-mm (1/8-in.) plywood and all-fire on 25-mm (1-in.) plywood has been selected for test purposes as representative of this capability. Guidance is provided by laser illumination of the target.

The M820 fuze is point initiating, base detonating (PIBD) and contains an S&A mechanism with a double-integrating accelerometer. This accelerometer has a setback responsive weight that unlocks an unbalanced rotor whose rotational rate is governed by a runaway escapement mechanism. An electrically initiated delay launch latch constitutes the first safety feature. The second safety feature is the requirement for an environment of 7.5 to 10 g to release the setback weight and power the rotor to the armed position. Delayed arming is 150 to 300 m (492 to 984 ft) from the launch position.

The fuze is hermetically sealed and contains an inert atmosphere of 95% dry nitrogen and 5% helium to provide long-term storage life. An internal red and green indicator flag shows the armed or safe status of the fuze.

1-3.4 MINES

Fig. 1-19 is a sectioned illustration of the M21 heavy antitank mine. A land mine is a charge of HE, incendiary mixture, or chemical composition encased in a metallic or nonmetallic housing with an appropriate fuze, firing device, or both that is designed to be actuated, unknowingly, by enemy personnel or vehicles (Ref. 16). Although a land

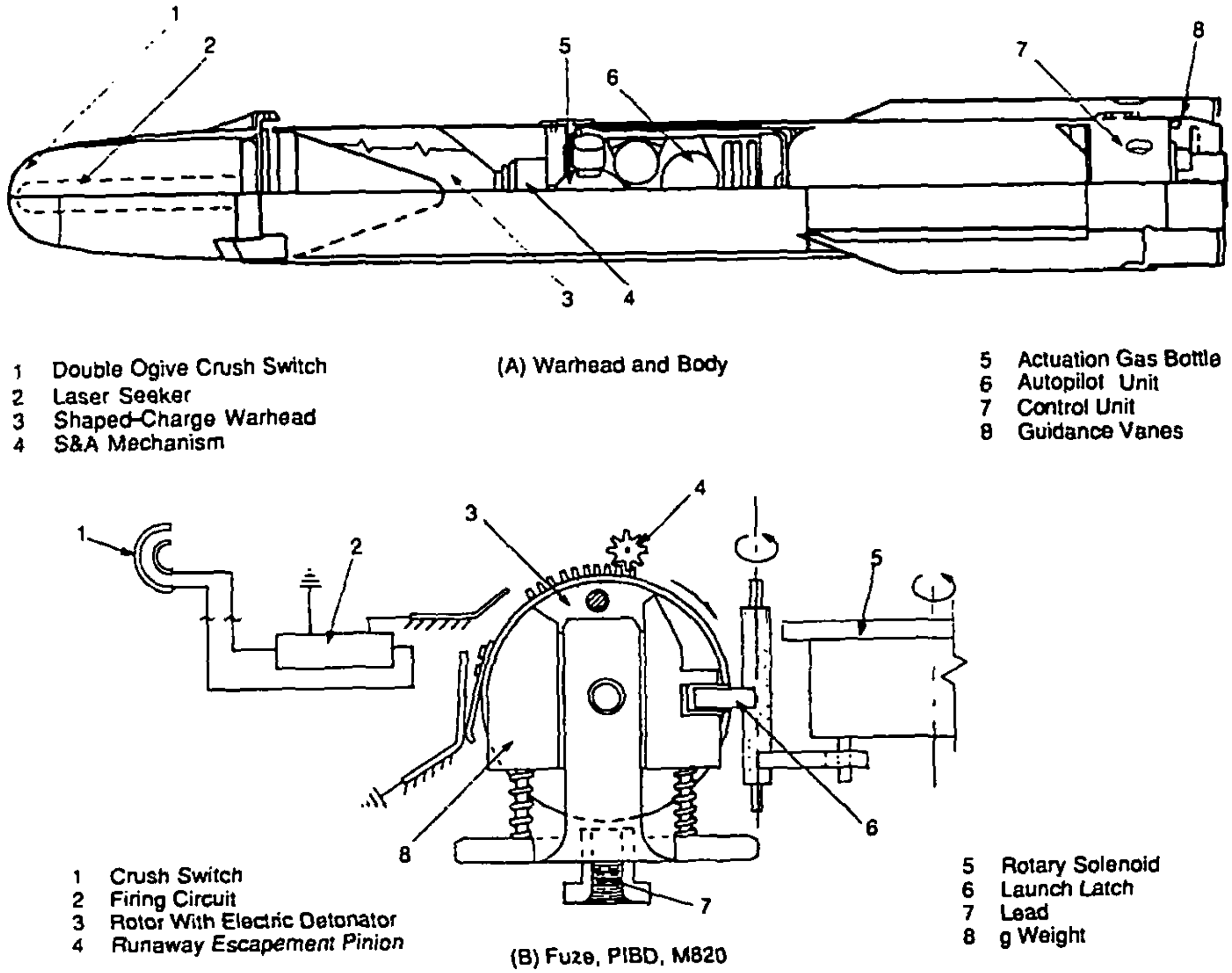


Figure 1-18. HELLFIRE Missile, GM, HEAT, XM265

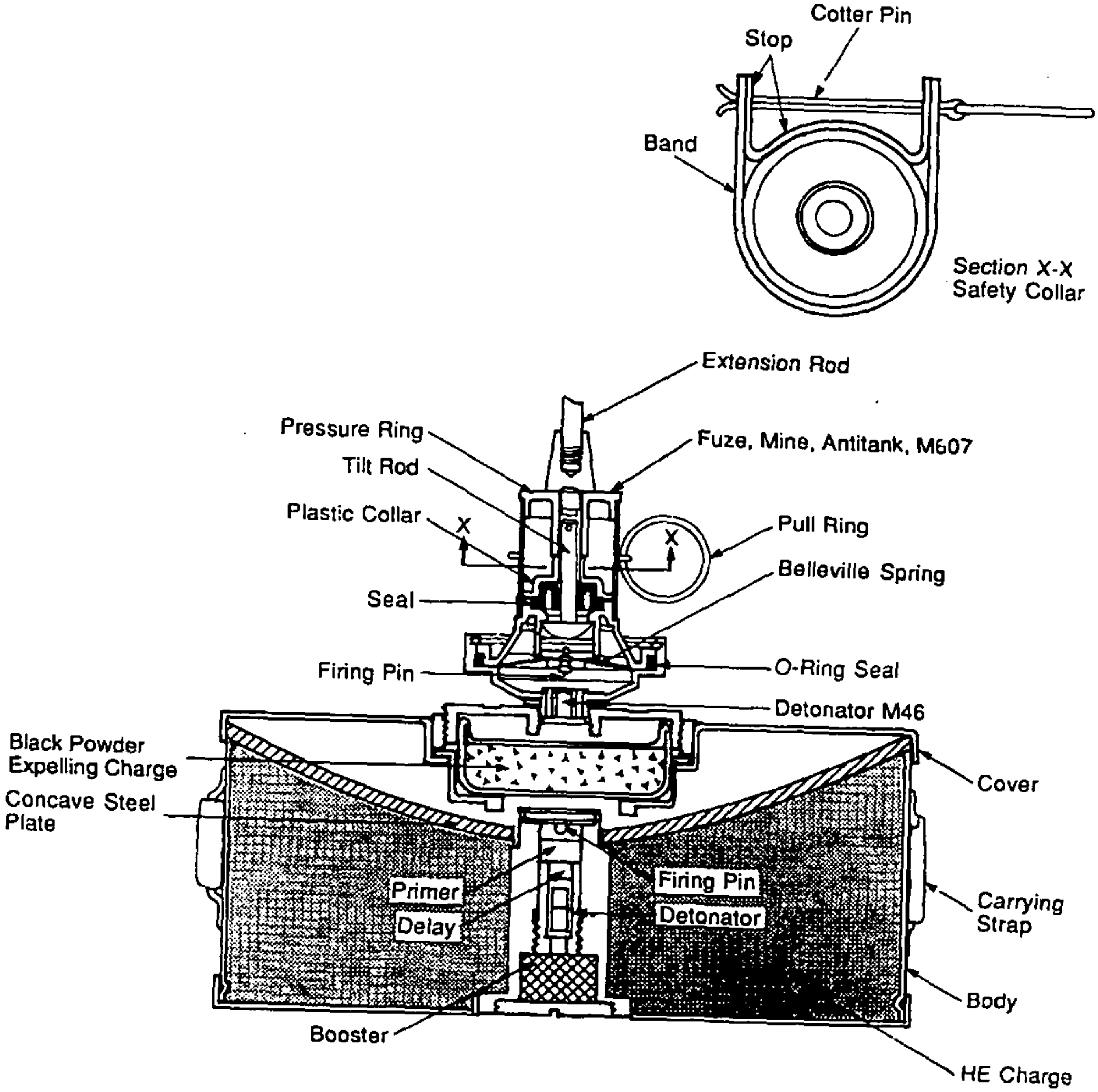


Figure 1-19. Mine, Antitank, HE, Heavy, M21

mine is meant to damage or destroy enemy vehicles and other materiel or to kill or incapacitate enemy personnel, its primary function is to delay and restrict the movements of the enemy.

Land mines are divided into two general classes designated antipersonnel and antitank. Antipersonnel mines may be of fragmentation or blast type. Both types may be designed to explode in place, whether buried or emplaced aboveground. Others, known as bounding mines, contain an expelling charge that projects the fragmenting component of the mine aboveground before detonation. Antitank and antivehicular mines are used against tanks, other tracked vehicles, and wheeled vehicles. These mines may be of the blast type or may employ the shaped-charge effect. Mines are emplaced manually or mechanically by mine dispenser or delivered aerially.

Land mines are triggered mechanically by pressure, pull, or a release of tension. Pressure-operated antipersonnel mines are designed to be triggered by loads of about 111 N (25 lb). Antitank mines are designed so that they will not initiate when a person walks on them. They are triggered by a force of 890 to 3336 N (200 to 750 lb). Hidden trip wires can be used to set off the mine when they are pulled (tension) or cut (tension released).

Influence devices, such as magnetic dip needles or magnetometers, may also be used to fire antitank mines when it is desirable for firing to occur between the treads of the vehicle. Here technology must be applied that involves the study of the disturbances in the magnetic field of the earth produced by the weight and speed of the moving armor to be intercepted.

Modern tactics have threatened the effectiveness of our conventional mines. Radical change in mine design has occurred because

1. The permanent nature of conventional minefields restricts later mobility of friendly troops.
2. New and more effective countermeasures have reduced the conventional mine threat.
3. The accelerated pace of modern combat restricts and limits the manpower and time available for placement and clearing of conventional mines.

To overcome these limitations, a family of scatterable mines (FASCAM) has been developed with quick-strike emplacement capabilities through air, artillery, and special purpose ground vehicle delivery techniques. These mines are described in par. 1-3.4.2.

1-3.4.1 Manually Emplaced Mines

One of the fielded manually emplaced mines is the M21 heavy, antitank, HE land mine, as shown in Fig. 1-19, with fuze M607. It is approximately 229 mm (9 in.) in diameter by 76 mm (3 in.) thick. The Misznay-Schardin shaped-charge effect (Ref. 4) is employed to direct the explosive energy into the tank. The mine is buried at a nominal depth of 152 mm (6 in.) and is activated by pressure exerted by tanks, other tracked vehicles, or wheeled vehicles. The expelling charge is necessary to clear the earth cover in front of the steel plate kill mechanism. A description of the fuze for this mine is presented in par. 1-11.1.

1-3.4.2 Scatterable Mines

A new FASCAM emplaced on the surface by hand, cargo-carrying artillery, rockets, aircraft, and towed dispensers has evolved. Due to the latest state-of-the-art electronic technology, scatterable mines have significantly greater utility than conventional mechanical mines. Deployment is rapid and requires substantially less manpower. FASCAM minefields automatically clear themselves for use by friendly forces because each mine contains a self-destruct or sterilization feature.

Although antiarmor and antipersonnel mines can be deployed in minefields of a single type, considerable synergism results when they are deployed together. Antiarmor mines deny easy breaching and clearing with armored vehicles, and antipersonnel mines deny clearing attempts by enemy troops. Table 1-1 lists the current FASCAM concept and delivery matrix.

One example of a FASCAM system is the remote antiarmor mine (RAAM), a magnetic influence, artillery-delivered, antiarmor mine, as shown in Fig. 1-20. Nine of these mines are carried in the M718 cargo projectile, as shown in Fig. 1-21, for 155-mm (6-in.) artillery and are

TABLE 1-1. FASCAM CONCEPT AND DELIVERY MATRIX

DELIVERY MODE	DELIVERY MECHANISM	ANTIARMOR WEAPON	ANTIPERSONNEL WEAPON
Artillery	155-mm Howitzer M109, M198	RAAM M718/M741	ADAM* M692/M731
Ground Vehicle	Towed Dispenser M128	GEMSS** M75	GEMSS M74
Remotely Activated Ground Dispenser	Two-Man Hand Carry	MOPMS† XM131	MOPMS XM132
Aircraft	GATOR Dispenser CBU-78/B CBU-89/B	GATOR†† BLU-91/B	GATOR BLU-92/B
Helicopter	SUU-13 Dispenser	M56	N/A

*ADAM = area denial artillery munition
**GEMSS = ground-emplaced mine scattering system
†MOPMS = modular pack mine system
††GATOR = ground laid interdiction minefield

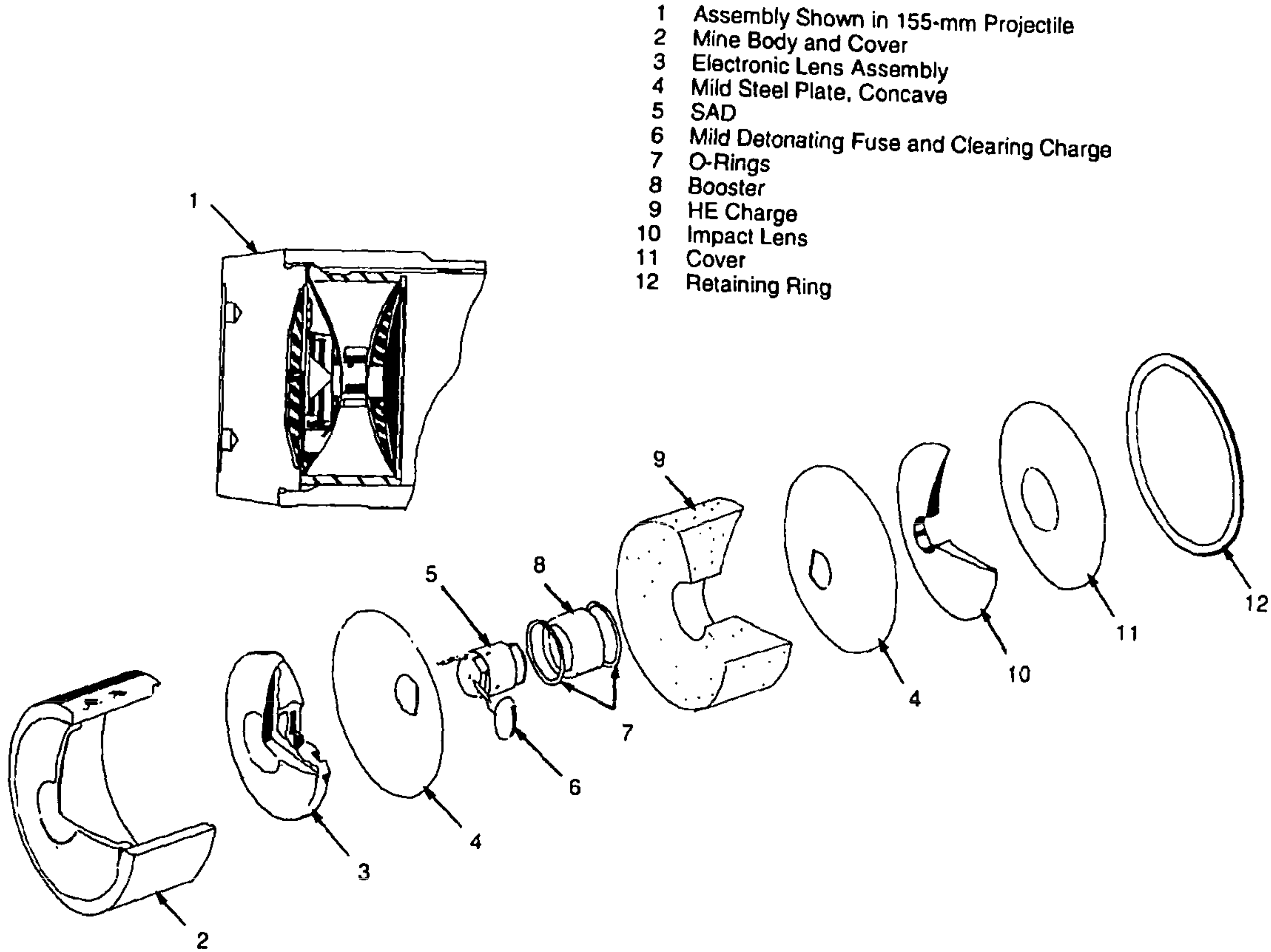


Figure 1-20. Remote Antiarmor Mine (RAAM)

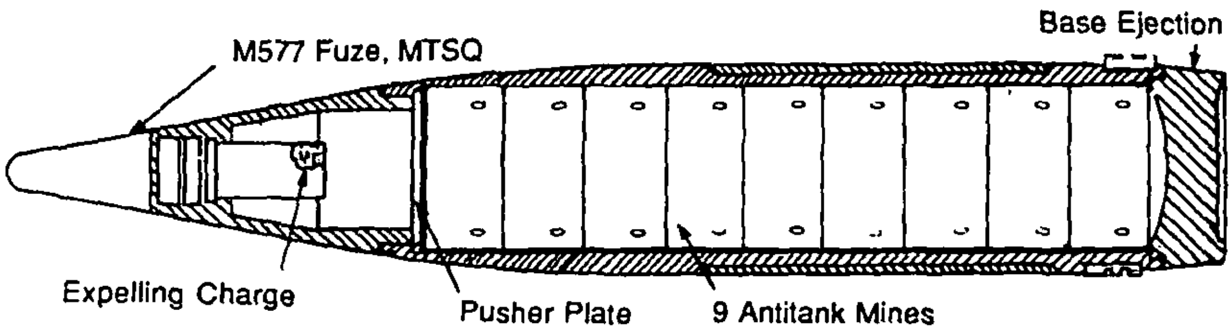


Figure 1-21. 155-mm (6-in.) Cargo Projectile, M718 for Antitank Mines

dispensed from the rear of the projectile while over the target. Ten projectiles can produce a minefield of 250 by 300 m (819 by 984 ft).

These warheads employ the Misznay-Schardin effect, which results in a very high-velocity slug capable of penetrating tank belly armor. Such penetration leads to almost certain tank destruction. The slugs can form from each end of the mine to avert an orientation problem. The firing takes place in two stages. In the first stage a clearing charge removes the upward-oriented mine cover and any debris that may have covered the mine. The high-explosive detonation, the second stage, occurs 30 ms after clearing.

The S&A mechanism in each mine senses the spin, initial gun setback, and rearward-ejecting environments for arming. Par. 1-11.2 provides a detailed description of the S&A mechanism.

1-3.5 GRENADES

A grenade is a small munition for close range infantry combat (Ref. 17). Among all the weapons used in infantry combat, grenades have a unique position because they are the individual infantryman's area-fire weapon of opportunity.

The payload of a grenade may be broadly classified as either explosive or chemical. Explosive grenades are either of the fragmentation or shaped-charge type. Fragmentation grenades are used primarily to inflict personnel casualties but can also be used against light materiel with limited effectiveness. Shaped-charge grenades are used primarily to defeat armored vehicles but have antipersonnel effectiveness as well. Chemical grenades are of three basic types: irritant, incendiary, and smoke. Irritant grenades are used to harass or incapacitate enemy personnel. They are also used for riot control. Incendiary grenades contain WP that burns with a very high temperature. They are used primarily to destroy equipment by fire. Smoke grenades are used for screening and for signaling.

Grenades may be projected either by hand or by a special launcher.

1-3.5.1 Hand Grenades

The hand grenade, shown in Fig. 1-22, weighs approximately 454 g (1 lb) and, as the name implies, is thrown by hand without the use of auxiliary equipment.

The range of the hand grenade is limited to approximately 40 m (131 ft). The lethal range for a fragmentation grenade is a radius of 18 m (60 ft). The danger zone, however, extends outward such that the user must take cover.

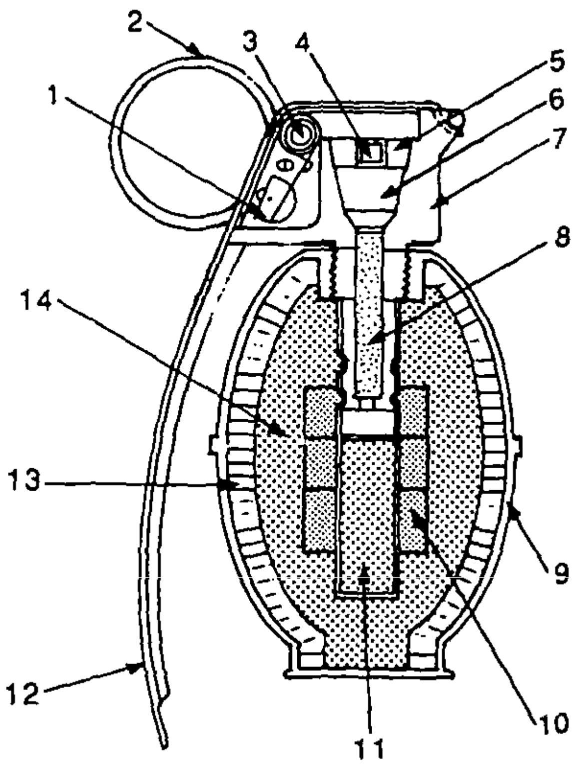
All standard hand grenade fuzes contain in-line explosive trains and are of a pyrotechnic delay type. This type of fuze employs a delay column of slow-burning powder that is ignited when the grenade is released by the thrower. Smoke and incendiary grenade fuzes typically have a shorter ignition time (0.7 to 2.0 s) than fragmenting grenade fuzes (4 to 5 s).

The delay-type grenades have a number of tactical limitations. The most important are (1) an enemy might be able to take cover before the grenade detonates, (2) the grenade might roll back downhill and detonate near friendly personnel, and (3) the grenade might be picked up and thrown back by an enemy. Accordingly, impact fuzes have been developed, but in view of their complexity and expense, they have not replaced the simple pyrotechnic time delay fuzes.

1-3.5.2 Launched Grenades

The original meaning of "rifle grenade" was a grenade launched from a standard infantry rifle by means of a blank cartridge. The grenades were fragmenting, chemical, or shaped charge. Adapters, attached to the grenade or as part of the grenade, were used to mount the munition centerline to centerline on the rifle muzzle. This system, now obsolete, was used on the M-1 rifle.

Current launched grenades may be projected either by an adapter that is attached to the M16 rifle, shown in Fig. 1-23, or by a special single-shot, 40-mm (1.57-in.), shoulder-fired, shotgun type of weapon, with break-open action, as illustrated in Fig. 1-24.



1 Striker
2 Pull Ring Assembly
3 Spring
4 Primer
5 Primer Holder Assembly
6 Expansion Volume
7 Body
8 Delay
9 Sheet Metal Case
10 Booster Pellets
11 Detonator
12 Safety Lever
13 Notched Wire
14 HE Filler

Figure 1-22. Fragmentation Grenade, M26

A typical launched grenade cartridge is the HE, dual-purpose type, which uses both setback and spin to effect arming. The propellant for the grenade is in the grenade cartridge, as shown in Fig. 1-25. Characteristics are 75 m/s (245 ft/s) muzzle velocity, 3675 rpm spin, and a maximum range of 400 m (1312 ft).

1-3.6 SUBMUNITIONS

Conventional munitions, such as HE projectiles, bombs, and rockets, are primarily suited to destruction of hardened or semihardened point targets. On lighter targets of dispersion, such as personnel and small groups of vehicles, the localization of energy amounts to overkill.

Successful attempts to overcome these shortcomings have been made. These munitions are designated as improved conventional munitions (ICM), or cargo-carrying rounds. Two basic types of submunition have evolved to form the payload of such warheads.

The M42 grenade, shown in Fig. 1-26, is an antimateriel (shaped-charge) and antipersonnel (fragmenting) submunition that fires on impact and is capable of penetrating 70 mm (2.75 in.) of homogeneous armor plate and radiating fragments from the point of impact. Eighty-eight of these grenades are contained in the M483 155-mm (6-in.) projectile.

The M43 grenade, shown in Fig. 1-27, consists of a fragmenting spherical warhead that pops up after impact and detonates at 1.22 to 1.83 m (4 to 6 ft) aboveground. The 155-mm (6-in.) cargo projectile M449 contains 60 M43-type grenades. Both types of submunition are dispensed over the target area by an electronic or mechanical time fuze in the nose of the ICM round.

An example of an aircraft-released submunition is the ROCKEYE bomblet, illustrated in Fig. 1-28. Two hundred forty-seven of these submunitions are contained in a 227-kg (500-lb) cluster bomb. Dispersion of these submunitions is effected by a mechanical time fuze that opens the dispenser over the target at a pilot-controlled time (two selections) depending on the delivery mode.

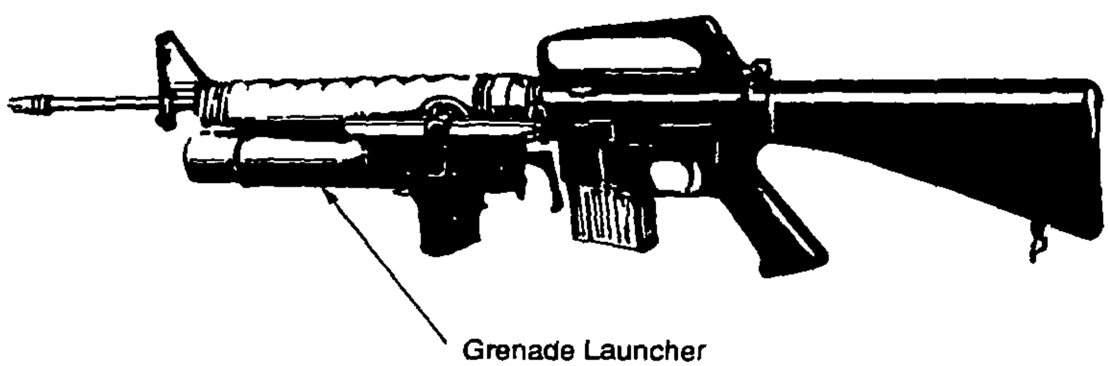


Figure 1-23. Grenade Launcher, 40 mm, M203 Attached to M16E1 Rifle

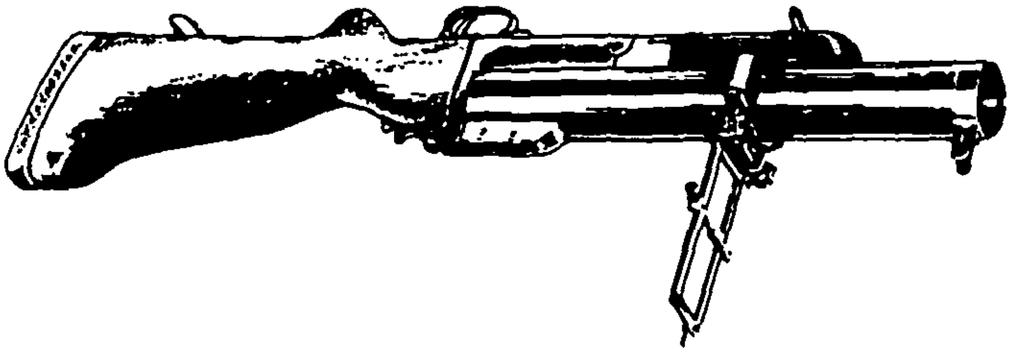
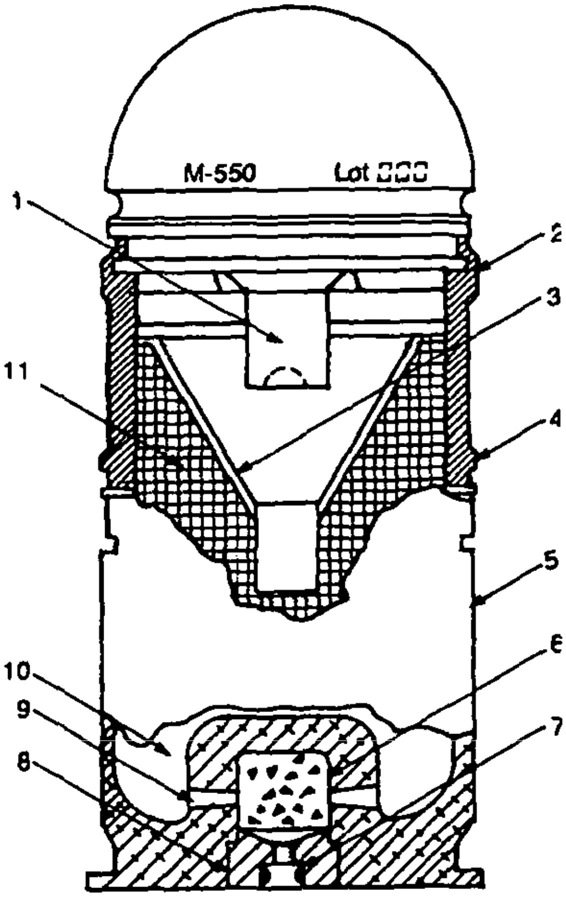


Figure 1-24. Grenade Launcher, 40 mm, M79



1 Fuze, Spit Back Booster
2 Projectile Body
3 Copper Cone
4 Rotating Band
5 Cartridge Case
6 Propellant Cup, High-Pressure Chamber
7 Primer
8 Closing Plug
9 Vent
10 Low-Pressure Chamber
11 Shaped Charge

Figure 1-25. Cartridge, 40 mm, HEDP, M433

Fuzes for submunitions must be very simplistic in design, yet they must contain all of the essential safety features and be capable of mass production at low cost. Delayed arming is generally a requirement for submunition fuzing to achieve safe separation and to prevent premature detonation from submunition collision on ejection from their canisters. Delayed arming has been achieved in a number of ways including escapements, rotation of an arming screw turned by a ribbon in the airstream (par. 1-13), flutter arming mechanisms (par. 6-7.2), or by air bleeding through a porous plug.

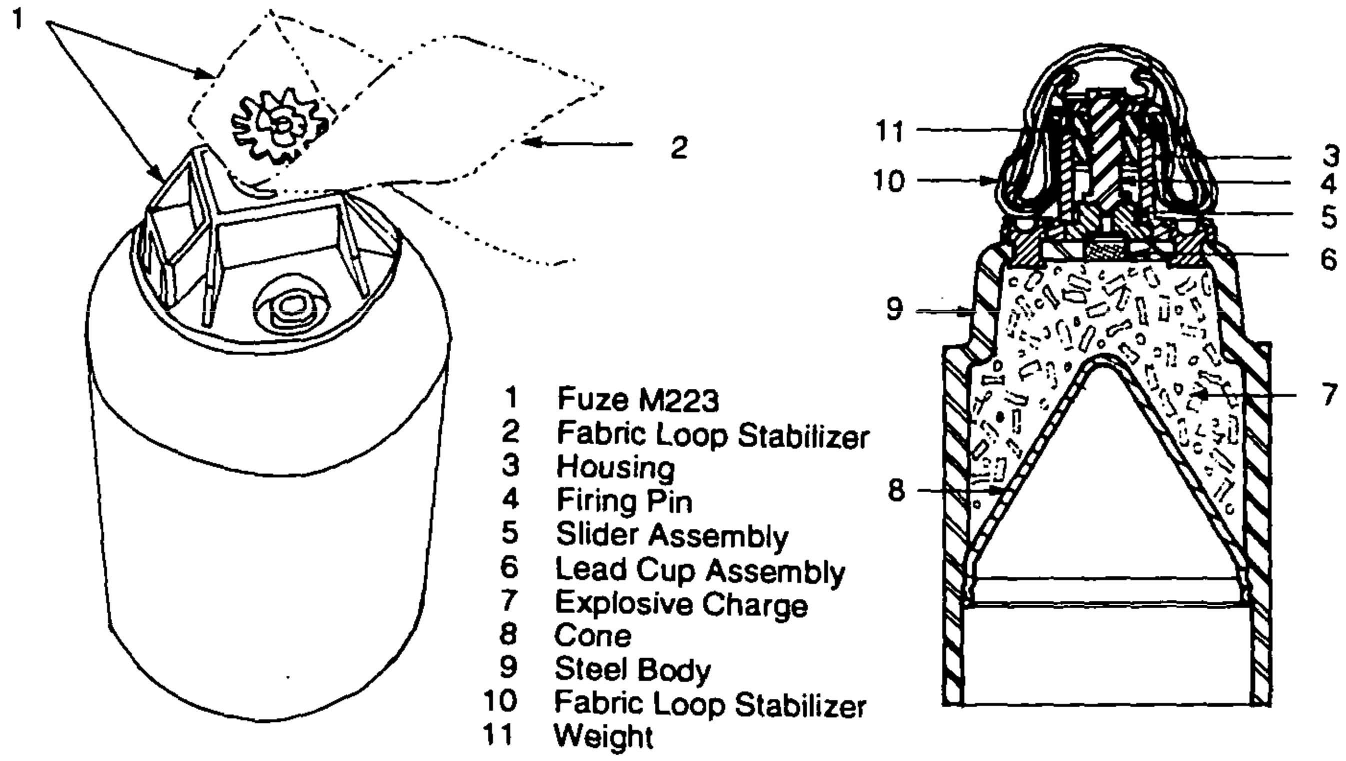
1-3.7 FUEL-AIR-EXPLOSIVES

Fuel-Air-Explosives (FAE) (Ref. 14) operate on the same principle as the internal combustion engine, i.e., a fuel, which in this case is propylene oxide, is mixed with air in proportions that enable detonation. The resulting detonation produces overpressures in the order of 2.1 MPa (300 psi) in an ambient atmosphere. This pressure is sufficient to neutralize buried or surface-laid mines and is also effective against personnel and light materiel.

The technique employed to realize this damage mechanism requires a cylindrical container of propylene oxide, liquid at ambient temperature, and a delivery system capable of positioning the canister over the target area in a near-vertical position at a height of 1.8 m (6 ft) at the time of dispersion into a detonable cloud.

The canister is explosively ruptured in such a manner as to obtain a cloud of air and fuel mix in the form of an oblate sphere with the flattened surfaces parallel to the ground. A typical cloud diameter is 15 m (50 ft) with a thickness of 3.5 m (12 ft). The cloud is then detonated by detonators explosively launched 10 ms prior to canister burst and into a position to effect two points of ignition for maximum reliability.

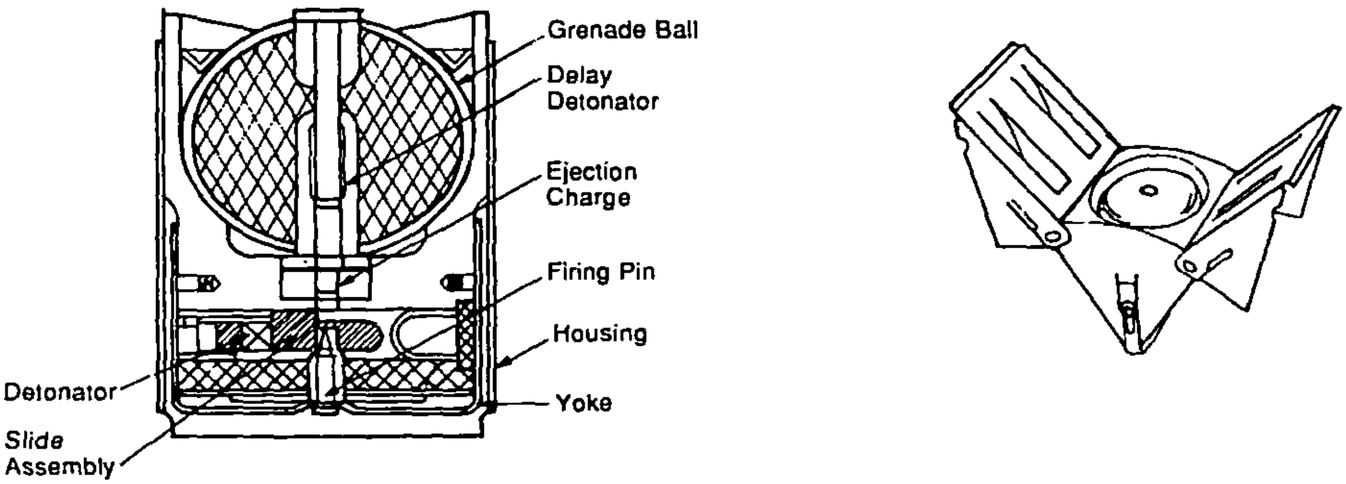
Two types of launch platforms have been used: (1) bombs containing three canisters released from rotary-wing or high-speed, fixed-wing aircraft and (2) rocket-delivered canisters from a tracked vehicle.



(A) Full View M42 Grenade

(B) Cross Section M42 Grenade

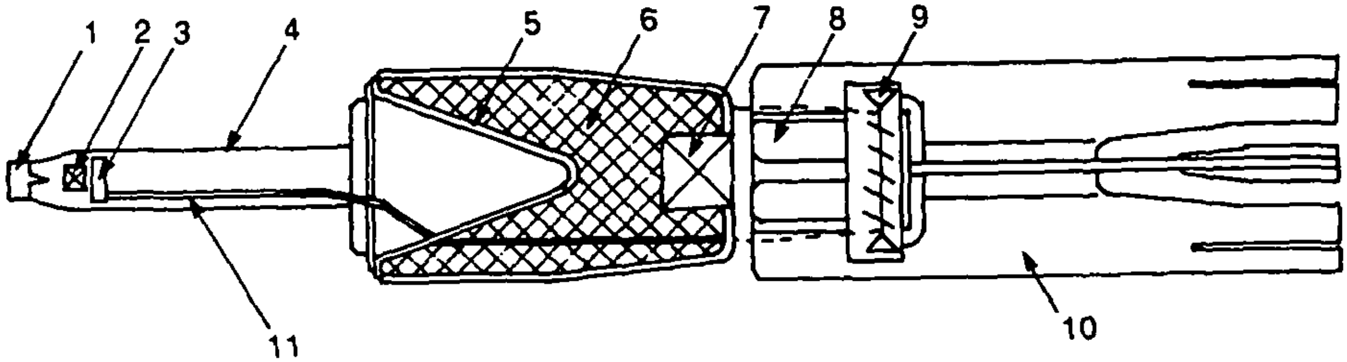
Figure 1-26. Dual-Purpose Grenade M42



(B) Grenade With Vanes Open

(A) Cross Section

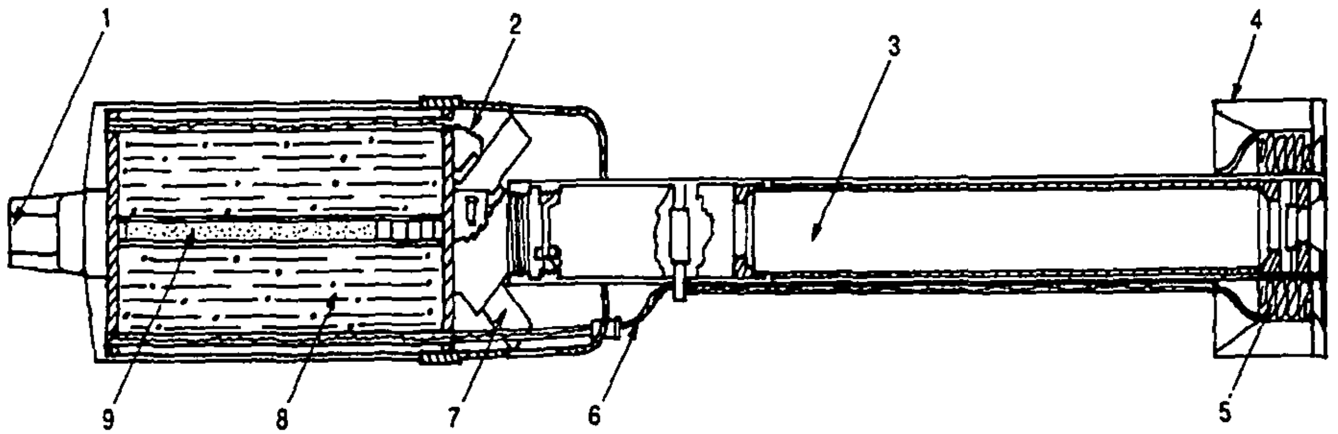
Figure 1-27. Antipersonnel Grenade M43



1 Stab Firing Pin, Shear-Mounted
2 Stab Detonator
3 Piezo Crystal
4 Standoff Probe
5 Copper Cone
6 Shaped Charge
7 Fuze Booster
8 Fuze
9 Air-Driven Arming Vane
10 Plastic Tail Vane
11 Wire Conductor to Electric Detonator in Fuze Rotor

Figure 1-28. 53-mm (2.1-in.) Submunition MK 118-0, Aircraft Released

The 345-mm (13.6-in.) Surface-Launched Unit Fuel-Air-Explosive (SLUFAE) System (XM130), as shown in Fig. 1-29, is an all-weather system intended primarily for assault breaching during daylight or darkness of defended enemy minefields. Rocket-propelled, FAE canisters are ripple fired from a launch module mounted on an M548 tracked cargo carrier. Normal employment will be to program and fire up to 30 rounds to breach an 8-m (26.2-ft) wide path for a minimum distance of 100 m (328 ft). The maximum range is 1000 m (3280 ft). The SLUFAE system consists of the round and the launcher.



1 Fuze (XM750) with Stowed Nose Probe
2 Mild Detonating Fuse (MDF)
3 Rocket Motor
4 Tail Shroud
5 Parachute
6 Fuze Communication Wire and MDF
7 Ejection Tubes (2) with Cloud Detonator Assemblies
8 Fuel
9 Central Burster Charge

Figure 1-29. 345-mm (13.6-in.) Surface-Launched Fuel-Air-Explosive System XM130

The complete SLUFAE round is 2.55 m (100.4 in.) long, 0.35 m (13.6 in.) in diameter, weighs 84.8 kg (187 lb), and is ready for loading immediately after unpacking and inspection. It is rocket propelled, fin and parachute stabilized, and consists of a fuze plus associated electric wiring harness and mild detonating fuse (MDF) cords, warhead, parachute, and rocket motor. The warhead contains fuel, a burster charge, and two cloud detonators. The fuzing system for SLUFAE is described in Ref. 14.

1-4 FUZE CATEGORIES

Fuzes may be identified by their end-item, such as rocket, mortar, or projectile; by the purpose of the ammunition, such as armor-piercing or training; by their tactical application, such as air-to-air; or by the functioning action of the fuze, such as point detonating or mechanical time. Fuzes may also be grouped according to location, such as nose or base; according to functioning type, such as mechanical or electrical; or according to caliber. Table 1-2 lists common fuze categories. Subtitles within groups, however, are not mutually exclusive.

TABLE 1-2. FUZE CATEGORIES

By End-Item	**By Functioning Action**
Bomb	Impact
Grenade	Point Detonating (PD)
Guided Missile	Base Detonating (BD)
Mine	Point Initiating, Base Detonating (PIBD)
Mortar	
Projectile	Graze
Rocket	Time
	Pyrotechnic Time (PT)
By Purpose	Mechanical Time (MT)
Antipersonnel (APERS)	Electronic Time (ET)
Armor Piercing (AP)	Self-Destruction (SD)
Chemical	Delay (short or long)
Concrete Piercing (CP)	Proximity
High Explosive (HE)	Pressure
High-Explosive Antitank (HEAT)	Hydrostatic
Illumination	Barometric
Signal	
Smoke	
Target Practice	
Training	
By Tactical Application	**By Location**
Air-to-Air	Base
Air-to-Surface	Internal
Emplaced	Nose
Surface-to-Air	Tail
Surface-to-Surface	

Typical nomenclature for a fielded fuze would be Fuze, PD, M739; the experimental designation would be XM739. Although identifying features, such as projectile, nose, and tail, formerly were added to fuze nomenclature, the current trend is to minimize such descriptive terms.

1-4.1 BY FUNCTIONING ACTION

1-4.1.1 Impact Fuzes

These are fuzes in which action is created within the fuze by actual contact with a target; the action includes such phenomena as impact, crush, tilt, and electrical contact. Among the fuzes operating by impact action—alternatively referred to as contact fuzes—are (1) point-detonating (PD), fuzes located in the nose of the munition, which function upon impact with the target or by a time delay initiated at impact, and (2) base-detonating (BD), fuzes located in the base of the munition, which function with inherent short delay after initial contact. The delay depends on the desired target penetration and may vary from as little as 250 μs to as much as 250 ms. The base location is selected to protect the fuze during perforation of the target, as in the case of AP projectiles. In shaped-charge projectiles the fuze is PIBD. In this case the target-sensing element is in the nose of the projectile, and the S&A mechanism of the fuze is in the base. Base initiation is required to permit the explosive wave to move over the shaped-charge cone in the proper direction and to preclude the need for heavy fuze components in the nose, which would degrade performance.

Contact fuzes are conveniently divided according to response into superquick, nondelay, and delay. A superquick (SQ) fuze is a nose fuze in which the sensing element causes immediate initiation of the bursting charge (typically less than 100 μs). The methods employed are stab initiation of a primer or detonator, crushing of a piezoelectric crystal, or closure of a crush-type switch. Initiation of the shaped charge must occur prior to significant degradation of the round from impact damage; consequently, at impact velocities where times less than 50 μs could induce such damage, electrical initiation must be used and the sensing element must be located in the extreme nose end of the fuze or round.

A nondelay fuze does not have an intentionally designed delay, but there is some inherent delay because of inertial components that initiate the explosive train. Nondelay elements (inertial mechanisms) may be incorporated into either PD or BD fuzes. The inertial device is used when a small degree of target penetration is acceptable or desired and for graze action.

Delay (DLY) fuzes contain deliberately built-in delay elements (Refs. 4 and 18)—pyrotechnic, inertial, or electronic time—which delay initiation of the main charge until after target impact. Delay elements may be incorporated into either PD or BD fuzes; however, fuzes for very hard targets generally use BD functioning.

1-4.1.2 Time Fuzes

Time fuzes are used to initiate the munition at a desired time after launch, drop, impact, or emplacement. The time on these fuzes is generally set just prior to use, and the timing function is performed by such methods as mechanical clockwork, analog or digital electronic circuitry, pneumatic devices, or chemical and pyrotechnic reactions. Originally, time fuzes were used in HE projectiles for antiaircraft fire and bursts at low level over enemy troops; however, the proximity fuze has supplanted this usage. Their main uses now are in illuminating, chaff-dispensing, smoke, and cargo-dispensing rounds. Time fuzes are also used in cargo-dispensing rockets, and they range from those having set times as low as fractions of a second to as high as several hours or days. The latter use is in bombs or demolition charges. Typically, the time on current projectile fuzes can be set up to 200 s.

Self-destruction (SD) is an auxiliary timing feature provided in the fuzes of certain munitions fired over the heads of friendly troops, primarily to explode or "clean up" surface-to-air munition in case of target miss or failure of the primary functioning mode. Selectable SD times are provided in all of the new FASCAM to clear the area for use by friendly troops and vehicles. SD may be accomplished by various timing mechanisms or, in the case of more sophisticated munitions, by command destruct through a radio or radar link.

1-4.1.3 Proximity Fuzes

These are fuzes in which action is created within the fuze from sensing characteristics other than actual contact or elapsed time. Proximity fuzes—alternatively referred to as influence fuzes—initiate the munition when they sense that they are in the proximity of the target, which is typically around 4.5 to 6 m (15 to 20 ft) for artillery projectile applications. This action is particularly effective against personnel, light ground targets, aircraft, and superstructures of ships. These fuzes are the subject of separate Engineering Design Handbooks.

The mode of target sensing is largely by radio frequency reflection although there are proximity fuzes that employ IR reflection or direct IR emissions from the target. The direct-IR-emission-activated fuzes are not affected by electronic countermeasures but can be influenced by decoy sources of heat. Recent developments and studies have addressed triboelectric (electrostatic), millimeter wave, capacitive, inductive, and magnetic target sensing. The magnetic method requires a ferrous target. The capacitive, inductive, and magnetic methods are useful only for close proximity. The close-in proximity (Ref. 19) serves as standoff* for shaped-charge rounds, certain chemical rounds, and, in the case of mortar projectiles, to prevent masking of the fragments by deep grass and brush.

*The distance between the shaped charge and the target at the time of initiation.

1-4.1.4 Command Fuzes

These are fuzes in which action is created externally to the fuze and its associated munition and is deliberately communicated to the fuze by electrical, mechanical (wire), optical, or other means involving control from a remote point. An example is the surface-to-air missile (SAM) PATRIOT. This missile uses charged capacitors for self-destruction, which can be triggered by inadvertent loss of the RF ground control signal or on command from ground control.

Another example, although it is not strictly a munitions fuze, is the modular pack mine system (MOPMS). This system is a portable container that can be initiated by remote RF command to eject antiarmor mines (activated by magnetic influence) or antipersonnel mines (activated by trip lines). A distinct advantage of this system is that it can be retrieved for reuse if it has not been deployed.

1-4.1.5 Combination Fuzes

Fuzes designed with multioption capabilities are now in the inventory, and new ones are under development. In addition to supplementing the basic function, there is a decrease in logistic problems and an improvement in response time and versatility of gun crews.

Some time fuzes, both electronic time (ET) and mechanical time (MT), have been equipped with an automatic point-detonating capability. The M734 fuze for the new 60-mm mortar is a multioption system that has proximity mode as its basic function. Near-surface burst, impact, delay, or proximity can be selected prior to firing.

1-4.1.6 Other Fuzes

A simple element, such as a stab firing pin, held, for example, by a shear wire, and a primer comprise a fuze. An even simpler arrangement is found in the MK 26-1 PD fuze, shown in Fig. 1-30, for 20-mm cannon rounds where only a detonator is used. Obviously, these systems lack adequate safety features.

Modern fuze design requires an interruption in the path of the explosive train wherever primary (sensitive) explosives are used and provisions for aligning the explosive train by environmental stimuli associated with a launch system. A further refinement is delaying the arming until a safe separation distance from the launch platform has been attained.

Generally, the S&A mechanism is an integral part of the fuze. When the shaped-charge weapon was introduced, the fuze was divided into two widely separated parts. The trigger is located in the very forward part of the ogive or probe in the interest of rapid response, and the S&A mechanism is located at the base of the warhead to achieve initiation of the warhead at an optimum point. Accordingly, PIBD terminology has evolved.

In guided missiles the S&A mechanism is generally far removed from the trigger, and the fuze often takes on an unrecognizable physical appearance, such as a hermetically sealed can filled with electronics, microcircuitry, digital timers, and an S&A mechanism fitted with mechanical and photoelectric switches. The trigger can be a simple crush switch or a complex radar-emitting proximity system.

Another category is the stationary fuzes used in munitions that wait for the target to come into range, i.e., mines (Ref. 16) and booby traps. Such fuzes are set apart from the others along with the hand grenade fuze in that there is generally a lack of suitable environmental stimuli associated with their arming cycle to effect safety. Special methods must be employed to arm them safely.

1-4.2 TRAINING AND PRACTICE FUZES

These fuzes are generally nonexplosive and have specialized uses. A dummy fuze is completely inert and is an accurate replica of a service fuze. For ballistic purposes it may duplicate the weight, center of gravity, and contour of the service fuze. A practice, or training, fuze is a service fuze that is modified for use in training exercises. It may be completely inert (a dummy fuze), may have its booster charge (See Chapter 4.) replaced by a spotting charge, or may differ in other significant ways from a service fuze.

1-4.3 MODEL DESIGNATION

Army service fuzes are assigned the letter "M" followed by a number, e.g., M100. Modifications of "M" fuzes are given suffix numbers starting with "A", e.g., M100A1.

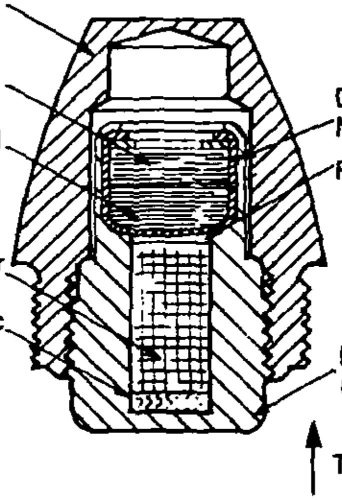


Figure 1-30. Fuze, PD, MK 26-1 for 20-mm Projectile

Developmental Army fuzes have the letters "XM" preceding a numerical designation, e.g., XM200. When standardized, the "X" is dropped. Earlier developmental Army fuzes were identified by a separate "T" number, e.g., T300, which was discarded when the fuze was adopted for manufacture. Although many fuzes with "T" numbers are still in existence, they are obsolete or obsolescent.

Current Navy service projectile and older bomb, rocket, and submunition fuzes that are still in the inventory carry a "MARK" number, and their modifications are followed by a "MOD" number, such as MK 100 MOD 1, or this can be shortened to MK 100-1. Experimental Navy projectile fuzes carry "EX" as part of their nomenclature, e.g., EX200. Prior to World War II some Army service fuzes and projectiles also carried MARK numbers, and items of Army ammunition so marked may still exist.

Air Force and current Navy bomb, rocket, submunition, and missile service fuzes use Fuze Munition Unit (FMU) numbers, such as FMU-100.

1-5 DESCRIPTION OF REPRESENTATIVE ARTILLERY FUZES

Artillery fuzes can be subjected to high setback accelerations (10,000 to 43,000 g) and therefore must have a strong structure. Exceptions are fuzes for mortars and recoilless rifles, which can experience setbacks as low as 1000 g and can use plastic, die-cast, and other low-strength materials to a greater degree. Artillery fuzes are used mainly in spin-stabilized rounds in the range of 20 to 1730 rps; exceptions are the nonspin, fin-stabilized rounds. Accordingly, for most artillery fuzes significant environmental forces are available to operate safety mechanisms adequately. For the exceptions, other means, such as safety wires and bore riding pins, must be devised to provide safety. The fuzes can be ignition (flame-producing) types or detonating types and can fit the categories of PD, BD, PIBD, ET, MT, pyrotechnic time (PYRO TIME), proximity, or multioption.

1-5.1 DESCRIPTION OF A REPRESENTATIVE IMPACT FUZE

The M739 PD Fuze, shown in Fig. 1-31, and the M739A1 PD Fuze, shown in Fig. 1-32, are used with 105-mm (4-in.), 108-mm (4.2-in.), 155-mm (6-in.), and 200-mm (8-in.) HE projectiles. The fuze body is a one-piece design of an aluminum alloy and has a standard 51-mm (2-in.) threaded base to match the projectile nose. Both fuzes consist primarily of five modular assemblies (Refer to Figs. 1-31 and 1-32.): (2) crossbar and holder assembly, (4) firing pin and detonator assembly, (6) setting sleeve assembly, (7) impact delay element assembly, and (9) the S&A assembly.

The crossbar and holder assembly is a rain desensitizing sleeve with nose cap that allows firing in heavy rain with a reduced probability of downrange premature functioning due to raindrop impact. The assembly is in the nose section of the fuze and consists of a nose cap over five crossbars

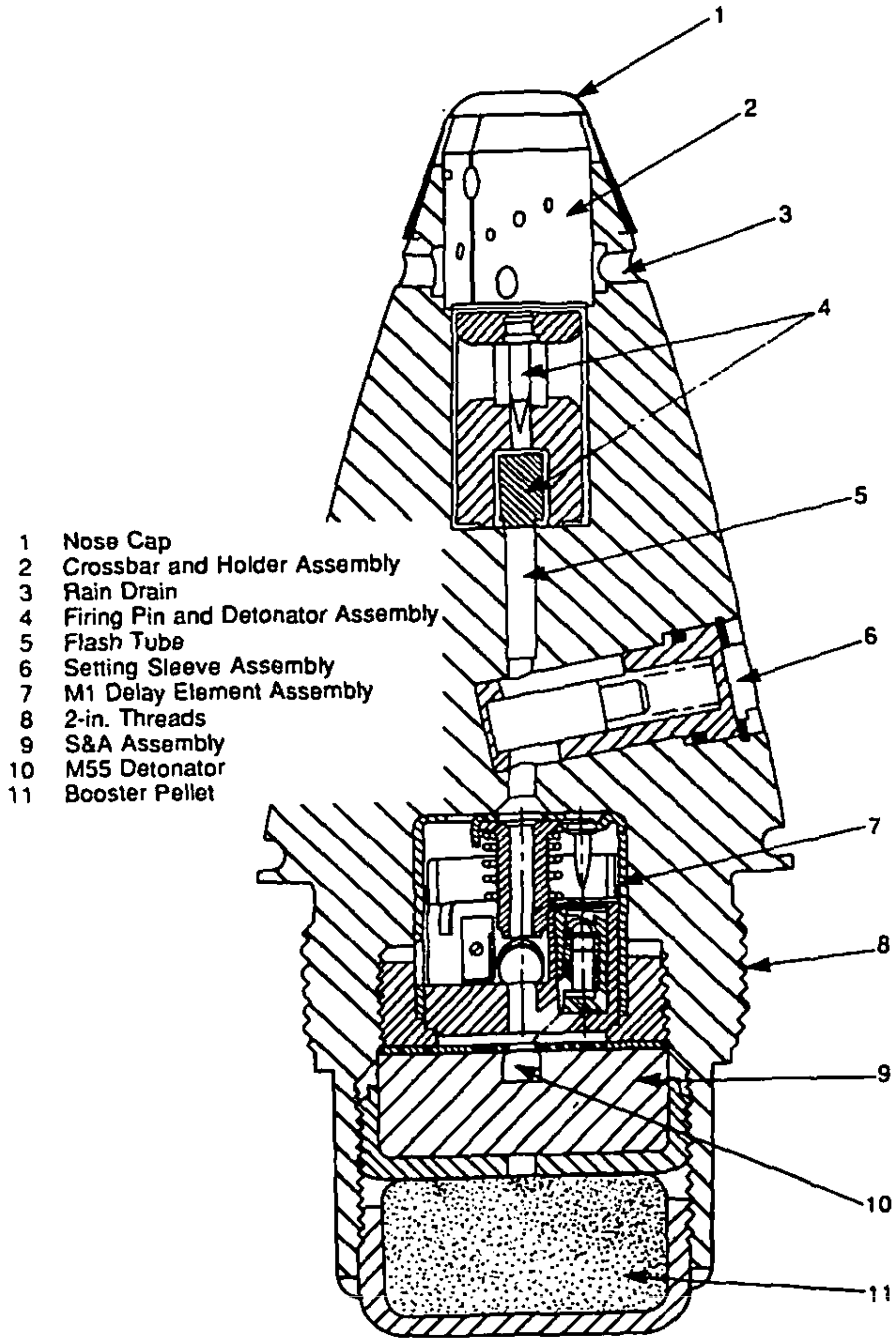


Figure 1-31. Fuze, PD, M739

that break up raindrops and foliage in event of nose cap erosion and thus reduce fuze initiation sensitivity without affecting ground or target impact sensitivity. For soft targets the large cavity in this assembly must become packed full of target medium to drive the firing pin into the detonator.

The firing pin and detonator assembly are located below the rain desensitizing sleeve and provide the superquick action impact. The firing pin is held in position by a firing pin support cup, which prevents initiation of the M99 Stab Detonator until impact.

The setting sleeve assembly (interrupter) is located in the side of the fuze body, extends through, and thus blocks the flash path of the M99 detonator. The selection of a PD mode is made by allowing centrifugal force to move this interrupter from the path of the nose detonator. The delay mode is activated by allowing the setting sleeve to block the flash hole regardless of interrupter position. Blocking the

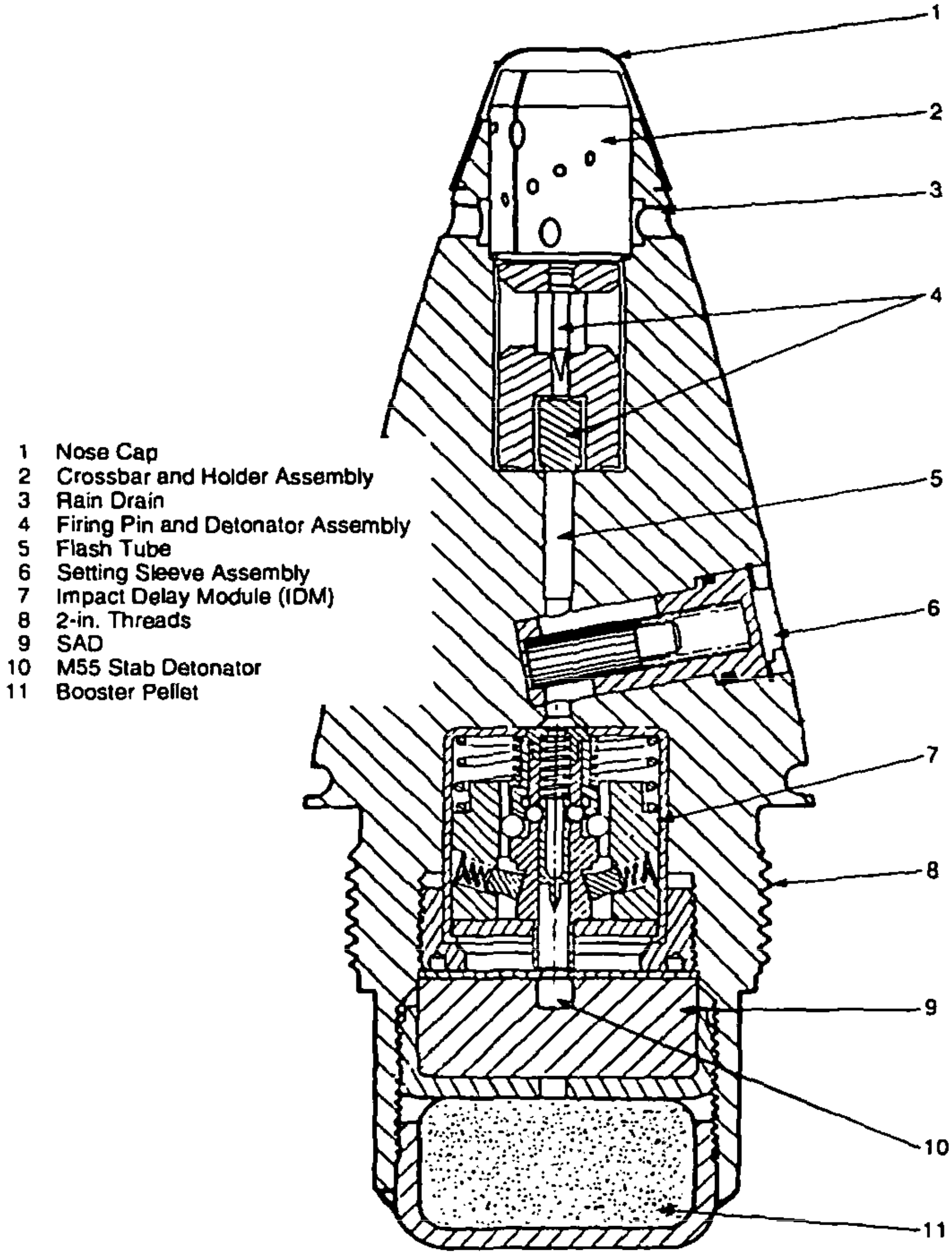


Figure 1-32. Fuze, PD, M739A1

flash hole prevents the detonator flash from initiating the explosive train. A coin or screwdriver may be used to turn the slot to the desired setting. The delay impact assemblies for the two fuzes are different. The M739 uses a centrifugally armed, impact-fired plunger (M1 Delay Element) containing a pyrotechnic delay element of 50 ms to allow penetration of the target prior to detonation. The M739A1 uses an Impact Delay Module (IDM), which is a reaction plunger containing no explosives. This mechanism cocks on target impact and releases a firing pin after the deceleration from target drag drops below 300 g.

An advantage of the reaction plunger system over the fixed time system is that it senses target thickness and therefore allows penetration through a thick target so that detonation occurs behind the target. A disadvantage is the requirement for mechanical action after impact, which is not always assured because there is potential for structural damage to the fuze.

Both fuzes are prone to target-inflicted damage from their position in the round, i.e., at the nose. Being of light aluminum alloy construction, the fuzes are useful in the delay mode against only lighter-type targets, such as plywood, brick, cinder block, and loose earth. For actions against concrete, lightly armored targets, and sandbags, consideration must be given to other fuzes.

The S&A module of both fuzes is located below the delay assembly. It contains an unbalanced rotor with an M55 Stab Detonator, an escapement that delays arming until the safe arming distance is achieved, and an explosive lead. When initiated, the explosive lead will detonate the booster pellet, which is held by an aluminum booster cup assembled into the base of the fuze.

Upon firing and during flight, the following actions occur:

1. When the setting sleeve is set for SQ, centrifugal force moves the interrupter and unblocks the flash hole.
2. In the delay assembly, centrifugal force moves each detent outward and locks each detent in the outward position by means of a centrifugal plunger pin lock.
3. In the S&A assembly the setback pin retracts from the rotor due to the acceleration, and the spin locks move outward under centrifugal force. This frees the rotor and allows it to turn and carry the M55 detonator into line with the flash hole. This arming action is briefly delayed by a runaway escapement, but once it is armed, the rotor is held in place by the rotor lock pin.
4. When fired in rain, the crossbars—in the event of erosion of the nose cap—serve to break up raindrops and prevent functioning of the superquick detonator. Excess water is expelled through the holes in the crossbar holder assembly by centrifugal force created by the spin of the round.

When the projectile hits a soft impact surface, the material ruptures the nose cap and then flows between the crossbars to strike the firing pin. If the projectile hits masonry or rock, the entire crossbar holder assembly drives the firing pin into the SQ detonator, which flashes down the tube and initiates the M55 detonator in the S&A mechanism.

If set for delay, the SQ flash tube is blocked. In the M739 fuze the M1 plunger moves forward against the firing pin and functions the primer of the M2 Delay. The delay burns for 50 ms and then initiates the M55 detonator that in turn initiates the explosives lead and booster and detonates the projectile. In the M739A1 fuze the reaction plunger moves forward against its spring and frees two balls, which release a spring-loaded sleeve. When the deceleration is sufficient, this sleeve is driven rearward by its spring and frees two other balls that in turn release the spring-loaded firing pin to strike the M55 detonator contained in the S&A mechanism.

1-5.2 DESCRIPTION OF A REPRESENTATIVE MECHANICAL TIME FUZE

The M577 MTSQ Fuze, shown in Fig. 1-33, is used with 105-mm, 155-mm, and 8-in. projectiles to deliver antipersonnel submunition grenades and antiarmor and antipersonnel mines. It is also used with the 4.2-in. mortar illuminating round. The fuze is essentially composed of four mechanical assemblies and an explosive train. The assemblies are (1) a counter assembly (including a setting gear mounting), (2) a timer assembly (timing movement with mainspring and timing scroll), (3) a trigger assembly, and (4) a safe separation device.

The counter assembly, in conjunction with the setting gear, simultaneously sets and indicates the safe, point-detonating, or timing functions of the fuze. The counter assembly consists of a setting shaft, three digital counter wheels, and two counter wheel index pinions. The counter wheels are observable through the fuze window. The setting shaft is also coupled to the timer assembly through the setting gear. Setting the fuze is accomplished by applying torque to the setting shaft through a setting key. Settings from 1 to 199 s in 0.1-s increments are possible. The applied torque rotates the timing mechanism, displacing the scroll follower pin for the set time desired.

The timing mechanism provides for the delay of fuze firing for the desired period of time (set time) and relates fuze settings made into the counter assembly to the trigger assembly. The clockwork has an improved, tuned, three-center escapement with folded lever and an axially mounted torsion spring (par. 6-6.1.3). The mainspring arbor is geared to the timing scroll disc and is also fixed to the timing scroll. This arrangement causes the timing scroll disc to rotate at the running rate of the timing movement. The timing scroll disc accommodates the scroll follower pin, which is part of the trigger assembly. Safety is provided by a combination of the spin detent holding the balance wheel and a setback pin holding the spin detent. The timer cannot start until it sees the proper combination of setback and spin.

The trigger assembly performs two functions: safe separation device rotor release and firing pin release. Both actions are performed at the desired times by actuation of the rotor detent release lever and the firing pin release lever. The firing arm on the upper end of the firing arm shaft has a scroll follower pin, which rides in the spiral groove of the timing scroll disc. The torsion spring mounted on the firing arm shaft supplies the torque to rotate the shaft clockwise and actuate the release lever. The rotation of the firing arm shaft and the movement of the scroll follower pin are controlled by the timing scroll rotation rate (rate of timing movement). A combination setback-spin detent arrangement is one of the safety features incorporated into the trigger to provide handling and safe separation device safety. The combination consists of a pin-actuated safety lever that restrains the firing arm and a spring-loaded setback pin that restrains the safety lever. A spring-loaded firing pin is restrained by the firing pin release lever. The rotor detent release lever has a rotor release detent pin, which restrains one of the two rotor spin detents. The rotor detent release lever acts as an interlock to the safe separation arming de-

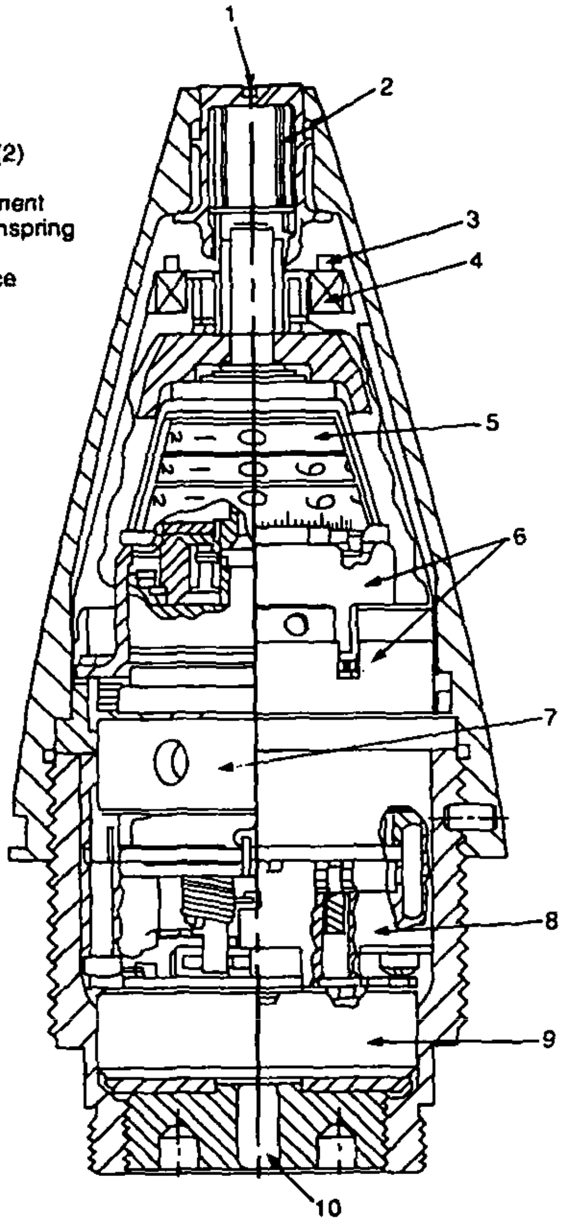


Figure 1-33. Fuze, MT, M577

lay movement. The functioning of the safe separation device is dependent on trigger assembly operation, and the slots on the firing arm shaft are arranged to actuate the rotor detent release lever approximately 3 s prior to actuation of the firing pin release lever.

The safe separation device provides the S&A feature of the fuze. A rotor, which carries a detonator, is held out of line with respect to the firing pin by two spin detents. The detents are held in place by detent springs; one detent is additionally restrained by the rotor detent release assembly (interlock) in the trigger assembly. A properly sequenced firing environment (setback and spin) will actuate the interlock and spin detents and thus allow the rotor to rotate to the in-line (armed) position. When set for PD or for a time of less than 3 s, the rotor is released immediately. When set for a longer time, however, the rotor is not released by the interlock until approximately 3 s before the set time. This delay provides overhead safety for friendly ground troops. Motion of the rotor is controlled by a runaway escapement that has its arming distance independent of the subjected spin rate. Whatever the weapon, it nominally requires 37 revolutions of the projectile from the time of release of the rotor for the fuze to arm.

The explosive train consists of four elements: an M94 detonator, a multipurpose lead, two M55 detonators, and MDF. The multipurpose lead is housed in the lower body plug and has the capability to initiate both the HE and propellant properly. The M94 detonator is housed in the rotor and can be initiated by either the firing pin or the MDF. When the rotor is in the armed position, the M94 detonator is in line with the lead. The MDF is a column of explosive (RDX) contained in an oval sleeve of lead and nylon, as shown in Fig. 4-14(A). It runs from a position in the nose of the fuze under the M55 detonators down the inside wall to a position over the M94 detonator. The M55 detonators are located in the nose of the fuze beneath a stamped plate containing pointed projections, which serve as firing pins.

When set PD, the fuze must strike a target with sufficient force to actuate a crush element in the setting key located in the nose of the fuze. A flange on the setting key then drives the firing pins into the M55 detonators. The M55 detonators initiate the MDF that in turn initiates the M94 detonator, which initiates the multipurpose lead.

When set for time, the firing pin is released when the timer reaches "0". The firing pin in the trigger strikes the M94 detonator in the rotor; neither the MDF nor M55 detonators, however, are used for time function.

1-5.3 DESCRIPTION OF A REPRESENTATIVE ELECTRONIC TIME FUZE

The M762 fuze, shown in Fig. 1-34, consists of five major subassemblies: S&A assembly, electronic assembly, liquid crystal display (LCD) assembly, power supply assembly, and receiver coil and impact switch assembly. The S&A assembly is an electromechanical device that holds the detonator "out of line" until three events occur. These are (1) 1200-g minimum setback, (2) simultaneous 1000-rpm minimum spin, and (3) an arm signal received from the electronics. There are two explosive elements in the S&A mechanism, i.e., a detonator and a piston actuator. The detonator is always both mechanically and electrically inoperable until it is "in-line".

The electronic assembly houses the electronics, and a liquid crystal display provides a readout. Encapsulant is used around the electronic components to provide support needed for launch survivability. A spin switch in the electronic circuit must experience a continuous spin environment of at least 1000 rpm before the "mission" electronics will function and continue to function. The LCD in this assembly provides the user with visual feedback of the setting encoded in the fuze.

The power supply assembly consists of a liquid reserve lithium battery and its associated activating mechanism. The battery is completely inactive until a glass ampule within the battery is broken by initiating an actuator positioned at the bottom of the battery. This can be done mechanically during the setting of the fuze by initial rotation of the ogive or electrically via the inductive setter.

The receiver coil and crush impact assembly is located inside the nose of the fuze and serves as the impact sensor. The receiver coil is connected to the electronics and receives setting data from outside the fuze through inductive

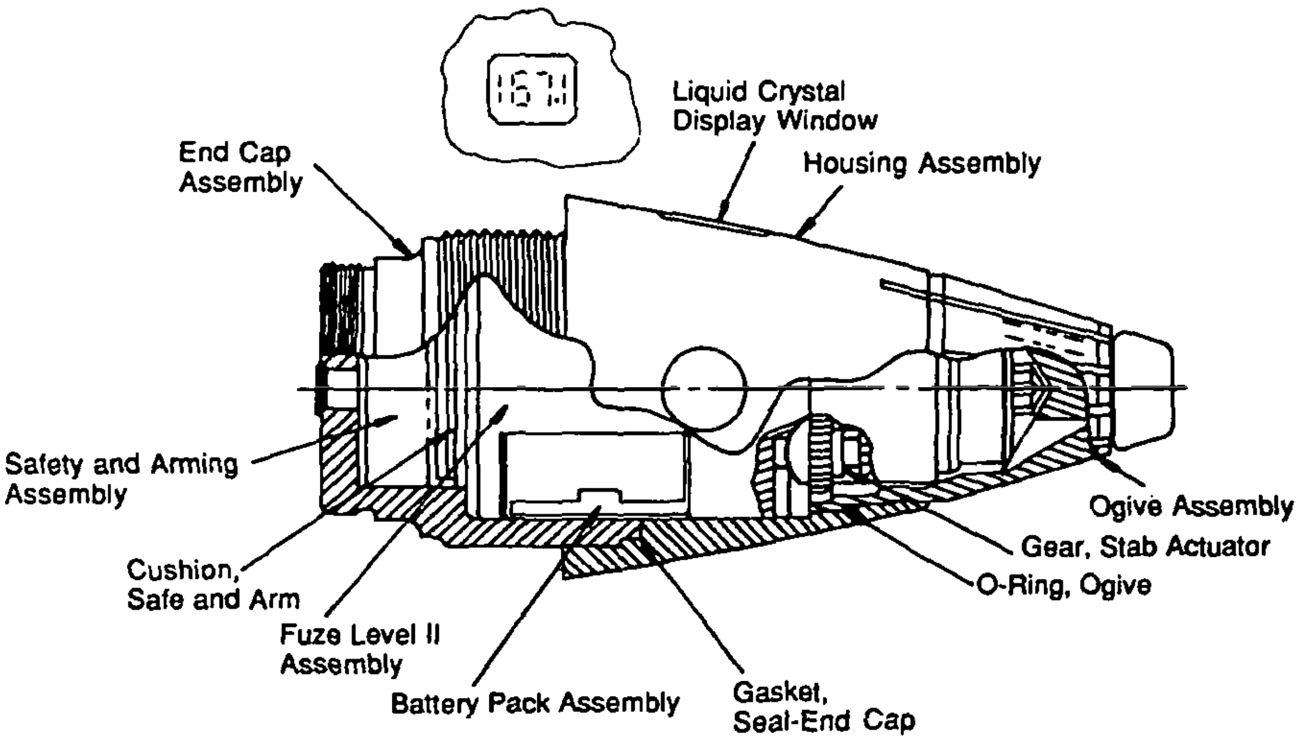


Figure 1-34. Fuze, Electronic Time, M762

coupling. This receiver permits rapid setting of the fuze without physical contact. As a safety feature, the fuze "talks back" to the setter by indicating the actual setting in the fuze.

Prior to launch, safety is maintained by restraining the slider of the S&A mechanism in the out-of-line position with a shear pin, a setback latch, and a spin latch.

The fuze can be set for time or PD mode either manually by rotating the nose cap and reading the set time on the LCD or remotely, prior to ramming, by transmission of a digital, coded message through the inductive coupling. Time settings are available from 0.5 to 199.9 s. Timing is controlled by a crystal oscillator, which yields function accuracies to better than 0.1 s. The fuze may be reset at any time during the useful life of the battery, which is at least 15 days.

Upon firing, setback removes the spring-biased pin that locks the slider in the S&A mechanism. Centrifugal force closes a spin switch to activate the time in the electronics and removes a spin detent to unlock the S&A slider. The piston actuator is fired at 450 ms in fuzes set for impact, but for time settings the actuator is fired at 50 ms less than the set time. The actuator shears the shear pin and pushes the S&A slider into the armed position to align the explosive train.

At the set time the timer functions the electric detonator. If set for impact, closure of the impact switch will initiate the electric detonator. In the impact mode, if the impact sensor is accidently closed at arm time, the impact function is disabled.

1-5.4 DESCRIPTION OF A REPRESENTATIVE PROXIMITY FUZE

The M732A1 Proximity Fuze, shown in Fig. 1-35, is a nose fuze used with 108-mm (4.2-in.), 105-mm (4-in.), and 200-mm (8-in.) HE projectiles (Ref. 20). It consists of an RF oscillator and amplifier (OSC-AMP) electronic subassembly, a spin-activated reserve power supply, an electronic timer assembly, a SAD, and a booster pellet.

The RF oscillator contains an antenna, a silicon RF transistor, and other electronic components that provide the radiating and detection system for the fuze. The antenna is located in the nose section of the fuze, which is electrically isolated from the projectile body to permit a pattern that is independent of the size of the shell on which it is installed. The antenna pattern is designed to provide an optimum burst height over a wide range of approach angles. The amplifier section of the OSC-AMP subassembly contains an integrated circuit consisting of a differential amplifier, a second-stage amplifier with a full-wave Doppler rectifier, transistors for the ripple filter, and a silicon-controlled rectifier for triggering the fire pulse circuitry.

The power supply provides an output of 30 V, nominally, with a load current of 100 mA. The cells are steel base stock with coatings of lead and lead dioxide. The electrolyte (fluoboric acid) is contained in a copper ampule that punctures under the influence of the combined linear setback force and spin force that allows the electrolyte to be distributed in the cell stack to initiate cell activation.

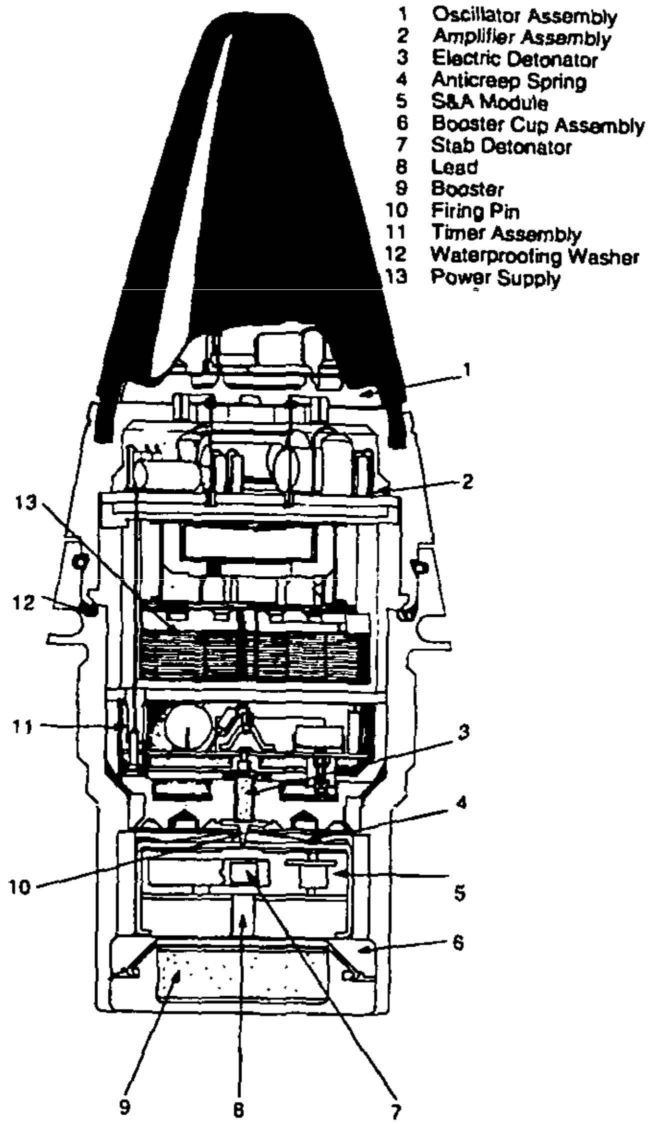


Figure 1-35. Fuze, Proximity, M732A1

The electronic timer assembly consists of electronic circuitry that provides delay of fuze turn-on, i.e., radiating of the fuze, until the set time. An integrated circuit consists of a variable duty-cycle multivibrator chopper that chops the RC charging curve; this permits a maximum 150-s delay time with an RC time constant that is only about 1 s. Finger contacts on the bottom of the timer make contact with a variable resistor on the detonator block below as the head of the fuze is turned during setting of the time.

The S&A module (Ref. 20) contains an eccentrically located rotor with a stab detonator, an escapement, two spin locks, and a setback pin. The module is housed below the detonator block assembly and is arranged to allow longitudinal movement of the S&A module. The bias spring assures the aft positioning of the S&A module during ballistic flight and thus prevents interference between the firing pin and the rotor of the S&A module.

Proximity (PROX) functioning is initiated by setting a fuze to a flight time to target derived from the ballistic tables. The fuze is set by rotation of the nose cone section so that the set line on the nose body is aligned with the appropriate engraved time (seconds) mark on the sleeve. The fuze will turn on—radiate—5 s, nominally, prior to target time.

The PD mode of operation can be selected by alignment of the nose body set line to the PD line on the sleeve.

Gun firing of the projectile, whether the fuze is set PROX or PD, starts the arming of the S&A mechanism into motion. The setback lock moves down and latches when the projectile acceleration exceeds 1200 g. As the projectile exits the gun muzzle, the spin locks swing out and allow the rotor to start moving. The rotor is unbalanced about its pivot axis so that it is driven by centrifugal force toward the armed position. Motion of the rotor is damped according to the square of its velocity by means of the gear train and runaway escapement. This type of damping results in a relatively constant arming distance for the projectile that is independent of its muzzle velocity.

The safe arming distance provided by the S&A module is most conveniently expressed in terms of the number of revolutions, or turns, made by the spinning projectile during the arming cycle. The S&A module arms at approximately 24 turns when spun at 2500 rpm in the laboratory. The number of turns to arm combined with the twist of the rifling establishes the arming distance for a given projectile. Most weapons have a twist of about 20 calibers per turn; therefore, the mechanical arming distance for this S&A module is somewhat greater than 400 calibers. This distance corresponds to about 42.1 m (138 ft) for the small diameter 105-mm (4-in.) projectile and about 81.4 m (267 ft) for the large 200-mm (8-in.) diameter projectile. Also this distance is roughly constant for all muzzle velocities from a few hundred to a few thousand feet per second.

After the rotor is driven through an arc of about 75 deg, it disengages from the gear train and snaps through an additional arc of about 45 deg to the fully armed position where it is locked in place.

The fuze is now armed (explosive train in-line) and will function with the fire pulse signal or on target impact, depending on the choice of fuze setting (PROX or PD).

During the proximity mode of operation, the fuze proceeds along the trajectory until target time minus 5 s, at which time the electronic timer switches power supply voltage to the oscillator, amplifier, and firing circuit. Voltage causes the oscillator to begin radiating an RF signal while the firing circuit is charging electrically, nominally, for 2 s before reaching the threshold voltage of 20 V, which is required to fire the electric detonator reliably.

As the fuze approaches the target, a return signal is received by the oscillator antenna and demodulated to obtain the Doppler signal, which is processed by the amplifier circuitry. When the required signal is received, the firing circuitry is triggered and the electric detonator is ignited setting the explosive train into operation to activate the round.

In the PD mode of operation, after the projectile is launched and the S&A mechanism armed, the fuze proceeds along the trajectory until it impacts the target. At this time the sliding detonator unit of the S&A mechanism impinges upon the firing pin and ignites the stab detonator, which causes the explosive train to operate and activate the round.

1-6 DESCRIPTION OF REPRESENTATIVE MORTAR FUZES

1-6.1 DESCRIPTION OF A REPRESENTATIVE IMPACT FUZE

Fuze, PD, M567, shown in Fig. 1-36, is used with HE and smoke projectiles for the 81-mm (3.2-in.) mortar. The fuze contains two side-by-side firing pins with separate setback locks. One pin initiates the M53 pyrotechnic arming delay at setback; the other is the main firing pin. A selection key mounted in the same transverse bore as the spring-powered S&A slider controls the position of the slider at arming. Two detonators—instantaneous and delay—are in the slider. The delay timer gives a delayed detonation 0.05 s after impact. These components are located in a threaded front body assembly, and the rear portion contains threads to mate with the projectile and a lead, and booster or booster pellet assembly.

Safety is obtained by locking the S&A slider by means of a pull wire, the main firing pin, and an arming pin. The arming pin is restrained by both the M53 pyrotechnic delay and the pull wire. Before firing, the fuze is set by rotating a slotted shaft in the ogive and the pull wire is removed.

On firing, acceleration moves a setback pin rearward against its spring. This frees a ball detent, which releases the fuze firing pin. This spring-loaded firing pin moves forward after acceleration and partially releases the slider. Acceleration also moves a second setback pin rearward to free a second ball, which releases a delay arming firing pin. Acceleration moves this pin rearward and functions the M53 delay. When the 2- to 6-s delay has burned, it removes the arming pin from the slider, which moves to the SQ or delay detonator alignment as selected. On impact the fuze firing pin functions the M98 SQ or the M76 Delay Detonator, which initiates the lead and booster.

1-6.2 DESCRIPTION OF A REPRESENTATIVE PYROTECHNIC TIME FUZE

Fuze, Time, XM768, shown in Fig. 1-37 (Ref. 21), is used with the illuminating projectiles for the 81-mm (3.2-in.) mortar. The fuze has a two-piece zinc and aluminum

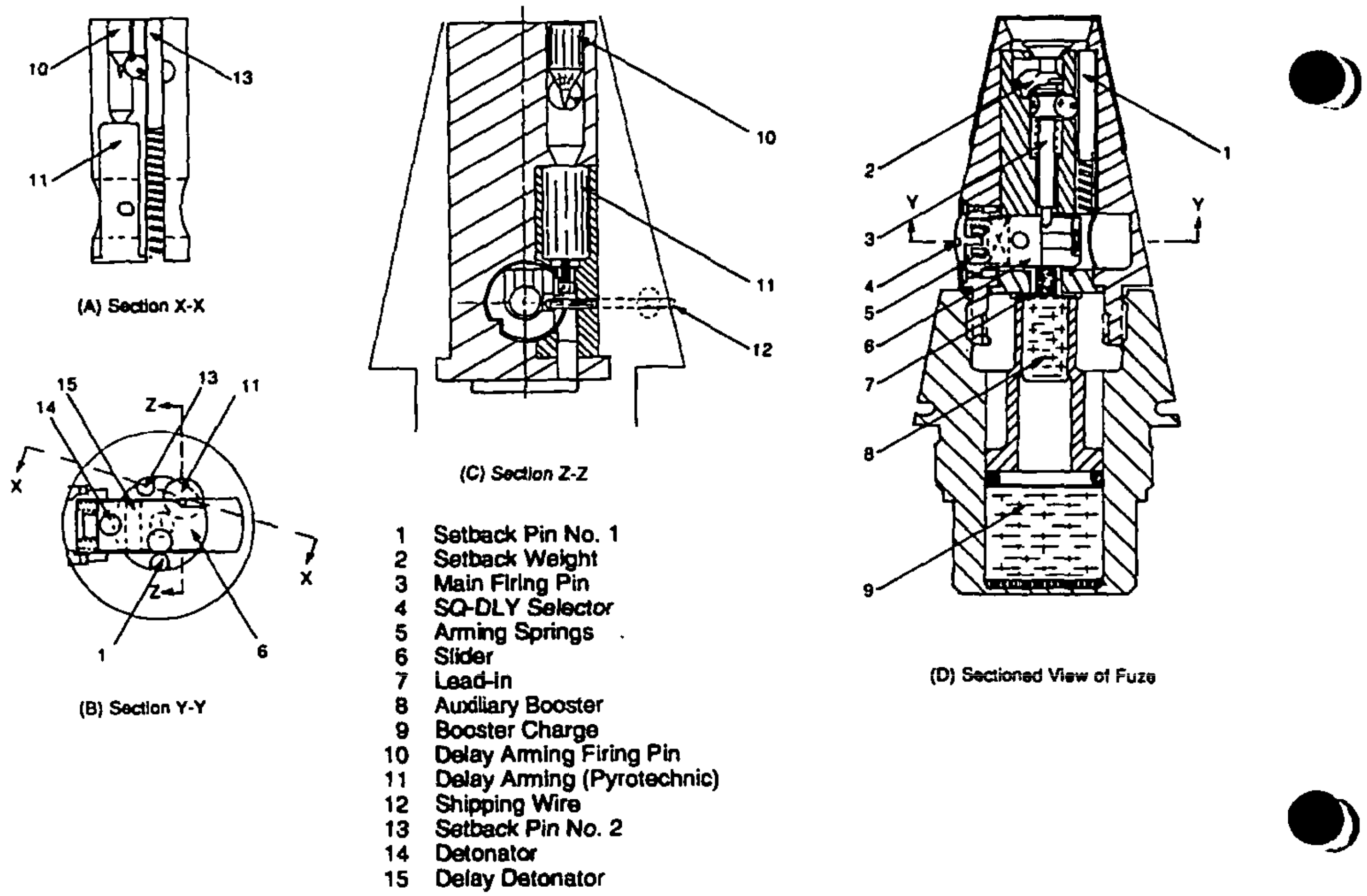


Figure 1-36. Fuze, PD, M567

die-cast body held together by a snap ring. The head assembly contains a percussion firing pin held in place with a shear wire and shipping pull wire. A percussion primer is mounted below this firing pin, and there is an angular hole leading from the primer to a point on the diameter over the circular powder train. A plastic, narrow slot orifice containing a detonator is mounted over the flash hole to confine the igniting detonator to a knife edge output that results in greater timing accuracy. The delay mix is the gasless tungsten type and burns for up to 62 s, and the expelling charge is black powder. Because this fuze is vulnerable to moisture, it has a plastic container seal for the black powder and a system of plastic and O-ring seals throughout.

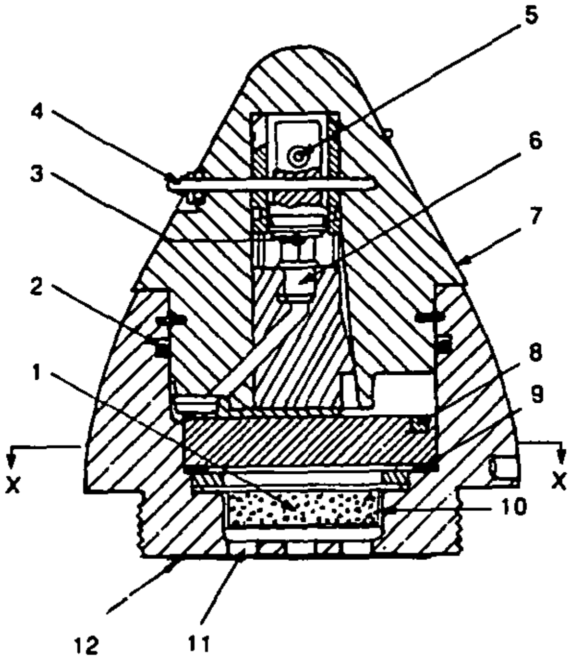
Fuze safety is provided by a pull wire, a shear pin in the firing pin, and by nonalignment of the firing train until the fuze is set. Time settings are made by rotating the fuze head relative to the time ring in the body. The pull wire is removed before firing.

On firing, acceleration moves the firing pin rearward, shears the shear wire, and functions the M39A1 primer. The primer ignites the A1A ignition powder, which ignites the tungsten delay composition in the time ring. After the set delay the time train ignites a boron-potassium-nitrate pellet, which ignites the black powder expelling charge.

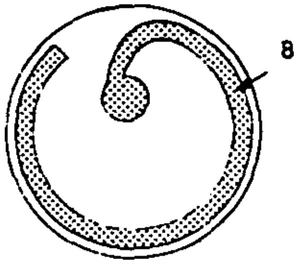
1-6.3 DESCRIPTION OF A REPRESENTATIVE PROXIMITY FUZE

The fuze, multioption, M734, as shown in Fig. 1-38 is used in 60-mm (2.3-in.) and 81-mm (3.2-in.) mortar ammunition. The fuze has four options: proximity, near-surface burst (NSB), SQ, and DLY. The M734 is an electromechanical fuze consisting of three major subassemblies, namely, the electronic assembly, the turbine alternator, and the S&A assembly.

The electronic assembly is a conventional RF Doppler system that consists of an RF oscillator section and an amplifier section. The RF oscillator assembly contains a single transistor oscillator, a longitudinal loop antenna, a transistor detector, and biasing components for the oscillator and detector. The amplifier assembly consists of two CMOS circuits for low power and high noise immunity, which

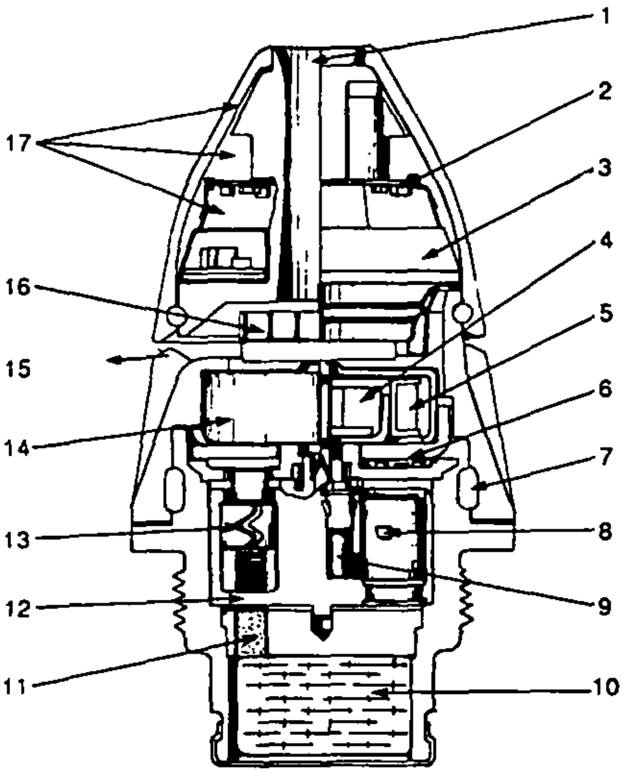


1 Black Powder Expelling Charge
2 O- Ring Seal
3 Percussion Firing Pin
4 Shipping Pin
5 Shear Wire
6 Primer, Percussion, M39A1
7 Rotatable Nose Delay Selection
8 Ring Delay
9 Ring Seal
10 Sealed Plastic Container
11 Vent Holes
12 Tape

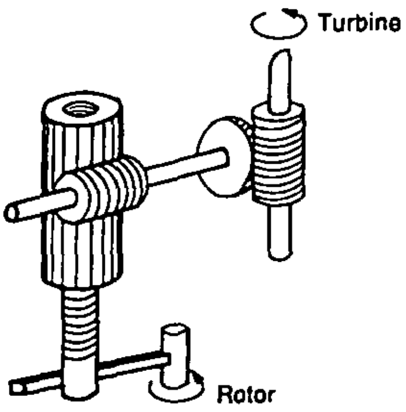


Section X-X

Figure 1-37. Fuze, Pyrotechnic Time, XM768



(A) Fuze M734



(B) Delayed Arming System
Driven by Turbine

1 Air Inlet to Venturi
2 Oscillator
3 Shielded Amplifier
4 Magnet on Turbine Shaft
5 Coil
6 Option Contact Wipers
7 Rotatable Seal
8 Delay Primer
9 Electric Detonator (Microdet)
10 Booster
11 Lead-In
12 S&A Rotor
13 Zigzag Setback Lock
14 Turbine Alternator
15 Air Outlet
16 Air Drive Turbine
17 Electronics, Foam Potted

Figure 1-38. Fuze, Multioption, M734 (Ref. 22)

perform amplification and logic functions, capacitors, a silicon-controlled rectifier (SCR) switch to fire the electric detonator, a full-wave bridge rectifier, and a spring-mass inertia-operated impact switch.

The air-driven turbine alternator converts in-flight ram air energy into electrical energy required by the fuze electronic assembly. During flight, air enters through the axial air intake port in the fuze nose and impinges on a molded plastic turbine wheel. The kinetic energy of the air is converted by the turbine to mechanical rotational energy. The air is then expelled through three exhaust ports uniformly spaced around the circumference of the fuze just behind the plastic nose cone. The rotational motion of the turbine drives a six-pole, cylindrical, permanent magnet rotor on a concentric shaft. The rotor turns between poles of a magnetic stator and induces an electromotive force (emf) in the windings. The emf is applied to the electronic assembly.

The concentric shaft extends through the alternator rotor and is coupled to the input of a speed reducer in the S&A mechanism to provide mechanical energy for the arming function.

The turbine alternator is capable of delivering sufficient electrical energy to perform its required functions over the full terminal velocity range of the projectile, approximately 38 to 244 m/s (125 to 800 ft/s), at rotational speeds ranging between 50,000 to 100,000 rpm, depending on air velocity.

The SAD consists essentially of a spring-driven rotor mounted in an aluminum housing. Prior to firing, the rotor is locked in the safe position by two independent safety elements. The first of these is a spring-mass setback integrator that is driven rearward by setback forces resulting from firing acceleration. The second lock is a jackscrew that is operated by energy derived from ram air pressure, delivered from the shaft of the turbine alternator through the speed reducer. The jackscrew and the speed reducer require the shaft of the turbine alternator to make approximately 1050 revolutions before the jackscrew releases the S&A rotor, permitting a torsion spring to drive the rotor to the armed position. The 1050 revolutions assure that when fired from the 60-mm mortar, the projectile will have traveled a minimum of 100 m (328 ft) from the launch point before arming occurs.

The S&A rotor houses the setback sensor assembly, the delay gear train components, the gear train declutching mechanism, and the three initiating explosive elements. The explosive lead and booster are mounted in the fuze base.

There are two ways to initiate the explosive train, namely electrical and mechanical. The electrical firing mode is used when the fuze is set for proximity, near-surface burst, or impact. In any of these modes fuze function occurs after mechanical and electrical arming when the electric detonator receives a fire pulse from the electronic firing circuit. The electric detonator (microdet) initiates the flash sensitive M61 detonator in the lower portion of the rotor, which, in turn, initiates the lead and booster. In the delay setting mode the firing circuit is disabled, and the fuze can function in a mechanical mode only. In this mode, function is initiated by a stab delay primer mounted in a carrier (cage) in the rotor. The cage can move axially but is biased rearward by a 5-g anticreep spring. (Maximum creep of a mortar projectile is less than 1 g.) When the rotor reaches the in-line position, the primer cage is aligned with a firing pin attached to the fuze base cover forward of the rotor. On impact, deceleration of the projectile overcomes the anticreep spring and drives the primer against the firing pin. A deceleration of about 100 g is required to initiate the primer reliably, which includes a 50-ms pyrotechnic delay. The output of the delay primer initiates the detonator that, in turn, detonates the lead and booster.

Before firing, the fuze is set to the desired mode by rotating the nose to align the arrow indicating the desired function with the setting mark (notch) on the fuze base.

Upon firing, the first safety element, i.e., the setback integrator, is moved rearward by the firing acceleration and locked in this position. This also unlocks the gear train. As the round leaves the mortar tube, air ingested through the air intake drives the turbine alternator and generates electrical energy to power the electronic assembly. It also removes the second (jackscrew) lock on the S&A rotor through the gear train speed reducer. Upon jackscrew release, the S&A rotor arms and locks, aligning the explosive train and completing the detonator firing circuit.

The fuze is now ready to function immediately in the impact or delay mode or, after an additional 3-s arming delay, in the PROX or NSB mode. When set for PROX, the fuze will function on approach to the target through operation of the RF target sensor. The NSB function is obtained in a similar manner—by employing the same target sensor functioning in a desensitized mode. Electrical impact function is achieved by closure of the inertial switch that completes a firing circuit between the firing capacitor and the electric detonator.

When the fuze is set for delay, the electronic circuitry is completely disabled. The fuze functions through initiation of a 50-ms pyrotechnic delay primer, which is initiated by axial inertial forces of impact. These forces cause the primer to impinge on a firing pin with which it aligns when the SAD arms. The delay function mode also backs up the three electronic function modes of the fuze.

1-7 DESCRIPTION OF A REPRESENTATIVE TANK MAIN ARMAMENT FUZE

The Fuze, PIBD, M764, as shown in Fig. 1-39, is used with a 120-mm (4.7-in.) shaped charge, fin-stabilized projectile shown in Fig. 1-5. The fuze is located in the base of the projectile, and target-sensing crush switches are located on the tip of a nose spike and on the shoulder of the round.

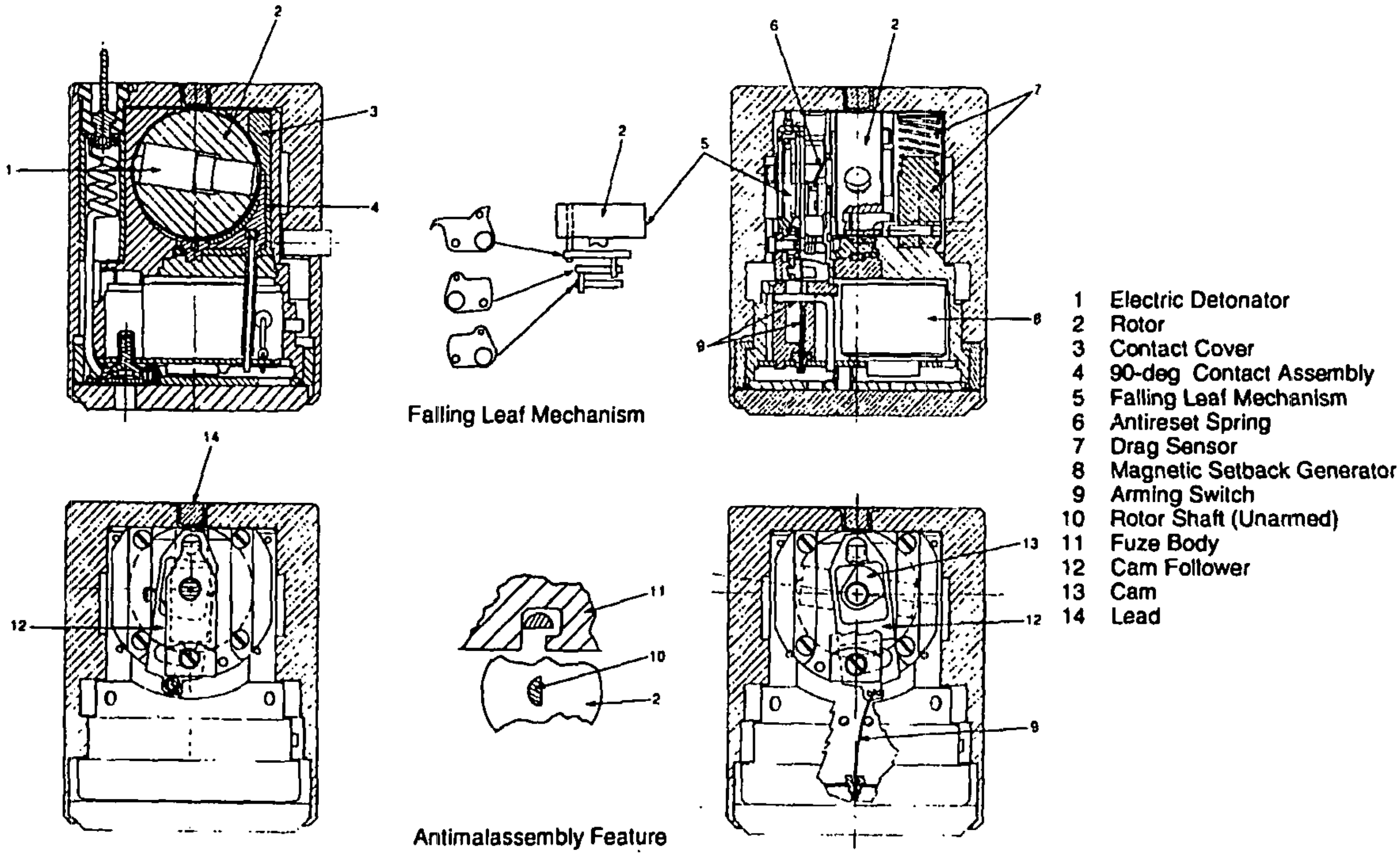


Figure 1-39. Fuze PIBD, M764

The fuze also contains an inertia spring-mass switch, which provides initiation of the fuze at low graze angles. Energy to fire the electric detonator is obtained from a magnetic setback generator. Fuze safety is achieved by two independent mechanical devices that are responsive to different environments, i.e., setback and drag, and by switching logic, which requires that the fuze is in the safe position in order to effect charging of the firing capacitor.

Operation of the M764 fuze is shown in Figs. 1-39 and 1-40. The rotor is locked in the safe position (263 deg from armed) by a three-leaf, sequential mechanism. (See par. 6-5.3.) In this position the spring-loaded electric detonator button is shorted to protect against electrical transients, electrostatic discharge, and electromagnetic radiation.

When the projectile is fired, sustained acceleration (to 4000 g) causes the two spring-biased setback leaves and one unbiased leaf to be displaced in sequence, and then the third leaf unlocks the rotor. Simultaneously, at approximately 10,000 g, the magnetic core of the setback generator ruptures the shear disc; movement of the core induces a voltage to charge the firing capacitor C1, shown on Fig. 1-41, via the closed S2a switch (safe position). A diode blocks discharge in the reverse direction.

Rotor movement starts when the setback frictional forces between the rotor and its housing are reduced to approximately 180 g.

When the drag sensor senses 2.0- to 4.0-g deceleration, the drag weight will move forward and remove the drag pin from the path of the rotor to allow it to complete its arming cycle. The rotor spring drives the rotor through the 263-deg arming cycle, and its residual torque holds the rotor in the armed position. However, if the drag sensor does not sense adequate drag environment, the drag pin will remain in the path of the rotor limit pin. Thus the second safety

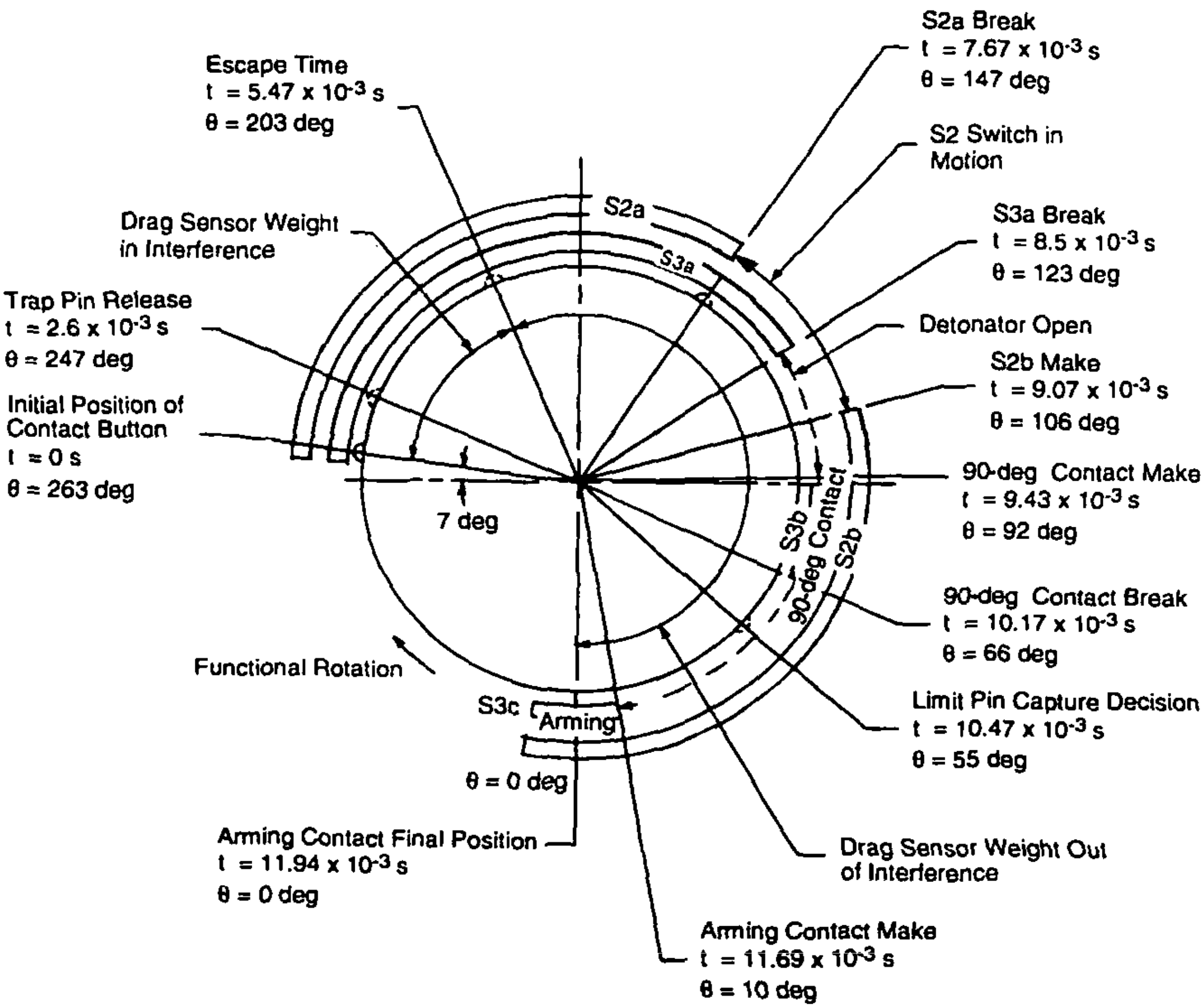
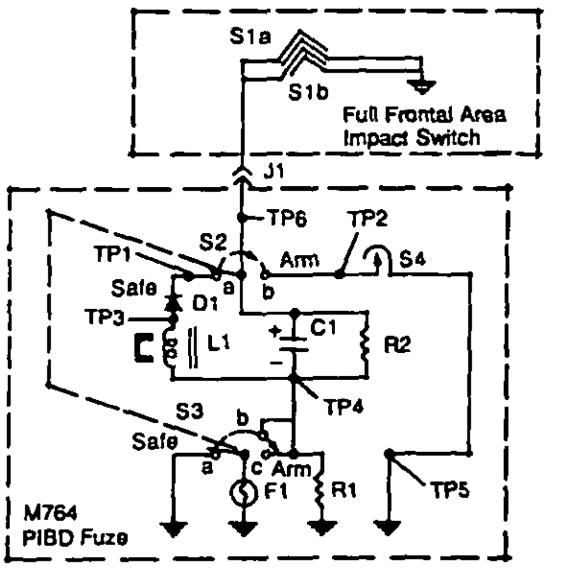


Figure 1-40. Fuze, M764, Operational Cycle Diagram



C1	Capacitor, 0.56 mF	R1	Resistor, 100,000Ω
D1	Diode	R2	Resistor, 680 MΩ
F1	Detonator, M69 (R = 1 to 10 kΩ)	S1a	Nose Switch
L1	Setback Generator Assembly L = 80 mH R = 12	S1b	Shoulder Switch
		S3	Detonator Switch
J1	Connector	S4	Trembler Switch

Figure 1-41. Schematic Diagram of the Fuzing System for the M830 HEAT Cartridge

locks the rotor at a 55-deg position from armed and thus disables the round in a safe condition.

In traveling the 263-deg excursion to the armed condition, a number of switching logic functions are performed, as shown on Fig. 1-40, namely,

1. Arming Switch S2a opens at the 147-deg position and removes the setback generator from the circuit.

2. Arming Switch S2b closes at the 106-deg position and places the inertia switch in the circuit.

3. The spring-loaded detonator button contact to the housing (S3a) opens at the 123-deg position and thus removes the ground from the detonator.

From the 92-deg position to the 66-deg position, the detonator is connected to the firing circuit (S3b). Any inadvertently closed sensor switch or circuit short will function the detonator at approximately 90 deg out-of-line and lead to a safe dud.

At the 66-deg position, the dudding contact S3b opens again, and at the 10-deg position the firing contact S3c is closed and the detonator is in-line with the explosive lead.

After fuze arming, closure of either of the crush switches or the inertia switch will dump the energy stored on the firing capacitor into the electric detonator, thus firing the explosive lead and booster and detonating the round.

1-8 DESCRIPTION OF REPRESENTATIVE FUZES FOR SMALL CALIBER AUTOMATIC CANNON

This group of fuzes is applicable to the smaller calibers of 20 through 40 mm (0.79 through 1.57 in.). Small caliber fuzes differ from those of larger calibers in three main respects:

1. Obviously, they are smaller. The initiation and arming mechanisms must be compact because little space is available for them. The arming devices most commonly used are disk rotors (See par. 6-5.1.), ball rotors (See par. 6-5.6.), and spiral unwinders (See par. 6-4.5.). Although the booster is small—because the main explosive filler is small—it nevertheless occupies a significant portion of the space allotted to the fuze.

2. Spin rates and setback acceleration of small arms fuzes are significantly higher than those of fuzes for larger caliber weapons. Rates of 583 to 1667 rps (35,000 to 100,000 rpm) with accelerations of 35,000 to 100,000 g are common.

3. Automatic cannon fuzes are subjected to additional forces while being fed into the weapon. During feeding from magazine or belt into the chamber of the weapon, the cartridges, and therefore the fuzes, are subjected to high acceleration and impact in both longitudinal and transverse directions. High rates of fire require considerable velocity in the feeding operation that leads to severe impact loading.

The fuzes for these rounds in US ordnance are PD and have out-of-line explosive trains with varying degrees of delayed arming. The usual mechanisms to obtain delayed arming are high-inertia ball rotors that slip and roll relative to their housing and spiral-wound metal ribbons that unwind. Recently, a pneumatic arming delay has been introduced.

Foreign fuzes of these calibers include many base fuzes to improve penetration of hard targets and are oriented toward the spiral-unwinder- or escapement-type arming delays.

Because of the large number required, simple, production-oriented designs are an important challenge to the designer.

1-8.1 DESCRIPTION OF A REPRESENTATIVE POINT-DETONATING, SELF-DESTRUCT (PDSD) FUZE FOR SMALL CALIBER AUTOMATIC CANNON

Fuze, PDSD, 25-mm M758, shown in Fig. 1-42, is a nose fuze used on 25-mm high-explosive incendiary, tracer (HEI-T) ammunition for the M242 automatic cannon, the BUSHMASTER. The S&A mechanism is a disk rotor mounted in a body assembly and held by two opposing centrifugal lock weights and by intrusion of the firing pin. The firing pin is mounted in a tandem piston assembly containing a porous, sintered metal restrictor and a peripheral

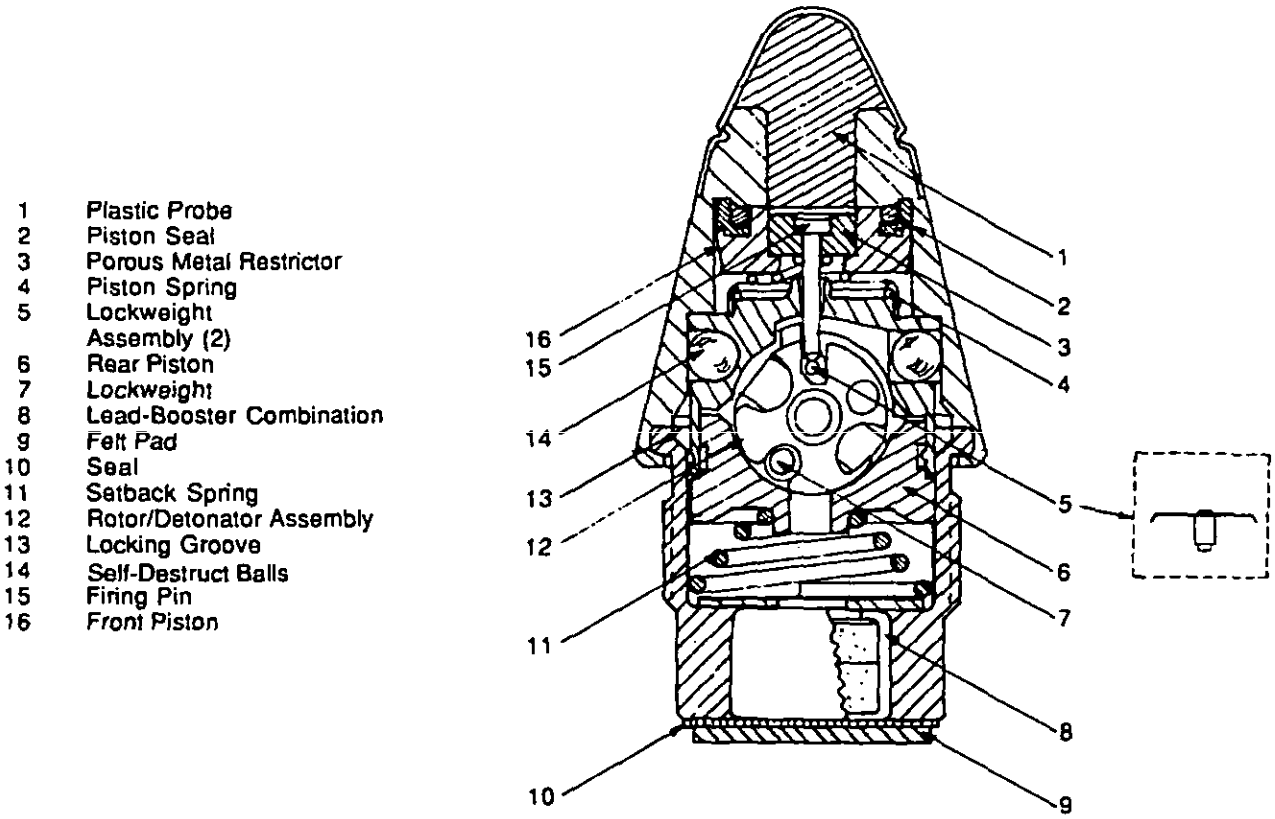


Figure 1-42. Fuze, PDSD, 25 mm, M758

silicone elastomer seal. Both the piston and body assemblies are held forward by a setback spring at the base. The assemblies are housed in a two-piece steel fuze body with a plastic ogival probe at the nose and an HE lead at the base.

Fuze-handling safety is accomplished by restraining the rotor in the out-of-line position with two spin-sensitive lockweights and with the firing pin acting as a detent.

On firing, setback (104,000 g) moves both piston and body assemblies rearward as a unit and displaced air passes into a cavity ahead of the piston. Centrifugal force (104,000 rpm) drives two balls into a groove in the fuze body, which locks the body assembly in the setback position, removes the two lockweights from the rotor, and expands the silicone elastomer cup to effect an air seal. When acceleration ceases, the piston spring moves the piston assembly forward to withdraw the firing pin from the rotor. The forward motion of the piston is delayed by air passing through its porous restrictor, which provides up to 10-m arming delay.

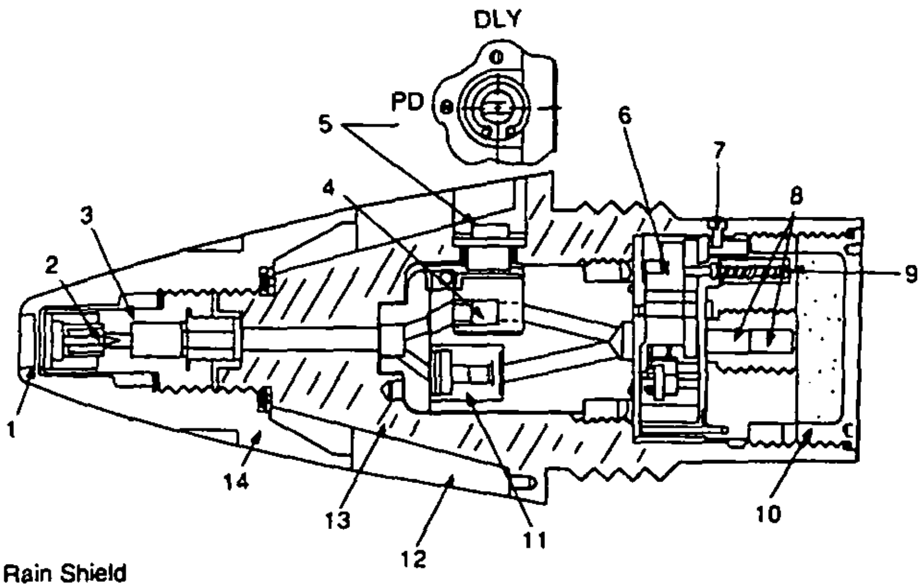
Centrifugal force arms the dynamically unbalanced rotor and locks it with a ball weight, which locks into a groove in the body assembly. On impact, the nose probe drives the firing pin rearward and initiates the stab detonator, which initiates the lead. If impact does not occur, spin decay allows the setback spring to overcome the centrifugal force of the locking balls and drive the body assembly forward; this action allows the detonator to strike the firing pin. On graze, either the nose probe is driven rearward or a combination of inertial force from velocity decay or a decrease of centrifugal force due to spin reduction allows the body assembly to move forward.

This fuze is one of a large family for automatic cannon from 20 through 40 mm. Many variants exist as to specific geometry as part of the M714 series of fuzes.

1-8.2 DESCRIPTION OF A REPRESENTATIVE POINT-DETONATING SQ/DLY FUZE FOR MEDIUM CALIBER AUTOMATIC CANNON

Fuze PDSQ or DLY MK 407 MOD 1, as shown in Fig. 1-43, is a nose fuze used by the Navy in a 76-mm HE round fired automatically from the "Oto-Melara" gun. The gun and mount are of Italian origin and are used by the North Atlantic Treaty Organization (NATO).

This fuze differs from the conventional PD fuze in several notable respects. The firing train is housed in a steel body that provides protection during target penetration. Thus attack against lightly armored craft is feasible. The delay element is dead pressed lead styphnate, and it has a nominal 8-ms time delay that, at a striking velocity of 610



1 Rain Shield
2 Firing Pin
3 Stab Detonator
4 Relay Detonator
5 Selector Switch Assembly
6 SAD, MK 49 Mod 0
7 Antimalassembly
8 Leads
9 Setback Pin Lock
10 Booster
11 Pyrotechnic Delay Unit
12 Plastic Insert
13 Hardened Steel Body
14 Metal Ogive

Figure 1-43. Fuze, PDSQ and DLY, MK 407 Mod 1

m/s (2000 ft/s), gives a penetration of 5 m (16 ft). It is effective against small, unarmored craft and against the superstructure of armored ships. The rain shield over the nose is an integral bulkhead in lieu of the bar-type shield on the M739 PD fuze.

Safety features consist of a crush cup support under the firing pin; an S&A mechanism, MK 49-0, with centrifugal and setback locks; and a runaway escapement to effect a safe separation distance.

Penetration capabilities include a 6-mm (0.25-in.) mild steel (MS) plate at 45 deg obliquity. Some success was obtained against 13-mm (0.5-in.) MS plate, but projectile strength became a limiting factor. Also a significant improvement was demonstrated against masonry and concrete bunkers over the conventional nose PD fuze.

1-8.3 DESCRIPTION OF A REPRESENTATIVE PROXIMITY FUZE

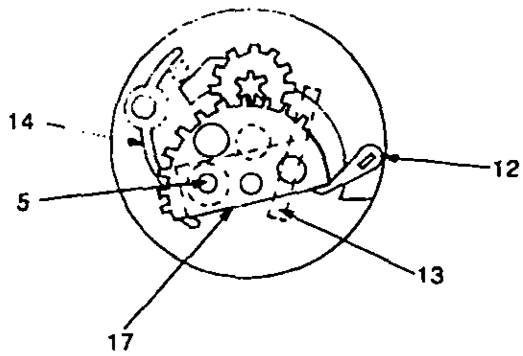
Fuze, Proximity, PD, SD, M766, as shown in Fig. 1-44, was under development for an HE projectile for the 40-mm (1.56-in.) automatic cannon as used in the armament subsystem for the SGT YORK. Even though the program was terminated, the fuze description is given here for illustrative purposes. The weapon was to consist of a dual-air-cooled 40-mm cannon adapted for automatic fire and mounted on a turreted tracked vehicle. It was to be a forward air defense weapon.

The fuze is comprised of a radome ogive with RF transmitter and processing electronics that include electronic counter countermeasures (ECCM), an impact switch, a shielded low-frequency section, a battery, a contact assembly, a SAD, and an explosive lead-in and booster pellet. Operation of the fuze is described in the paragraphs that follow.

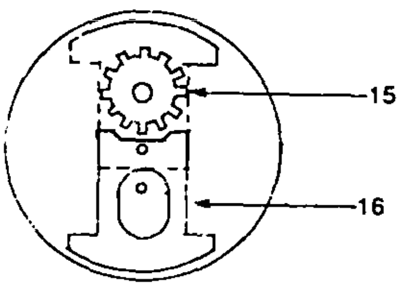
Safety is maintained by two independent locks, i.e., setback and spin, which hold the rotor in the safe position. An additional safety is the absence of electrical energy until setback acceleration breaks the battery ampule coupled with spin forces that must be present to maintain proper distribution of the electrolyte. A digital timer and logic sequence prevent firing energy from reaching the detonator for a minimum time interval of 0.230 s, which equates to 200 m (656 ft) downrange.

Under setback, bore safety of the fuze is maintained by the detent that locks the rotor in the out-of-line position until relaxation of setback acceleration forces. The detent

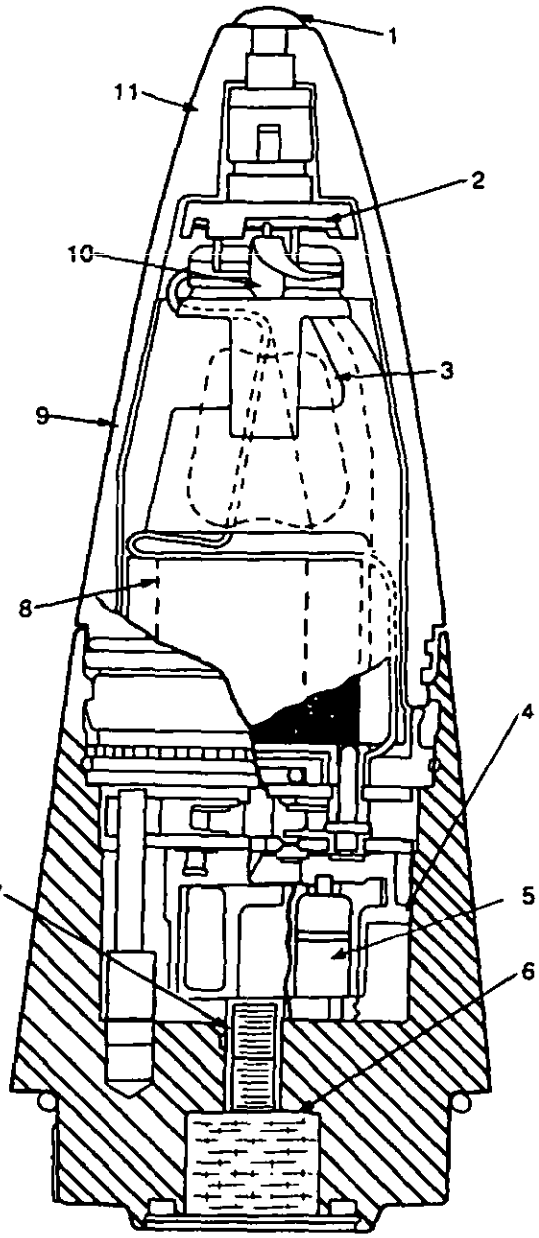
1 Proximity Disable Contact
2 Oscillator Detector Assembly
3 Low-Frequency Section
4 SAD
5 Electric Detonator
6 Booster
7 Lead-In
8 Battery
9 Shield
10 Impact Switch
11 Radome
12 Detent, Spin-Setback Combination
13 Detent Lock on Rotor During Setback
14 Spin Detent on Rotor
15 Runaway Escapement
16 Stamped Pallet Cover to Increase Inertia
17 Rotor



(A) SAD



(B) Pallet



(C) Fuze XM 766

Figure 1-44. Fuze, Proximity, XM766 for 40-mm (SGT YORK) Projectile

lock partially releases the rotor, and, as the spin rate increases, the spin detent lock also partially releases the rotor. Spin also prevents the detent from relocking the rotor. As the projectile leaves the barrel, setback decays to allow the detent lock to move out of the path of the rotor. Fuze arming is delayed by the escapement until a minimum of 0.070 s after muzzle exit.

Initially the fuze battery is in a dry, dormant state. Upon setback the ampule holder shears and the central member penetrates, breaks the ampule, and releases the electrolyte into the inner cavity of the battery cells. Centrifugal forces then cause an even distribution of the electrolyte within each individual cell and between the individual plates of the battery. The battery then produces an electromotive force that rises in an exponential fashion. The appearance of voltage produces a reset pulse that initializes all fuze electronics.

As the voltage appears, the master clock begins to oscillate. The master timer is responsible for generating the timing delay and for providing an electronic arming function within the fuze. It is not possible to obtain any fuze function prior to the preset arming delay.

The fuze igniter is initiated by the charge accumulated on the firing capacitor. From the instant power is available until the electronic arm time, the firing capacitor is electrically shorted. At arm time, the short is removed and the firing capacitor is allowed to charge; an action that requires approximately 20 ms. Firing of the igniter is enabled between 230 ms minimum and 305 ms maximum.

With the fuze powered up, electrically armed, and with the firing capacitor charged, there are three modes of initiation, namely, proximity, impact, and self-destruct. These modes are described as follows:

1. *Proximity Mode*. The fuze contains a complete RF transmitter and processing electronics that include ECCM features, which provide a highly accurate and reliable proximity function. The oscillator operates as a transceiver and senses signals reflected from the target. The target signal is dependent on target size, angle of attack, distance to the target, and relative velocities. In normal operation proximity functions occur approximately 5 m (16 ft) from the target. The fuze is designed to operate in the presence of electronic noise as encountered in low-altitude flights over water and land. In this case fuze sensitivity is automatically reduced to restrict early burst due to environmental perturbations. In this mode of operation the burst point about the target is reduced to 1 to 3 m (3.3 to 10 ft), depending on target size. Also included in the electronics section is an ECCM channel, which inhibits the firing signal in the presence of jamming until the fuze is close enough to the target to strengthen the reflected signal and trigger the firing system.

2. *Impact Mode*. The second mode of initiation is by an impact function. There are two impact switches as an integral part of the electronics assembly. In the case of a direct hit, either of the two parallel impact switches will close and cause an immediate and direct discharge of the firing circuit capacitor into the igniter. This mode bypasses the fuze proximity mode logic responsible for firing (after arming).

3. *Self-Destruct*. The third mode of initiation is by the self-destruct circuit. At power application the master timer begins to count the flight time. When a total time of 17 ± 4 s has elapsed without a valid firing pulse from either the proximity or impact modes, the unit self-destructs.

1-9 DESCRIPTION OF REPRESENTATIVE ROCKET FUZES

Rocket fuzes experience acceleration forces from as low as 25 g in the 70-mm (2.75-in.) rocket to as high as 3640 g in the 66-mm (2.57-in.) LAW round.

Rocket fuzes can be flame-producing (ignition) or detonating types, and they include such categories as PD, PIBD, electronic time, pyrotechnic time, proximity, and multioption.

Early rocket fuzes had wind vanes, which unthreaded locks in the out-of-line explosive train, or base fuzes, which used motor gas pressure exerted on the base of the rocket head and fuze to perform arming operations. Some of the earlier-designed rockets were spin stabilized, and these rounds were able to use some of the standard projectile fuzes of that time.

All modern rockets are fin stabilized and universally use sustained acceleration as an environment for arming. Double-integrating escapement mechanisms, zigzag pins (See par. 6-4.6.), and sequential leaf mechanisms (See par. 6-5.3.) are effectively employed as acceleration sensors in the modern rocket fuze. To meet the requirements of current safety criteria, rocket fuzes now use ram air, electrical energy (launcher supplied), and drag (See par. 11-2.2.) as second environments for actuating safety locks.

1-9.1 DESCRIPTION OF A REPRESENTATIVE MECHANICAL FUZE

Fuze, PD, M423, as shown in Fig. 1-45, is a nose fuze used in the 70-mm (2.75-in.) folding-fin aircraft rocket (FFAR) (par. 1-3.2.2) for helicopters. It is a simple, all-mechanical system with a fixed firing pin in the ogive and an S&A mechanism having an unbalanced rotor locked by a setback weight and time controlled with a runaway escapement. A lead and a booster charge are mounted below the S&A assembly.

The rotor is restrained in the unarmed position by a spring-biased setback weight and a gear sector that engages with the gear train of a runaway escapement. On firing, acceleration moves the setback weight rearward and releases the unbalanced rotor which, responding to sustained acceleration, rotates to the armed position delayed by the runaway escapement. If a minimum acceleration-time

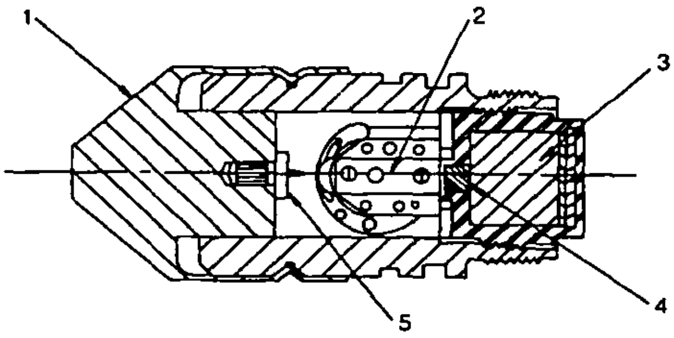


Figure 1-45. Fuze, PD, M423 (Ref. 2)

rocket motor boost is not obtained, the rotor will not reach a commit point and the returning setback weight drives the rotor back to the unarmed position. When armed, a spring-loaded pin locks the rotor in the armed position. On impact, the striker with the firing pin is driven directly rearward and functions the M104 primer that initiates the M85 Flash Detonator and in turn the lead and booster.

The fuze does not meet current safety standards because it contains only a single environmental lock on the rotor. This S&A mechanism has proven highly reliable, however, in a wide variety of applications over several decades, and a waiver from the safety standard (MIL-STD-1316) is in effect. In one application in rocket fuze MK 191 Mod 1, it was necessary to add a second environmental lock. This is covered in par. 6-4.9.

1-9.2 DESCRIPTION OF A REPRESENTATIVE ELECTRICAL FUZE

Fuze, Electronic Time, M445, as shown in Fig. 1-46, is used in the 228-mm (8.9-in.) multiple launch rocket system (MLRS), which has a warhead for dispensing submunitions. The fuze is composed of a fluidic (ram air) generator power source, an electronic module with telemeter umbilical and setter cables, an S&A mechanism, and an explosive lead charge.

Fuze safety is achieved by restraining a rotor by an acceleration-time sensor and a piston actuator initiated by the fluidic generator operated from sustained airflow.

On firing, a spring-biased setback weight moves rearward, oscillating in a zigzag path (See par. 6-4.6.). If a proper rocket motor boost is obtained, this partially releases the rotor and closes a switch to an electronic timer. In flight, ram air passes through an annular orifice into a resonating cavity and the acoustic vibrations oscillate a diaphragm connected to a reed in a magnetic field and thus generate an emf. After 1024 cycles of the diaphragm, a capacitor is charged, and after 1536 cycles, it is discharged into the piston actuator. The piston actuator removes the second lock to release the rotor completely. Sustained acceleration rotates the unbalanced rotor against a bias spring to the armed position; this rotation unshorts the detonator and closes the firing circuit. The rotor is then locked in the armed position by a lock pin. Timing is accomplished with a twin-t oscillator, a divider circuit, and a counter. To enhance overhead safety, at 3.4 s before set time the firing capacitor is charged and, at set time, functions the MK 84 Detonator, which initiates the lead. Because this munition is a cargo-carrying round, it has high lethality.

Before flight the fuze is set by the MLRS fire control system. A status switch, which is closed when the rotor is unarmed and open if the rotor moves, assures that the fuze can be set only if it is unarmed prior to launch. The S&A assembly is designed so that it cannot be installed in the fuze if the rotor is armed.

1-10 DESCRIPTION OF REPRESENTATIVE MISSILE FUZES

In military use the term rocket describes a free-flight missile that is merely pointed in the intended direction of flight and depends upon a rocket motor for propulsion. Guided missiles, on the other hand, can be directed to their target while in flight or motion—either by RF, laser, IR, radar within the missile or through wire linkage to the missile. Although commonly grouped with guided missiles, a ballistic missile is guided in the upward part of its trajectory but becomes either a free-falling body or a terminally guided body in the latter stages of its flight through the atmosphere.

Guided missiles generally have accelerations of less than 100 g. Like rockets, they have similar force fields—such as long time duration of accelerations—useful for arming. Because they are fin stabilized, centrifugal forces are not available.

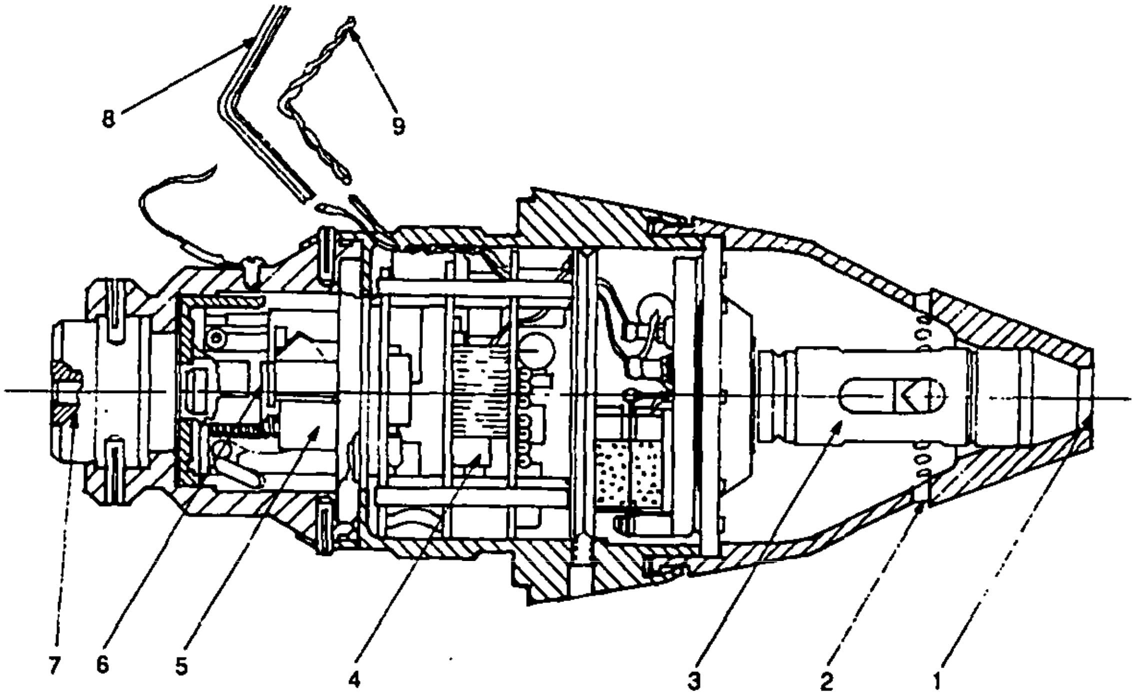
Fuzing of guided missiles is similar to that of rockets except that time fuzes are not used. Sensing can be magnetic for antivehicle use, PIBD for shaped-charge warheads, proximity, and delay firing after target contact to effect target penetration. In the more complex missiles such as PATRIOT and STINGER, fuzes are relatively complex.

Systems currently under development or in-service are

1. *TOW*. This is a heavy-duty antitank weapon launched from helicopters, ground vehicles, or a tripod, and it uses a PIBD fuze.

2. *HELLFIRE*. This is an antitank missile restricted to use in advanced attack helicopters, and it uses PIBD fuzing.

3. *DRAGON*. This missile is a medium-range complement to the TOW that is shoulder launched and uses PIBD fuzing.



1 Ram Air Inlet
2 Exhaust Ports
3 Fluidic Generator
4 Electronic Assembly
5 Zigzag Setback Lock
6 SAD
7 Lead Change Assembly
8 Fuze Setter Cable
9 Telemeter Cable

Figure 1-46. Fuze, Electronic Time, M445, for MLRS Cargo Rocket

4. *STINGER*. This is a shoulder-fired, antiaircraft weapon. It has an IR guidance system and uses a contact fuze with delay.

5. *PATRIOT*. This weapon is designed to counter large numbers of high-speed aircraft and short-range missiles at all altitudes. It uses proximity fuzing and either command or automatic self-destruct at loss of guidance.

1-10.1 DESCRIPTION OF A REPRESENTATIVE IMPACT FUZE (TOW) S&A MECHANISM

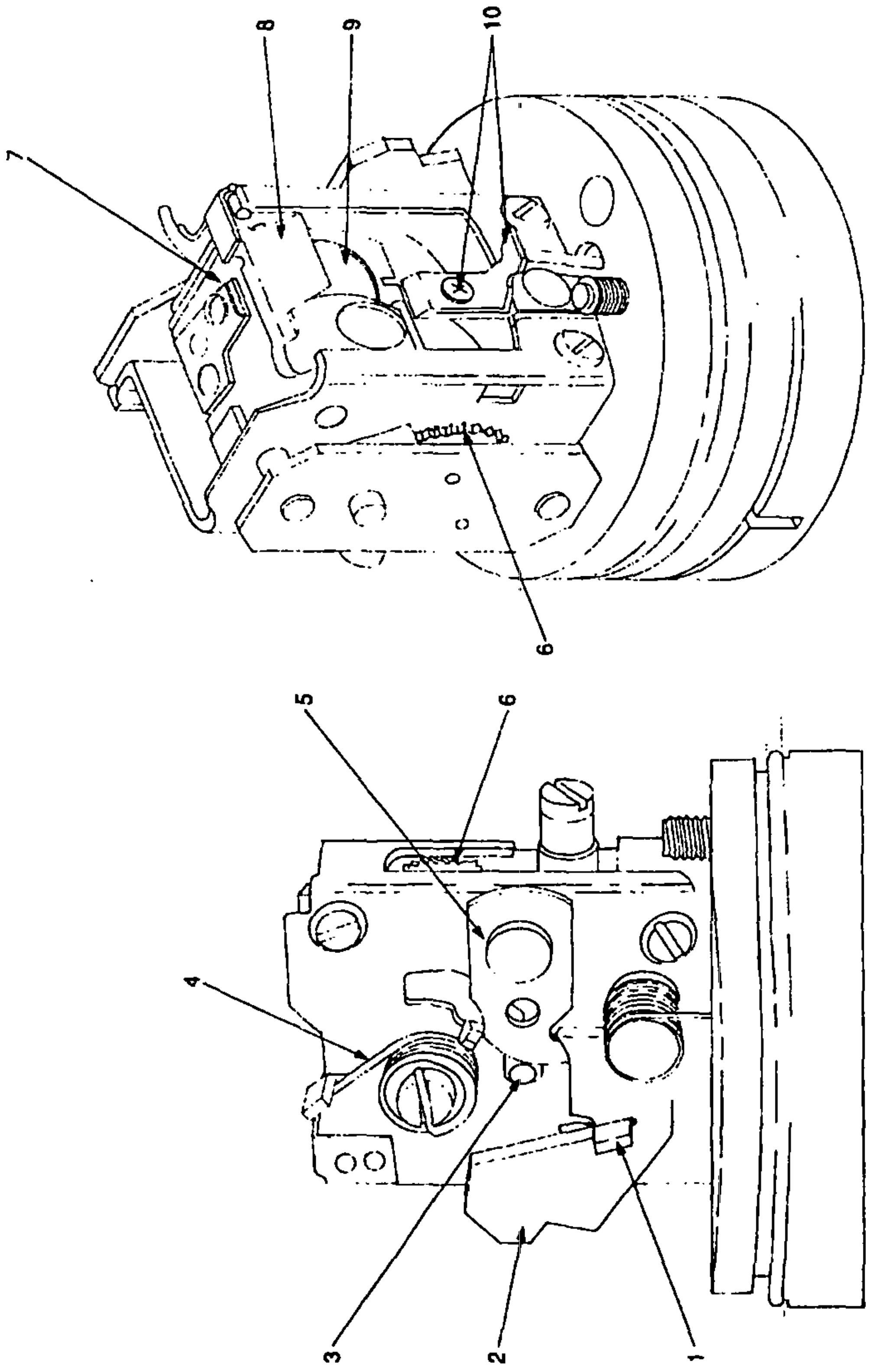
The fuze, PIBD, for the TOW guided missile is a simple arrangement consisting of a double ogive crush switch, which is a part of the warhead (HEAT) and the SAD M114 shown in Fig. 1-47. Power for the rotor and its escapement is supplied from a thermal battery and wound spring.

The rotor is restrained in the unarmed position by a setback weight and a piston actuator. The signal that initiates the flight motor also initiates the piston actuator, which removes its lock from the g-sensing leaf. Acceleration moves the spring-biased setback weight rearward and releases the spring-loaded rotor, which rotates to the armed position delayed by the runaway escapement.

1-10.2 DESCRIPTION OF A REPRESENTATIVE PROXIMITY FUZE (PATRIOT)

This is a large, complex, and expensive munition for use against high-flying aircraft; therefore, a sophisticated fuzing system is used. The rocket and warhead are 410 mm (16 in.) in diameter and 5.3 m (17.5 ft) in length and are launched from vehicles that contain ground control radar. The warhead is a directed fragmentation type plus directed energy, with the S&A mechanism (XM143) located at its base.

The S&A system, as shown in Fig. 11-6, is a dual-channel unit for reliability. Prior to missile launch, the firing capacitors are charged by the application of the charge command function, and the S&A receives an intent-to-launch (ITL) pulse. This pulse activates a rotary solenoid, which removes the rotor latch from a slot in the detonator rotor



1 Spring Detent
2 g-Sensing Leaf
3 Rotor Lock Pin
4 Rotor Spring
5 Latching Leaf
6 Escapement
7 Rotor
8 Electric Contact
9 Electric Detonator
10 Electric Contacts

Figure 1-47. Safety and Arming Device M114 (Ref. 2) and the latch from the g-weight. The g-weight restricts any motion of the detonator rotor by obstructing the path of the detonator rotor pin. When the missile is launched, the acceleration force moves the g-weight out of the path of the detonator rotor pin. The detonator rotor, which is in mesh with the balance rotor, begins to arm. Each of the rotors has an offset center of mass, such that the pair is balanced against the effects of lateral acceleration, and reacts only to the axial acceleration. The detonator rotor initially holds the detonator 90 deg out of line from the lead. A flight motor boost of 12 g for 3.5 s is required to complete the arming of the rotors. Arming delay is obtained during this acceleration phase by the reaction of a pin-pallet runaway escapement. The delay escapement acts as a double-integrating device to ensure arming at the safe separation range of 500 to 1000 m (1640 to 3281 ft). When the detonator rotor reaches the armed position, the detonator rotor pin trips the rotor latch detent (not shown) and locks the rotor in the armed position. When the "fire" or "self-destruct" signal is received by the S&A, the firing capacitor discharges its energy to the detonator and initiates the explosive train. Proximity function is by M818 fuze signal to the S&A. Self-destruct modes result from loss of missile or S&A power or loss of guidance.

1-11 DESCRIPTION OF REPRESENTATIVE MINE FUZES

Hand-emplaced mines are classed as stationary ammunition that is set in place to impede enemy advancement (Ref. 16). Whereas other ammunition travels to the target, stationary ammunition requires that the target approach it. Its fuzes are designed with the same considerations as those for other ammunition except that environmental forces cannot usually be used for arming action. Fuzes for stationary ammunition contain a triggering device, two independent arming actions, and an explosive output charge. This ammunition is often hidden from view by being buried in the ground.

Fuzes for the newer mines have more useful environments for arming. Deployment is always from a container—bomb, projectile, dispenser, or modular pack—which permits the use of bore riders and/or magnetic sensors to determine when the mine leaves the container. Delivery by artillery allows use of spin as one arming environment and setback upon base ejection as another. Ejection at altitude enables use of foldout drogues to remove locking pins.

Electronics are used in many new systems, and powering with a battery is no longer a problem for long-term storage. Development of the passive (until activated) lithium and ammonia batteries has solved the storage problem.

1-11.1 DESCRIPTION OF A REPRESENTATIVE MECHANICAL FUZE

Fuze, Mine, Antitank, M607, is an all-mechanical fuze for the hand-planted heavy antitank mine M21, shown in Fig. 1-19. It consists of an in-line stab detonator that has a stab firing pin held safe by and powered by a Belleville spring.

The fuze is attached to the mine by screw threads. The mode of firing is by tilt rod or pressure. The sensitivity is 132 kg (290 lb) through 3-mm (1/8-in.) displacement or 1.7 kg (3.75 lb) through a 20-deg movement of a tilt rod.

Safety is provided by an in-field, removable metal collar supporting the tilt mechanism assembly and the high loading required to cause firing by crushing.

1-11.2 DESCRIPTION OF A REPRESENTATIVE ELECTRICAL FUZE

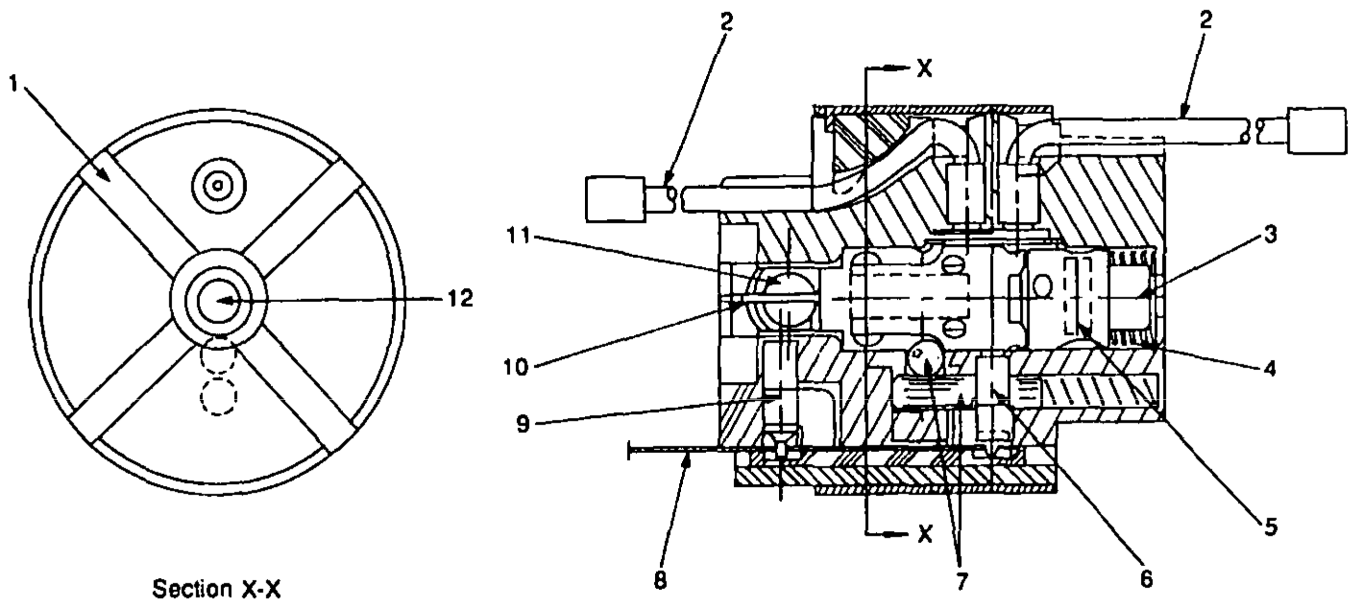
The RAAM, shown in Fig. 1-20, is an artillery-delivered mine system. Each 155-mm (6-in.) projectile carries nine magnetically fuzed M75 antiarmor mines. When the projectile is fired, the S&A mechanism in each mine senses the forces of setback, spin, and mine ejection for proper arming. The mines are expelled over the target from the rear of the projectile. After ground impact the mine is armed and ready to detonate upon sensing a proper armored vehicle signature. This S&A mechanism of the mine, shown in Fig. 1-48, and a detailed functioning sequence are described in the paragraphs that follow.

When the projectile is fired from the howitzer, the cargo of individual mines senses the forces of spin and setback. The setback provides a force that moves the setback pin away from the g-weight lock; the spin provides a centrifugal force, which (1) moves the centrifugal locks out of the line of travel of the slider and (2) moves the g-weight lock out, which unlocks the g-weight.

Over the target area the submunition is ejected from the projectile by means of a preset time fuze and expulsion charge. This ejection force—which is an accelerative force opposite that generated by artillery setback—moves the g-weight against its spring, an action which releases the ball that was locking the slider in the out-of-line position. Centrifugal force allows the ball to unseat itself. As this ejection force decays, the spring pushes on the slider (now unlocked) and forces it into the armed position. This aligns the explosive train. The axial position of the slider is maintained by the slider lock. As the slider moves into the armed position, its point strikes the stab primer of the battery that is located in the electronic lens package; this action initiates the reserve battery. The slider is locked in the armed position upon completion of its stroke by the slider lock as well as by the rear lock.

When the mine impacts on the ground and comes to rest, the interrupter falls into a position in the selector chamber. This provides an orientation-sensing feature by providing a barrier to explosive propagation of the clearing charge to the electronic lens if the mine should come to rest upside down.

When an activation signal is generated, a firing pulse is fed by the electronic circuit to the delay detonator and the fast-fire detonator simultaneously.



1	Main Charge Leads (4)	7.	g-Weight and Ball Lock
2	Mild Detonating Fuse	8	Flex Electric Cable
3	Slider Assembly	9	Main Charge Electric Initiator
4	Arming Spring	10	Firing Pin to Start Battery
5	Transfer Charge Lead	11	Centrifugal Locks
6	MDF Electric Initiator	12	Main Charge Lead

Figure 1-48. Safety and Arming Mechanism for RAAM M70 Mine

The fast-fire detonator initiates the clearing charge transfer lead, which in turn fires into the selector cavity. This initiates the MDF in the clearing charge train if the position of the interrupter so permits. This function clears the electronic lens. If the mine is upside down, the MDF is not initiated and the system remains intact until the main charge fires.

The delay detonator initiates the center charge lead, which propagates to the four main charge leads and then to the booster and main charge and thus completes the S&A function.

1-12 DESCRIPTION OF REPRESENTATIVE GRENADE FUZES

For many years the word "grenade" denoted a small explosive charge thrown by hand against enemy personnel or into buildings or dugouts where personnel may hide. The advent of the modern launched-type grenade changed the fuzing of grenades in major respects. Although the old system of a pyrotechnic fuze for the hand grenade is still very much in use, ways and means of curing its deficiencies are always being considered. (See par. 1-3.5.1.) The launched grenade (launched by propellants) offers environments useful in safing and arming the fuzes. Setback becomes a reasonable environment, and spin has been provided by rifling the launch tube. These fuzes have out-of-line explosive trains and mechanically delayed arming in the form of runaway escapements.

A whole new class of grenades employed as submunitions in aerial dispensers, cargo projectiles, and rockets is currently in the inventory. The fuzes for these rely on aerodynamic spin after launch as an arming environment, and other grenades make use of the proximity to each other and the presence of the delivery containers to effect safety.

1-12.1 DESCRIPTION OF A REPRESENTATIVE HAND GRENADE FUZE

Fig. 1-22 shows the 4.5-s pyrotechnic fuze M213 currently used in fragmentation hand grenades. The design is a type common to many countries; its origin is Belgium, circa World War I. The greatest improvement made to the early designs is the use of metallic fuels and oxidizing agents for the delay column (Ref. 17). These are stoichiometric mixes, which theoretically do not produce gas when burned. Impurities will cause some gases but not in sufficient quantities to generate the pressures that are likely to cause bypass with premature ignition. A missing delay charge is of utmost concern because this situation would reduce the delay time.

Undesirable characteristics of this fuze are its susceptibility to dudding from moisture in the primer and/or delay column after storage and its in-line detonator. Attempts to design out-of-line systems have been successful but fall short in regard to size, weight, and economics. In view of the immensely large quantities used, economical design becomes a significant factor. Although this type of fuze is excluded from having to satisfy the detonator safe requirement of MIL-STD-1316, having a practical detonator safe device incorporated into future designs remains desirable.

A West German hand grenade fuze with detonator safety (DM82) has been successfully tested by the US Army. This fuze is also a pyrotechnic delay system, but it has sufficient separation between the detonator and booster to give detonator safety until 2.5 s after the grenade has been thrown. Fig. 1-49 shows its salient features. The system will fit the standard US Army grenade. Two and one-half seconds after ignition, the pyrotechnic delay element melts a soldered joint and a spring moves the detonator against the booster. Concurrently, a flap valve interposed between the delay and the detonator moves out of the pathway. This fuze will fail if the delay charge is missing.

1-12.2 DESCRIPTION OF A REPRESENTATIVE LAUNCHED GRENADE FUZE

Fuze, PD, M551, shown in Fig. 1-50, is used in HE grenades M386 and M406 as used in the 40-mm (1.58-in.) M79 (Fig. 1-24) or M203 grenade launchers. The fuze is located in the nose of the grenade and consists of a stab firing pin inertia assembly that is centrifugally armed and responsive to impacts, including graze.

The S&A mechanism has a spring-powered rotor delayed by a runaway escapement. Safety is obtained by restraining the rotor with a setback pin, the firing pin, and a sector gear engaged with the gear train of a locked runaway escapement. A detonator and large booster complete the fuze, which is screwed into the grenade body and covered by a sheet metal ogive.

On firing, acceleration moves the setback pin to the rear and partially releases the rotor. Centrifugal force moves three hinged inertia hammer weights outward against their spring, an action that allows the cantilever spring-mounted firing pin to move out of the rotor. Centrifugal force also removes a spin detent and releases the escape wheel of the runaway escapement. The spring-loaded rotor rotates to the armed position, is delayed by the runaway escapement, and is locked in that position.

On direct impact the firing pin is driven rearward to function the M55 detonator, which initiates the lead and the booster. On graze the three hinged inertia weights rotate forward and inward to drive the firing pin into the detonator.

1-13 DESCRIPTION OF A REPRESENTATIVE SUBMUNITION FUZE

Fuze, Grenade, M223, as shown in Fig. 1-51, is used in the M42/M46 dual-purpose grenade submunitions (See par. 1-3.6.) carried and delivered by the 155-mm (6-in.) M483

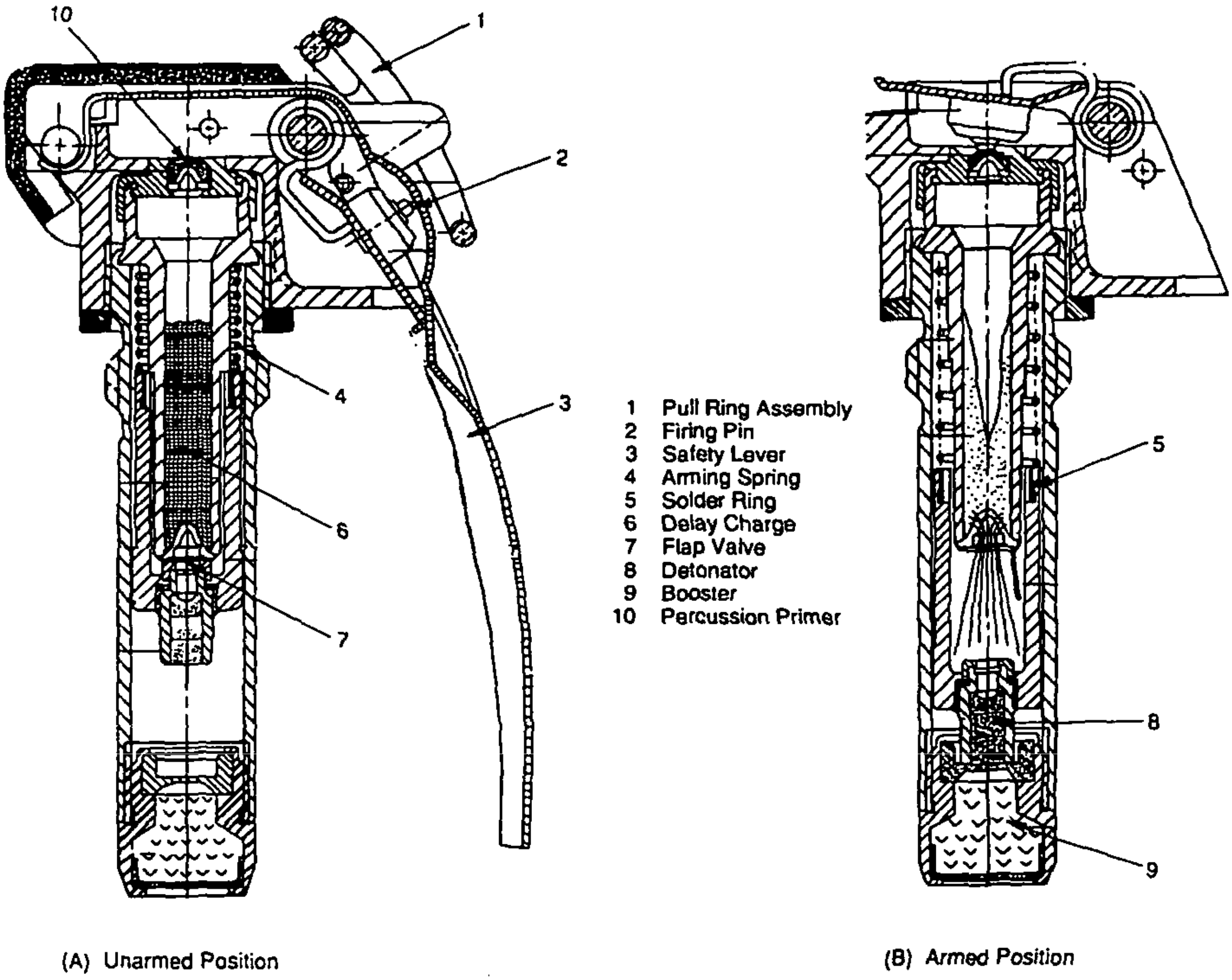


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Figure 1-49. German Hand Grenade Fuze, DM82

and the 200-mm (8-in.) M509 cargo projectiles. The M42/M46 are ground burst munitions consisting of a 38-mm (1.5-in.) diameter cylindrical body loaded with explosive material in a shaped-charge configuration.

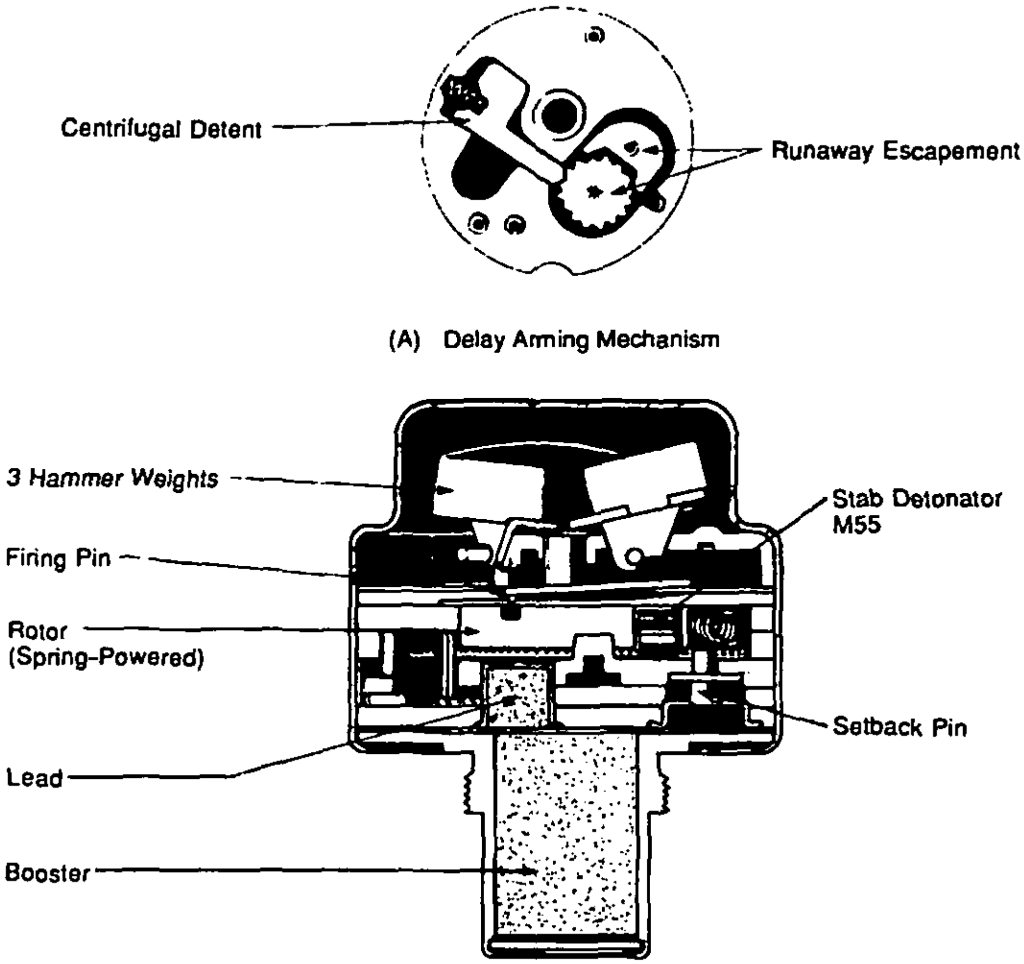
The fuze is simple. It consists of a spring-loaded, detonator-carrying slider locked by the firing pin and by proximity to the bomblet next in the stack. The firing pin is threaded into a weight assembly, and its tip extends into a cavity in the slider to secure it in the out-of-line position. An arming ribbon of nylon is secured to the firing pin shaft. The fuze has no lead or booster; the lead is in the grenade. Two rivets attach the fuze to the grenade.

Upon expulsion from the projectile base, the nylon ribbon stabilizer extends and orients the grenade and, due to rotational forces, unthreads the firing pin from the weight and pulls the firing pin out of the slider, but not free of the fuze. The slider is then free to move into the armed position by action of the slider spring and centrifugal force. The spring maintains the slider in the fully armed position.

Upon impact the inertia weight drives the firing pin into the M55 detonator and initiates the firing train. A shaped-charge jet is expelled downward while the body bursts into a large number of fragments. The jet is capable of penetrating 70 mm (2.75 in.) of armor plate.

1-14 DESCRIPTION OF A REPRESENTATIVE FUEL-AIR-EXPLOSIVE FUZE

Fuze, Electronic Time, XM750, (Refs. 14 and 15) is used in the XM130 rocket round shown in Fig. 1-29, which is used for minefield clearing and is discussed in par. 1-3.7. The SAD for this fuze is shown in Fig. 1-52. Attached to the fuze is an electrical cable and two MDF cords. One



(A) Delay Arming Mechanism

(B) Fuze Firing Mechanism and Explosive Train

Figure 1-50. Fuze, Grenade, M551, for 40-mm Launcher

MDF line leads to the parachute deployment mechanism; the other MDF line leads to the two cloud detonator deployment mechanisms. The fuzing system combines three separate explosive outputs in a single electronic fixed time fuze. The fuze consists of an impact-sensing element, a wound tubular probe extendable to approximately 2 m (6 ft), and a base element containing an electronic timer and logic package, SAD, and an omnidirectional inertial backup firing switch.

A variable timer for parachute opening, which determines the impact range of the round, is controlled by an intervalometer located on the launch vehicle. Because the fuze timer is fixed at 12 s, variable times are achieved by charging the fuze (starting the timer) while the round is in the launcher and then delaying launch for a specified time. For example, if a 10-s time for parachute deployment were desired, the rocket motor would not be ignited until 2 s after fuze charging. The intervalometer is also programmed to shorten the timer for succeeding rounds automatically so that a linear path through the minefield can be cleared and mines neutralized.

The S&A mechanism is a cylindrical steel rotor containing three MK96 electric detonators. It is unbalanced, so it derives its arming force from sustained acceleration. A spring-biased setback lock (g-weight) secures the rotor until 20 g are experienced and maintained for normal rocket boost time. A second lock consists of an explosive (piston) actuator. The safe separation distance is attained by use of a runaway escapement to control this rotor.

A printed circuit on a switch plate connected to a rotor trunnion has wiper contacts that perform three functions:

1. With the rotor in the safe position, two contacts are shunted to allow positive voltage to introduce charging current. The other contacts are open except for the explosive actuator contacts that are shorted.

2. After partial rotor rotation a second set of contacts is closed and allows stored energy from a capacitor to fire the explosive actuator to remove the second lock on the out-

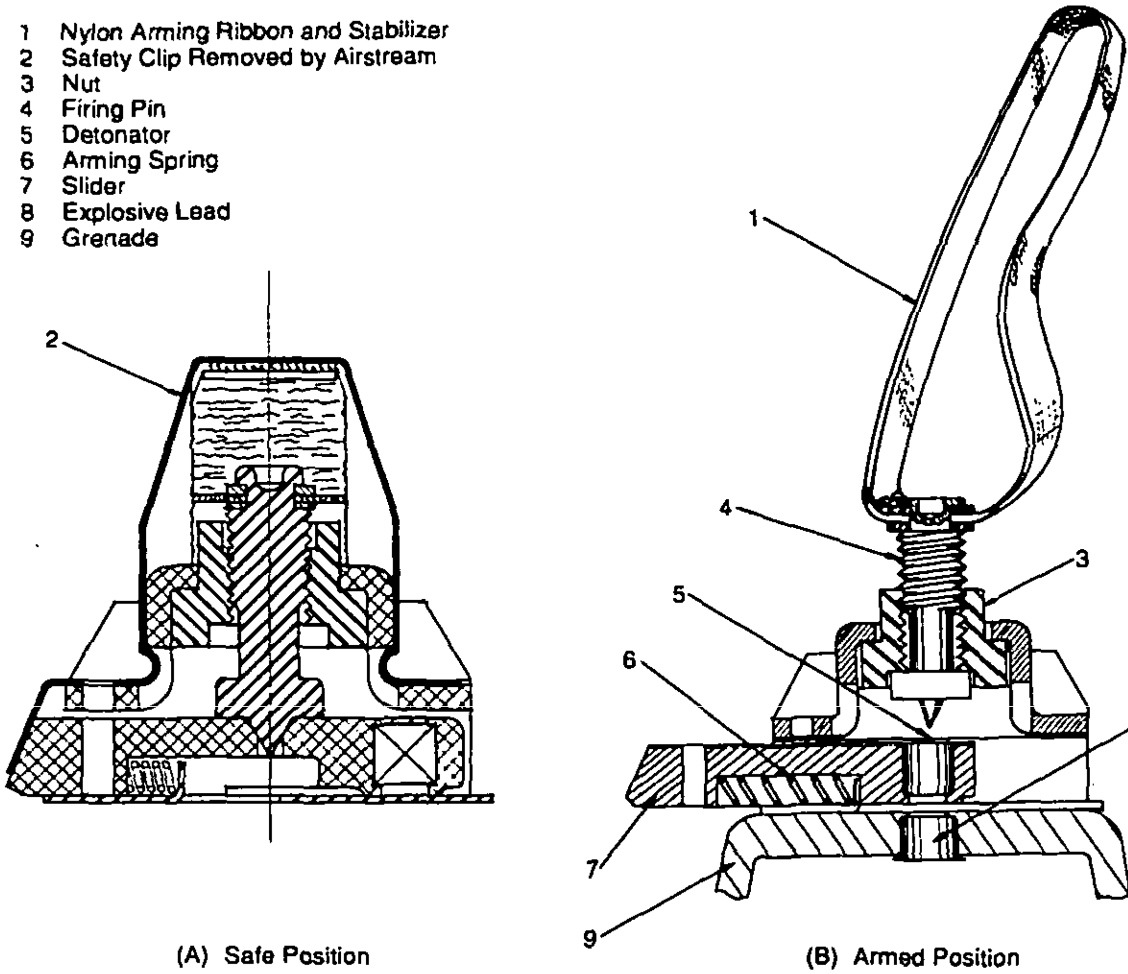


Figure 1-51. Fuze, Grenade, M223

of-line rotor. This occurs as the commit position is reached. The charging switch under Function No. 1 is now open.

3. Just prior to the rotor reaching the fully armed position, a third set of contacts closes momentarily and signals the electronics to disable a dump circuit and connect the firing circuit to the three detonators.

The rotor must rotate 80 deg to the armed position within 1 s from the application of launch voltage because that is the minimum selectable launch-to-parachute deployment time. At motor burnout, approximately 0.3 s from ignition, the rotor has turned more than 18 deg, which is past the commit point of 12 deg. If a rotation less than 12 deg occurs at motor burnout, the spring-biased setback weight reengages the rotor and drives it back to the safe position. Once past the commit point, the rotor cannot continue to the armed position because of an interlock with the retracted setback weight. This design prevents a runaway rotor escapement from permitting arming before burnout. The explosive actuator functions to remove itself from the path of the rotor just past the commit point. After rocket motor burnout the setback weight and springs are unloaded and the weight moves back toward its original position. In doing so it unlocks the rotor from the antirunaway trap and drives it to the armed position. As the rotor approaches the armed position, the spring-loaded button contacts on the three electric detonators are depressed and thus remove the short and put them in the firing circuit.

Twelve seconds after the fuze is charged in the launcher, the electronic logic circuit fires the first electric detonator, which, in turn, initiates the MDF and deploys the parachute.

Approximately 2.2 s after parachute deployment, the probe is released by a separate mechanical timer and permitted to extend. This delay is necessary to allow the round to slow down under parachute retardation to reduce the aerodynamic loads on the probe.

The probe is assembled in the forward end of the fuze housing and consists of a 76-mm (3-in.) wide, 0.18-mm (0.007-in.) thick, 3.38-m (133-in.) long, spiral-wound spring strip of stainless steel that is capable of self-extending 1.65 m (65 in.) to form a rigid tube as the coils overlap into a friction-locked helix. Within the first, or innermost, coil is a nose element assembly, which contains the target-

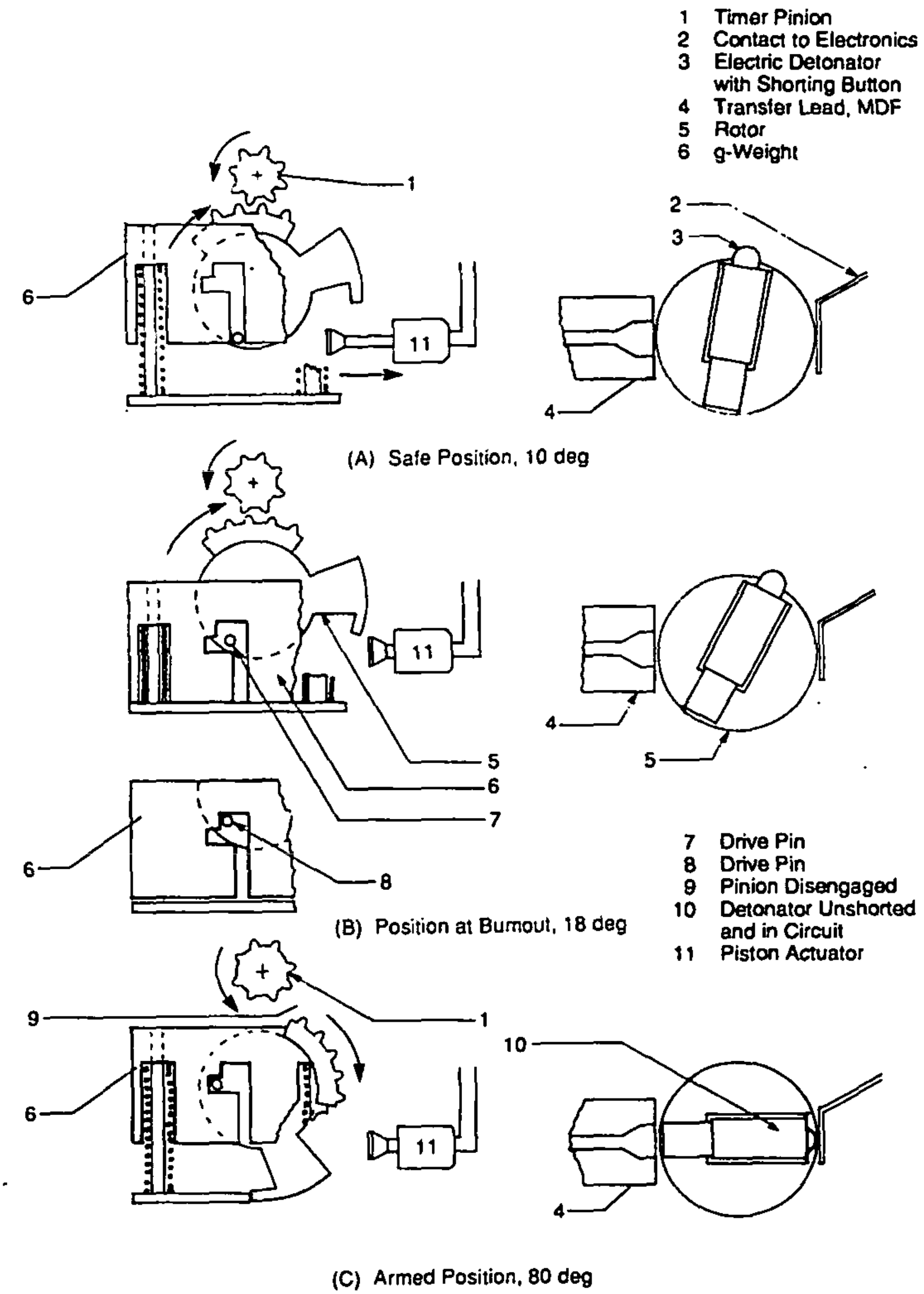


Figure 1-52. Safety and Arming Device for Fuze, ET, XM750

detecting impact switch and its associated spooled electric wire. It also contains a bobbin on which is wrapped a 1.6-m (62-in.) length of 320-N (72-lb) test braided nylon line. When the probe is deployed, both the wire and nylon line play out within the forming tube. During the last several inches of the deployment stroke, the nylon line tightens and gradually snubs, or slows down, the deployment velocity by its stretching action. Without the nylon snubbing line, the probe might overextend and have insufficient coil-to-coil overlap to provide satisfactory aerodynamic rigidity.

At target impact a switch located at the tip of the extendable probe closes and signals the electronics to initiate the second electric detonator in the rotor. The explosive output of this detonator and its transfer lead initiate the other MDF, which launches the cloud detonators. The logic circuit, 10 ms later, triggers the firing of the third electric detonator and initiates the warhead burster explosive charge.

Two inertia switches are positioned within the electronics package to provide an omnidirectional inertia backup firing initiation. In addition, bleeder resistors are provided to sterilize the fuze electrically within 15 min after impact if the fuze fails to arm or both warhead fuze firing modes fail.

The probe switch and backup inertia switches are inhibited by the electronics from activating the firing circuit for a period of 3 s after parachute deployment. This feature prevents premature operation of the warhead caused by the shock of parachute opening or probe deployment being sensed by the inertia switches.

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CHAPTER 2
GENERAL DESIGN CONSIDERATIONS

Principles of design and the relationship of fuzing with the environment are addressed in this chapter.

Section I addresses the procedures that have been formalized to plan and control the development and acquisition of new fuzes. It also discusses design practices and considerations that may be helpful to the designer in the areas of safety, reliability, economy, and standardization. The origin of a fuze specification is explained along with the structure of research, development, test, and evaluation (RDTE) plans. MIL-STD-1316, which controls the safety aspects of all fuzes, is explained along with specific rules and guides to assist in designing safe fuzes. Hazard analyses are explained as covered in MIL-STD-882, System Safety Program Requirements. *Assessment of reliability as inseparable from safety is discussed, and the methods of evaluating reliability by use of sampling plans, as given in MIL-STD-105, are mentioned. Economic aspects of the life cycle of the fuze; producibility; use of standard components; the need for formality in development; fuze standards; formal fuze groups of the Army, Navy, and Air Force; and human factors engineering are covered in some detail.*

Section II addresses the issues of fuze survival and arming and functioning in the environments associated with the use of fuzes. These environments include the stresses that exist during manufacturing, loading, handling, shipping, storing, launching, and impacting targets. The environmental requirements that a fuze must withstand can be obtained from a study of the factory-to-function sequence and from general specifications of the weapon and its munition. Environments are categorized as natural or as induced by man, equipment or munitions. The induced environments of representative munitions are covered under projectile fuzes, guided missile fuzes, rocket fuzes, mine fuzes, grenade fuzes, submunition fuzes, and mortar fuzes. Many of these environments and their magnitudes are presented in a table.

SECTION I
GENERAL

2-1 PHILOSOPHY OF DESIGN

2-1.1 INTRODUCTION

Although designing a fuze is not a simple task, it should not be considered overwhelming. Certainly, designing a fuze requires engineering knowledge to handle the forces for arming and functioning in the environment within which the fuze operates. Beyond this knowledge, the designer must also be familiar with the general factors that apply to fuze design, such as the characteristics of explosives, materials, manufacturing processes and methods, test procedures, and data analysis.

One of the methods used to solve a complex problem is to break it into separate, workable parts. To solve such problems, designers rely upon past experience, engineering judgment, and knowledge of exactly what a fuze must do and of all the environments to which it will be exposed. There are many areas in which precise equations have not yet been developed and many areas that will never lend themselves to precise solutions. These areas can be resolved only by repeated testing in the laboratory and at the proving ground.

The procedures that have been formalized to plan and control the development and acquisition of new fuzes and equipment are addressed in Section I. Design practices and considerations that may be helpful to the fuze designer in the areas of safety, reliability, economy, and standardization are also discussed in Section I. Section II addresses the issues of fuze survival and arming and functioning in the environments associated with the use of fuzes.

2-1.2 ORIGIN OF A FUZE SPECIFICATION

A requirement for a fuze or weapon system may originate with any element or individual of the armed services or with industry. A formalized document called the operational requirements document (ORD) is generated and establishes the baseline for a fuze or weapon system development program. The ORD contains a brief statement of need, time frame of development, threat or operational deficiency, operational and organizational concepts, essential characteristics, and technical assessment. New ideas for fuzes have the best chance of approval when a specific need can be demonstrated. The need can be based on increased effectiveness against a specific target, improved reliability or safety, lower cost or increased utility, or on an operational deficiency or threat. The ORD is operationally oriented and has only minimum essential features. Detailed fuze or weapon characteristics and objectives are developed later by the combat and materiel developers as part of the development plan.

2-1.3 STRUCTURE OF RESEARCH, DEVELOPMENT, TEST, AND EVALUATION (RDTE) PLANS

The process employed by all services for developing and fielding new fuzes is formalized into a management model called the acquisition process. The phases and milestones of the acquisition process are shown in Fig. 2-1. To facilitate planning, programming, budgeting, and managing the activities, the RDTE program is divided into four major categories: research (6.1), exploratory development (6.2), advanced development (6.3), and engineering development (6.4). These categories are defined and examples of projects appropriate to each are given in the paragraphs that follow.

2-1.3.1 Research (6.1)

The elements of research programs involve scientific study and experimentation directed toward increasing knowledge and understanding of those technologies directly applicable to fuzing. These programs are generally characterized by the use of basic research directed toward the solution of identified fuzing problems. One example might be the study of millimeter wave technology to improve effectiveness against high-speed jet aircraft and missiles and to improve countermeasure resistance. These programs also provide part of the base for subsequent exploratory and advanced development programs in improved state-of-the-art fuzing concepts.

2-1.3.2 Exploratory Development (6.2)

Exploratory development tasks are directed toward developing and evaluating the feasibility and practicability of proposed technologies identified in 6.1 programs. This category includes studies, planning and programming, and minor development efforts. The dominant characteristic is that the effort is pointed toward a specific fuzing concept. Expanding the millimeter wave example to include feasibility studies of component arrangements, environmental survivability, cost, and measurements of effectiveness and countermeasure resistance are examples of tasks to be performed during this phase.

2-1.3.3 Advanced Development (6.3)

Advanced development tasks include the design and development of prototype fuze hardware for experimentation and test to reduce technological uncertainties and to prove feasibility. Development testing begins during this phase to demonstrate that technical risks have been identified and that solutions are in hand. Components, subsystems, brassboard configurations, or advanced development prototypes are tested and evaluated to confirm preliminary design and engineering analyses. Development testing should be complete enough to demonstrate interface compatibilities and performance capabilities or limitations.

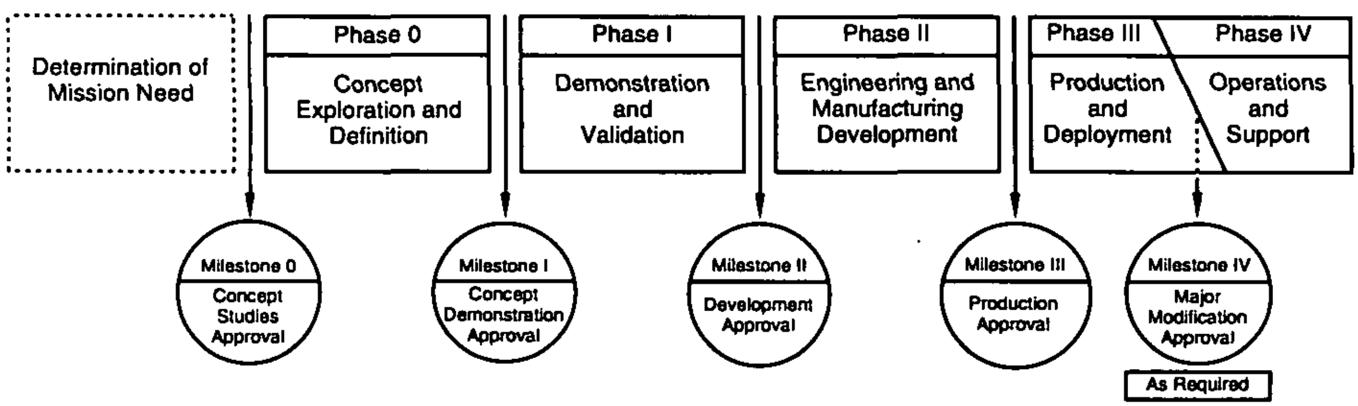
2-1.3.4 Engineering Development (6.4)

Engineering development involves the fabrication of fuze hardware for extensive test and evaluation to determine whether all fuze and system requirements and objectives have been met. Phase Two of development testing is conducted to measure the technical performance—including reliability, compatibility, interoperability, safety, and supportability considerations—of the fuze and associated munition and support equipment. Phase Two of development testing includes tests of human engineering aspects and tests of associated training devices and methods. During this phase the fuze—and all items necessary for its support—are fully developed, engineered, fabricated, and tested, and a decision is made whether the item is acceptable to enter the inventory. An important output of this phase is a complete set of design disclosures, the technical data package (TDP), (drawings and specifications) suitable for competitive procurement.

2-2 SAFETY

Safety is a mandatory consideration throughout the life cycle of a fuze. The designer must be concerned with the extent to which a device can possibly be made to function prematurely by any accidental or normal sequence of events that may occur at any time between its fabrication and its approach to the target. Fuze designs vary from very simple to ingenious with complex mechanisms and electronic circuitry. The means for obtaining safety can therefore vary from complete reliance on the user, e.g., hand-grenade fuz-

Figure 2-1. Phases and Milestones of the Acquisition Process (Ref. 1)



ing, to complete mechanization independent of the user. The success of a design depends on the designer's ability to recognize the hazards and harness the conditions that create them.

In terms of added complexity—which can be translated into terms of reliability, effectiveness, and cost—safety is expensive. Hence the problem of safety is a double one. The designer must be certain that his device is safe enough and yet imposes the least impairment to functioning. A number of standards, good practices, concepts, and logic have been promulgated to ensure the safety of fuzes. Several of these standards are discussed briefly in the paragraphs that follow.

MIL-STD-1316 (Ref. 2) is perhaps the most important and widely used guide for establishing design and safety criteria for fuzes. This document establishes requirements, design objectives, and design guides for all fuzes except nuclear, hand grenades, manually emplaced ordnance devices, and hand dispensed flares and signals. It covers mandatory features, procedures, and controls such as safety redundancy, arming delay, explosive sensitivity, explosive train interruption, noninterrupted explosive train control, logic functions, and safety system failure rate. It also establishes formal safety review milestones by the cognizant service authority for weapon safety at design concept and again at the completion of engineering development. MIL-STD-1911 (Ref. 3) establishes similar requirements, design objectives, and design guides for manually emplaced ordnance devices and hand grenades.

MIL-STD-882 (Ref. 4) requires the performance of hazard analyses to identify the hazards of abnormal environments and conditions, and personnel actions. Failure mode and effects analyses and fault tree analyses techniques are also described as methods used to evaluate the safety of the fuze design. Fault tree analyses and failure mode and effects analyses are discussed in more detail in pars. 13-11 and 13-12.

The rules and guides that follow can also serve as general guidance in the design of safe fuzes:

1. Whenever possible, use proven design concepts, explosive components, explosive train designs, packaging, and assembly techniques with established histories of safety.

2. To the extent possible, a safety system should require that operating signals be received in normal order. An extension of this idea is the use of time gates. When these are added, the system requires not only that operating signals be received in proper order but also in proper time references (Ref. 5).

3. Provide sterilization or self-destruct features for all electrically actuated fuzes. These features enhance safety for personnel responsible for disposal of ordnance and friendly personnel who might accidentally come in contact with unexploded munitions.

4. Isolate fuze monitor and mode selection circuitry in such a way that their chance of becoming safety bypasses is eliminated. This can be accomplished by careful physical and dielectric isolation or by limiting the current and voltage to levels below those needed for operation of critical components.

5. Design fuzes or fuze components so that defects affecting safety can be detected by means of nondestructive tests or inspection.

6. When critical operations requiring human actions must be performed, the design should provide maximum protection against human error. This protection can be provided by limiting access to critical points and by minimizing the extent of human actions.

7. Electrical connectors should be designed to make improper mating virtually impossible. Connector designs should provide for maximum protection against faults due to moisture, electromagnetic radiation, and static discharge.

2-3 RELIABILITY

Reliability is the probability that an item will perform its intended function for a specific interval under stated conditions. Acceptable fuze reliabilities vary depending on fuze complexity, effectiveness, and the unfavorable environments in which the fuze must operate. Reliability requirements and objectives for munitions, including fuzing, are usually stated in the operational requirements document.

Considerations of safety and reliability cannot be separated. The fuze must function as intended (reliability) but must not function under other than the appropriate conditions (safety). The fuze designer must make a conscientious effort to achieve an optimum balance between safety and reliability so that both requirements are satisfied without undue compromise of either. The proper safety/reliability balance for a fuze system is achieved by safety/reliability tradeoffs. Reliability can be improved by parallel redundancy. Improved safety can be achieved by series redundancy. Since series redundancy degrades reliability, the proper amount of redundancy is a safety/reliability tradeoff.

As pointed out, redundant components can be used to improve the overall reliability of a fuze. For example, 99% reliability can be achieved by two redundant components having reliabilities of only 90%. Fig. 2-2 illustrates a fuze circuit having three switches arranged so that closure of any two of the three double-pole switches assures circuit continuity. When a component failure is likely to be the result of a normal or accidental environment, dissimilar series redundancy using components—one of which is less sensitive or immune to the environment—is best.

The fuze designer should use the tools and practices discussed in this chapter to minimize all known potential weaknesses whether inherent in the design, the manufacturing process, and/or materials used or due to human error.

A number of standards, requirements, and tasks applicable to reliability have been promulgated to assist the designer. Some of these are briefly described in the paragraphs that follow.

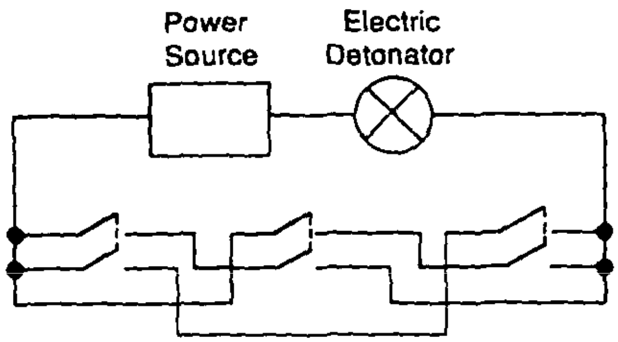


Figure 2-2. Two Out of Three Voting Arrangement for Safety Switches

MIL-STD-785 (Ref. 6) provides general requirements and specific tasks for reliability programs during development, production, and initial deployment of systems and equipment. These tasks include such items as reliability program plan guidelines; failure reporting; analysis and corrective action; reliability modeling; reliability allocations and predictions; failure modes, effects, and criticality analysis; sneak circuit analysis; and electronic parts and circuits tolerance analysis.

MIL-STD-883 (Ref. 7) establishes the uniform methods and procedures used to test microcircuit devices, which include the basic environmental tests used to determine resistance to the deleterious effects of the natural elements and conditions surrounding military operations. This standard establishes three distinct product assurance levels to provide reliability commensurate with the intended application of the product.

MIL-M-38510 (Ref. 8) defines the requirements a manufacturer must meet to qualify his microcircuit products and to maintain the qualification. This specification requires that a supplier establish a product assurance program, maintain detailed configuration control for critical processing steps, and design criteria to ensure adherence to specific requirements.

MIL-STD-105 (Ref. 9) establishes sampling plans and procedures for inspection of end-items, components, operations, and materials. This document is used by the fuze designer to establish acceptable quality levels (AQL) (maximum percent defective) that can be considered satisfactory for the purpose of sampling inspection of production hardware. MIL-STD-105 provides tables that define sample size and accept/reject criteria. Defects, i.e., nonconformance to drawing or specification, in the product are usually classified according to their seriousness as

1. *Critical*. A defect likely to result in a hazardous or unsafe condition
2. *Major*. A defect other than critical that is likely to result in failure or reduce materially the usefulness of the product
3. *Minor*. A defect not likely to reduce materially the usefulness of the product.

The designer should thoroughly review all drawing and specification attributes and establish AQL criteria that are consistent with the safety and reliability requirements of the design.

The rules and guides that follow can also serve as general guidance for the design of reliable fuzes:

1. Whenever possible, use standard components, e.g., detonators, leads, mechanisms, electronic components, etc., with established quality levels.
2. In complex and high-value weapon systems, use redundant components to the maximum extent commensurate with cost-effectiveness.
3. Specify materials, processes, and finishes for which the properties of importance to the application are well-defined and reproducible. Avoid proprietary products if possible.
4. Ensure that the development test program covers all pertinent environmental conditions to which the fuze will be subjected during its life cycle.
5. Provide adequate sealing, lubrication, finishes, and design margin to minimize the effects of aging, moisture, and thermal changes.

2-4 ECONOMIC CONSIDERATIONS

During recent years a number of new management tools and engineering disciplines have been promulgated to establish cost as a parameter equally important to technical requirements and schedule throughout the development, production, and operation of weapon systems, subsystems, and components (Ref. 1). Projected defense budget levels and the rising costs of acquiring, operating, and supporting defense systems and equipment have created the need to make cost a principal design parameter. Although some of these disciplines mainly apply to major weapon systems, the fuze designer should become familiar with these tools and implement them when applicable. Some of these disciplines are briefly discussed in the paragraphs that follow, and references are provided for further information:

1. *Producibility*. Producibility is defined as the composite of characteristics that, when applied to equipment design and production planning, leads to the most effective and economical means of fabrication, assembly, inspection, test, installation, checkout, and acceptance (Ref. 10). Specified materials, simplicity of design, flexibility in production alternatives, tolerance requirements, and clarity and reliability of the TDP are some of the elements of the design that affect producibility. Production rate and quantity, special tooling requirements, manpower skills, facilities, and availability of materials are factors to be considered in the production planning of the design. MIL-HDBK-727 (Ref. 11) is an excellent reference to assist the designer in recognizing producibility implications and to provide guidance in designing to maximize producibility benefits.

2. *Life Cycle Costs (LCC)*. LCC is a technique that considers operating, support, maintenance, storage, transportation, and other costs of ownership as well as acquisition price. The objective of this technique is to ensure that the hardware procured results in the lowest overall ownership cost to the Government during the life of the hardware. One of the most basic and fruitful approaches to controlling operating and support costs is the control and reduction of manpower requirements in the operation and support of weapon systems. Manpower has become the most expensive element in the defense budget. For example, the design of a projectile fuze that permits assembly to the munition at the loading depot would greatly reduce handling, transportation, and storage costs and at the same time would reduce the manpower required to fuze projectiles in the field. In the past, the emphasis on performance often became overriding to the detriment of all other factors. Design engineers must now balance performance, reliability, safety, unit production costs, logistic support costs, and many other parameters against the overall objective of minimizing LCC. Additional details of LCC are covered in other documents, such as Refs. 12, 13, and 14.

3. *Design to Unit Production Cost (DTUPC)*. DTUPC is a technique sometimes employed as an incentive in contracts in order to obtain the lowest unit production cost consistent with performance requirements, delivery schedules, and total contract cost. A specific difficult, but achievable, target cost goal is established along with the minimum essential performance characteristics necessary to satisfy the required operational capability. Each technically feasible alternative is analyzed and cost performance tradeoffs are made to ensure selection of the lowest unit price solution. Implementation of DTUPC goals yields at least two important benefits: It makes cost a strong, visible design parameter, and it usually results in a lower production cost.

4. *Value Engineering (VE)*. VE is an organized effort directed at analyzing the functions of a system for the purpose of achieving the required function at the lowest cost of effective ownership consistent with the requirements for performance, reliability, quality, maintainability, and safety (Ref. 15). Value engineering usually is employed after the design has been completed and the system is in the limited or full production phase. Most fuze production contracts contain VE clauses, which permit contractors to generate proposals to reduce unit costs and allow them to share in future profit benefits from Government-approved VE changes. The VE approach first considers what the item is supposed to do and then the item itself. For example, before considering a fabrication method improvement for a certain part, the actual need for the function should be satisfied. Then other ways of performing the function of the item are investigated. VE can be considered a "second look" to achieve higher value of a product that was well-designed within the original constraints of time and circumstance.

2-5 STANDARDIZATION

2-5.1 USE OF STANDARD COMPONENTS

The fuze designer often is confronted with deciding whether to use standard components or to design a new component especially suited to a requirement. There is a wide variety of off-the-shelf components and proven design concepts available. Depending on the way these are applied, they can either assist or constrain the designer. The advantages of the use of standard components are reduced development time, money, and manpower and proven reliability, performance, and safety history. The disadvantages might be that an overly complex item would be used, a factor that would limit opportunities for improving performance or reducing cost. Analysis usually is required to choose the approach that best fits the program requirements. Generally, the standard item should be given first consideration and preference. It should be remembered, however, that design is a creative process and cannot always take place in an atmosphere of restrictions and reliance on old concepts. The end product of such an atmosphere is imitation, not creation (Ref. 11).

Several standards have been developed to assist the designer in the selection of components for fuze design. Some of these are listed with a brief description of their contents.

MIL-HDBK-777 (Ref. 16) covers the explosive components used in current fuzes as well as some explosive items suitable for use in fuze designs. Data sheets contain functional and performance specifications, illustrations, physical dimensions, and explosive composition.

MIL-STD-333 (Ref. 17) establishes standard designs for projectile fuze threads, fuze contours, and projectile cavities and accessories for 75-mm and larger caliber gun projectiles and 60-mm and larger mortar projectiles. Fig. 2-3 shows the standard contour for the artillery fuze of 75-mm and larger caliber. This figure is taken from MIL-STD-333 as an example of what it contains.

MIL-M-38510 (Ref. 8) (also discussed in par. 2-3), enables users to procure from a qualified parts list standardized integrated circuits that meet various levels of screening.

MIL-HDBK-145 (Ref. 18) lists technical data for production, development, and stockpiled fuzes. MIL-HDBK-146 (Ref. 19) lists technical data for fuzes that have been designated limited standard, obsolescent, obsolete, terminated, or cancelled. Each handbook consists of two-page data sheets listing drawings, specifications, applications, arming and functioning data, physical dimensions, and other useful information. The designer can use these two handbooks as reference documents to survey hundreds of proven unique and ingenious safety and arming mechanisms, electronic circuitry, packaging techniques, and design concepts that might be suitable for a new design.

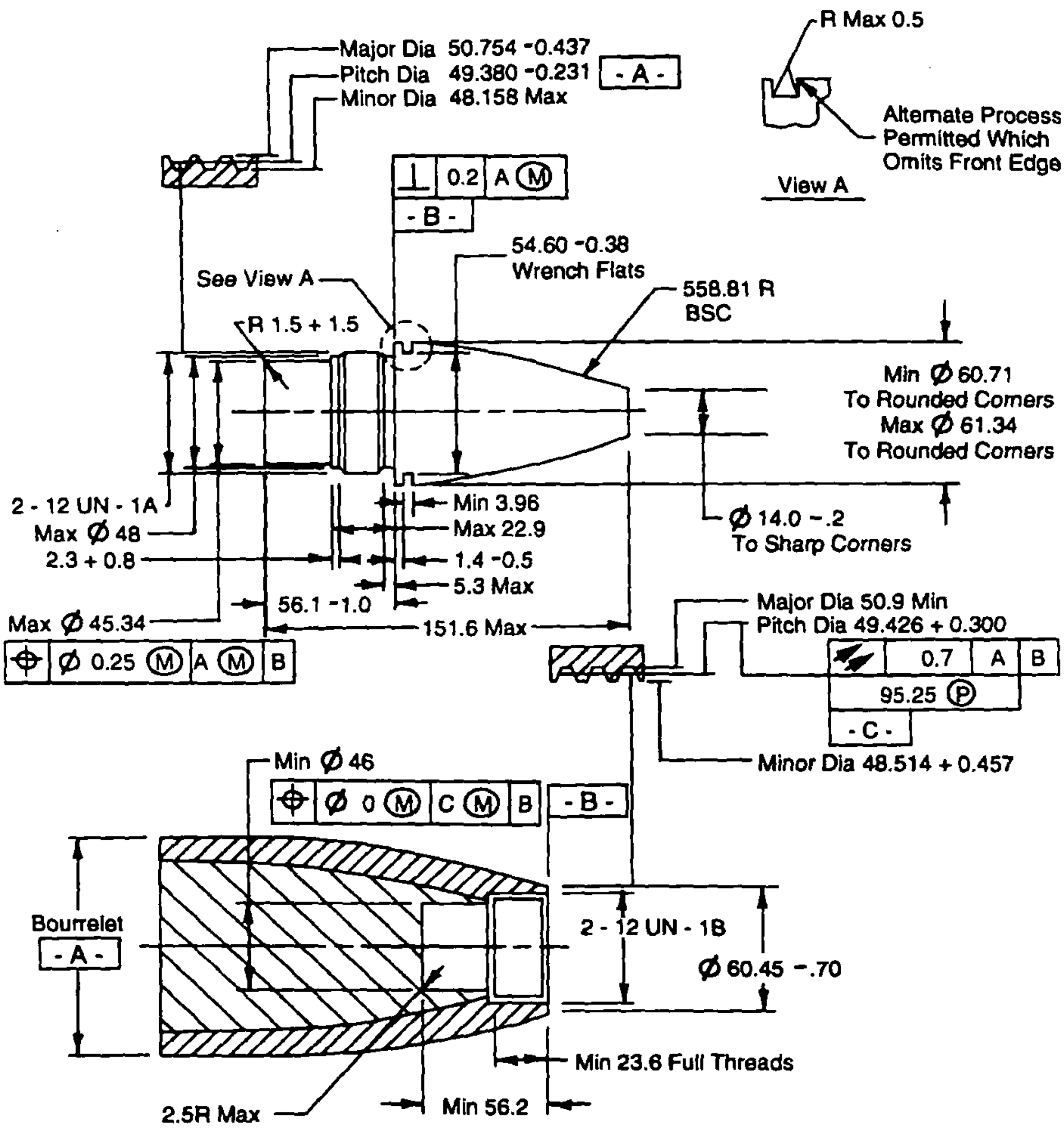


Figure 2-3. Standard Contour for 2-in. Nose Fuzes With Booster and Matching Cavity for Artillery and Mortar HE/WP Projectiles (Spin and Fin Stabilized) (Ref. 17)

2-5.2 NEED FOR FORMALITY

Formality is an absolute requirement in the development of new fuzes and weapons. Experience has revealed that the old system of managing fuze and weapon system development became inadequate with the advent of more complex and expensive weapon systems. The requirement for optimum cost-effectiveness and the need to plan and control a new item or system development effectively through its service life demonstrated that life cycle management was necessary.

Par. 2-1.3 discusses the acquisition process for development and fielding of Army systems. Fig. 2-1 illustrates several major management decision milestones. Continued funding and support of a program are contingent upon the progress and success achieved and reported in these formal decision point reviews.

Within the structure of the fuze research and development effort, there are many procedures, guidelines, and methods that have been formalized to assist the fuze program manager achieve the most cost-effective, reliable, safe, and operationally effective fuzing system. All major weapon system developments and most fuzing developments now require formal safety and reliability programs, design to cost, life cycle cost consideration, producibility, human engineering, and standardized test procedures. These subjects are discussed in detail throughout this handbook, and references are cited to provide the fuze manager and designer with a working knowledge of these techniques and methods.

2-5.3 FUZE STANDARDS

A number of military standards applicable to all services have been established to provide guidance and uniformity in testing, safety criteria, contour standards, and terminology for fuzes. A compilation of these standards is provided in Table 2-1. It is the responsibility of the designer to become familiar with these standards and implement those that are specifically applicable to his design.

2-5.4 FORMAL FUZE GROUPS

There are several triservice—Army, Navy, and Air Force—working groups that have fuze-related missions. These groups are composed of members from each service and perform such functions as establishing standardization of fuze test methods and procedures, coordination of joint-service fuze development efforts, technology exchange, and monitoring development programs to minimize duplication of effort and proliferation of fuze design. A brief statement of the mission of each of these groups follows:

1. *Joint Ordnance Commanders' Group (JOCG)/Fuze Sub-Group (FSG).* The JOCGFSG is a joint-services organization whose mission is to review and monitor fuze technology and development programs for the purpose of ensuring commonality across the services. The organization participates in and assumes responsibility for formulation of a coordinated annual Joint-Service Fuze Plan, program monitoring, recommendations, studies, and analyses and assures interservice awareness of all defense fuze R&D programs. Other functions of the JOCGFSG are

a. To identify programs and projects for joint sponsorship or management

b. To identify voids in fuze R&D or areas requiring increased emphasis

c. Resolve interservice fuzing issues.

2. *Fuze Engineering Standardization Working Group (FESWG).* The FESWG is a triservice group whose general mission is to facilitate standardization of fuzes, fuze design concepts, fuze packaging and logistic techniques, and testing and evaluation procedures. Some specific functions of the FESWG are to

a. Provide new military standards and military handbooks to keep pace with progressing technology

b. Provide a mechanism for the timely exchange of technical information between military activities

c. Establish ad hoc task groups for the purpose of revising or preparing individual standardization documents. MIL-STD-331 (Ref. 20), MIL-STD-1316 (Ref. 2), MIL-HDBK-145 (Ref. 18), and MIL-HDBK-146 (Ref. 19) are typical examples of documents generated by the FESWG.

3. *Joint-Services Fuze Management Board Armament/Munitions Requirements, Acquisition, and Development (AMRAD) Committee.* The AMRAD Committee's mission is to assist the Department of Defense (DoD) in the development of harmonized requirements that fulfill more than one service's conventional munitions needs. The ultimate aim is to produce munitions that meet the needs of more than one service and, where practicable, achieve interoperability with munitions in use or planned for use by the North Atlantic Treaty Organization (NATO). The committee's interest begins when the services establish a munition or fuzing requirement or when a program enters advanced development and continues throughout the life of the program.

TABLE 2-1. COMPILATION OF FUZE STANDARDS PROVIDING GUIDANCE IN FUZE DESIGN

MIL-STD-331B, *Environmental and Performance Tests for Fuze and Fuze Components*, 1 December 1989.
MIL-STD-333B, *Fuze, Projectile, and Accessory Contours for Large Caliber Armaments*, 1 May 1989.
MIL-STD-1316D, *Safety Criteria for Fuze Design*, 9 April 1991.
MIL-STD-1385B, *General Requirements for Preclusion of Ordnance Hazards in Electromagnetic Fields*, 1 August 1986.
MIL-STD-1911, *Safety Criteria for Hand-Emplaced Ordnance Design*, 6 December 1993.

One AMRAD function is to identify and recommend to the Under Secretary of Defense for Research and Development areas in which it would be practical for the services to pursue a joint fuze development effort. If such a development is approved, a joint-service ordnance requirement (JSOR) document is formalized and approved by the cognizant services, and one service agency is selected as the lead for the development effort.

2-6 HUMAN FACTORS ENGINEERING

The term "human factors engineering" is the area of human factors that applies scientific knowledge to the design of items to achieve effective operation, maintenance, and man/machine integration. Whenever a human is the user in the design, his/her capabilities and limitations must be considered. Although many aspects of human factors engineering rely on common sense, it is often difficult for a fuze designer to visualize the intended use, the field conditions, and difficulties due to carelessness or environmental stress, all of which impact the user. The fuze designer must consider user variability in reasoning and in diverse physical characteristics, such as hand strength. Human factors specialists can support the fuze design process by providing knowledge of human behavior, design data, and analysis of competing designs.

2-6.1 SCOPE OF HUMAN FACTORS ENGINEERING

Human factors engineering is a discipline that determines the human's role in man/machine systems. After studying and analyzing the system, the human factors specialist can determine which tasks human beings can perform best in order to optimize system effectiveness. For example, the missetting of a delay mode may lessen the effectiveness of a projectile. Missetting the time of burst by one or two seconds, however, may kill or injure friendly troops. At each point of human use, it is possible to estimate the magnitude and the potential effect of human error. Understanding what humans can and cannot do regarding physical forces, mental tasks, vision, and hearing can help in the design of man/machine systems that enhance performance and eliminate or reduce human error.

Over the past several decades human factors specialists have compiled data on vision, audition, learning, memory, design of controls and displays, workplace layout, fatigue, strength, motivation, and anthropometrics (body size). Much of these data are listed in Refs. 21, 22, and 23. These references provide design guidelines for factors such as maximum torque setting, minimum lighting for good visibility, and optimum letter size for labels and instructional markings. More complex applications of human factors engineering principles, such as determining and analyzing the frequency and magnitude of human errors, are best left to human factors specialists.

2-6.2 APPLICATION TO FUZE DESIGN PROBLEMS

Applying human factors engineering to fuze design problems requires that fuzes be considered both as a system and as a component of a larger ammunition system. In the second case, the human factors specialist must consider the factory-to-function sequence of the ammunition system and assess the impact of such factors as (1) how and where the system will be used, (2) under what environmental conditions (e.g., weather and illumination) it will be used, (3) by what types of troops it will be used, and (4) under what limiting conditions it will be used. As an example, ammunition designed for rapid salvo firing may preclude using multiple-setting fuzes unless they can be set very rapidly. These settings should require minimum torque and provide both visual and auditory feedback of setting status. If fuzes can be set before mission firings, more complex settings and arming procedures may be used. Human factors studies can show the designer how many fuzes can be set, or changed, per minute under varying battlefield conditions.

Examining fuze design as a component or system is achieved by investigating each interaction between the human and the fuze. If fuzes contain visual displays, e.g., arm-safe marks, time marks, and special instructions, the reference data provide guidance for numeral size, style, color, etc. Choice of control modes, such as setting rings, push buttons, selector switches, or screw settings, can also be made on the basis of previous studies.

Fuze design, like other types of design, is impacted by new findings in other technologies. Human factors engineering studies have shown that setting a fuze using a vernier device produces many setting errors. The vernier device uses a display with both digital and linear scales. Fuzes using an improved digital-scalar display, such as the M577 fuze, or a completely digital display, such as the M762 fuze, incur fewer and smaller errors among users (Refs. 24, 25, and 26). Fig. 2-4 shows linear and digital displays.

During future warfare, combat troops may be exposed to chemical and biological (CB) agents. The protective mask may distort displays. Thus future fuze displays should be

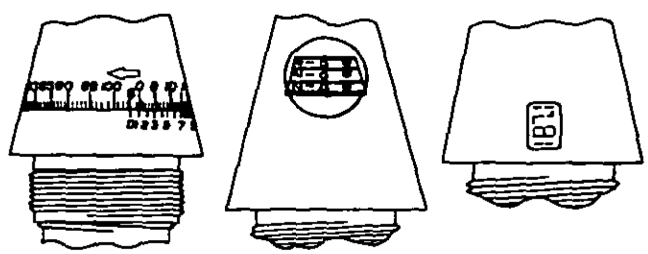


Figure 2-4. Linear and Digital Methods for Display of MT and ET Fuzes

visible, and future controls should be operable while the various levels of mission-oriented protective posture (MOPP) clothing and handwear are worn. Users wearing full MOPP gear for prolonged periods may be severely weakened. Control forces should be minimal to permit rapid and accurate fuze setting in nuclear, biological, and chemical (NBC) environments. Low-control forces may allow high-volume salvo firing over extended time periods.

Currently, many fuzes in the inventory require a tool for setting, and tools are easily misplaced or lost. Human factors engineering studies have shown that using tools to set fuzes requires more time and may be less accurate (Ref. 26). All future fuzes will be required to be set and/or adjusted without tools.

Present Army doctrine requires high-volume artillery fire, rapid deployment, effective employment, and long-term sustainment. All the preceding emphasize rapidly and accurately delivered munitions controlled by quickly and accurately set fuzes. Even though some fuzes will be set remotely by electronic devices, they will still require a manual backup. Designers of the fuzes of tomorrow will be challenged to provide hardware that will be fully compatible with the military user and still meet the multiple requirements of the future battlefield.

SECTION II RELATIONSHIP OF FUZING WITH THE ENVIRONMENT

2-7 INTRODUCTION

It is mandatory that the designer give proper consideration to the environments to which a fuze will be exposed from manufacture to delivery to the target. These environments will affect the design, service life, and ability of the fuze to function as intended. Environments include the various stresses to which the fuze will be exposed during manufacture, loading, handling, shipping, and storage in the geographical location of expected deployment as well as the forces resulting from launch-to-target impact. Environments are classified as either natural or induced. Natural environments are independent of humans and include such stress mechanisms as temperature, humidity, pressure, rain, hail, snow, dust, and salt spray. Induced environments are conditions that are predominately human-made or equipment and munition generated. These include such forces as acceleration, spin, vibration, aerodynamic heating, drag, creep, and target impact.

The environmental requirements for a fuze can be obtained from a study of the factory-to-function sequence and general specifications of the weapon and its munition. The environments that occur during the logistic flow can be tabulated in chart form with stress levels for each environment. The parametric levels are based on data from measurement of the environment, on previous programs, or on estimation until hardware testing can establish more accurate definitions. The designer uses this environmental information as a guide in determining strength, performance levels, moisture protection, and other essential characteristics of the weapon system.

This section deals primarily with the induced environments and how fuzes are designed not only to survive in these environments but also how the environments can be used to perform safety and arming (S&A) functions.

2-8 PROJECTILE FUZE

Projectile fuzes experience launch forces greater in magnitude than any other class of ammunition. The range and magnitude of some of these forces are listed in Table 2-2. All fuze parts are subjected to inertial or setback forces by the forward acceleration of the projectile in the gun barrel. These forces range from as low as 2500 g to as high as 125,000 g and can cause breakage of parts, unseating of staking, initiation of sensitive explosives, and other deleterious effects. Spin creates centrifugal, tangential, and Coriolis forces on fuzing components. (See pars. 5-4.3 through 5-4.5 for further discussion.) These forces can bring about structural failures, cause increased bearing friction on moving parts, affect timing accuracies in mechanical timers, and degrade explosive transfer in some explosive trains for which the output must follow a circuitous path or considerable distance to initiate the next element in the train. Balloting is the impact of the projectile against the wall of the gun barrel as the projectile travels through the barrel, and it results in radial forces on fuze components that increase in magnitude as the diameter of the gun barrel wears. Projectile fuzes are usually tested with worn barrels of one-fourth to three-fourths life to verify survivability in a balloting environment. Other induced environments the designer must consider are those created during ramming of the projectile in the breech, torsional forces when the projectile engages the rifling, forces of muzzle blast at barrel exit, aerodynamic heating, and aerodynamic forces resulting from eccentric spin, pitch, and yaw of the projectile. Fuzes must sometimes be sealed against leakage of high-pressure propellant gas.

The forces most commonly used for arming projectile fuzes are setback and spin. These forces are reasonably predictable for the various guns, and numerous ingenious mechanisms have been designed by using those forces to provide safety and arming for projectile and spin-stabilized mortar fuzes. Fig. 2-5 illustrates one type of setback operated device used to prevent unintentional arming of a projectile fuze. The setback pin is held by a compressed coil spring in a position that prevents movement of the rotor. On setback the force acting on the setback pin overcomes the force from its spring and causes the pin to move rearward, an action that partially frees the rotor. Note that although this configuration can be defeated by the impulse resulting

TABLE 2-2. FORCES ON FUZES DURING LAUNCH AND FREE FLIGHT

	PROJECTILE		ROCKET	MISSILE	LAUNCHED GRENADE	MORTAR
	Small Caliber	Large Caliber				
Setback, g	71-125 × 10^3	2.5-60 × 10^3	40-6500	12-40	18-65 × 10^3	0.3-10 × 10^3
Spin revolutions per second (rps)	1917-2030	45-500	0-50	3-12	63-200	10-50
Velocity, m/s ft/s	825-1080 2707-3544	610-1173 2000-3850	514-1116 1686-3662	96-supersonic 315-supersonic	76-366 250-1200	242-320 794-1050
Creep, g	>10	3-32	3	n/a	n/a	<1
Aerodynamic Heating, °C °F	480 896	400 752	425 797	Negligible	Negligible	Negligible
Balloting, g	20 × 10^3	20 × 10^3	n/a	n/a	n/a	n/a
Ramming, g	5 × 10^3	5 × 10^3	n/a	n/a	n/a	n/a

from dropping the fuze, the system is usually designed so that the magnitude of the impulse needed to retract the pin exceeds that which would normally be experienced in service handling. This lock by itself, however, is not adequate to provide the required level of fuze safety.

Spin-operated detents are usually used in projectile fuzes to provide a second independent lock on the out-of-line mechanism. Fig. 2-5 also illustrates a typical spin-lock detent system. Once the setback pin has been removed and the projectile nears or leaves the muzzle, the centrifugal force generated by the spinning projectile overcomes the frictional forces of setback, and the detents move out of their slots to unlock the rotor. The rotor, being dynamically unbalanced, is then rotated to the armed position at a rate that is governed by the runaway escapement and the spin rate. Two diametrically opposed detents are used to ensure that one always remains in place if the round is accidently dropped.

2-9 GUIDED MISSILE FUZE

Missile fuzes have some distinct environments associated with their operation. The first and foremost is acceleration. Missile acceleration is used almost universally as one source of arming energy. Most missile fuzes employ onboard batteries or energy transferred to the missile at launch time to operate solenoids or electroexplosive devices, which provide a second lock on the out-of-line mechanism. These devices, plus those operated by setback acceleration, satisfy the requirements of MIL-STD-1316 (Ref. 2) for two independent safety features, each activated by a different environmental stimulus. A typical acceleration-operated S&A mechanism for missile fuzing is discussed in par. 11-3. Par. 11-3 also provides equations that describe the motion of a runaway-escapement-regulated missile S&A mechanism. The fuze designer must also consider other forces that may influence the reliability of the arming mechanism. Vibration due to motor burning, aerodynamic instability, and buffeting can create forces detrimental to arming. Table 2-2 lists the magnitude and range of some of the environments associated with missile fuzing. Fig. 11-6 depicts an acceleration-operated S&A mechanism for a guided missile fuze.

2-10 ROCKET FUZE

Rocket fuzes are subjected to the same general environments as missile fuzes, except that their launch acceleration levels are usually higher, as shown in Table 2-2. Since rockets are carried on and launched from aircraft and helicopters, they are also subjected to the high-frequency vibration associated with these platforms. Most of the rocket fuzes currently listed as standard procurement items use only the single environment of acceleration to effect arming. These fuzes do not meet current military safety criteria, but their S&A mechanisms have withstood the test of time for providing a high degree of safety and reliability. One S&A mechanism used extensively in rocket fuzes is depicted in Fig. 2-6. This mechanism is a double integrating device (discussed further in par. 6-6.1.1) that provides a nearly constant arming distance independent of rocket acceleration. In this mechanism the rotor is held captive in the safe position by a spring-biased "g" weight that interferes with a pin pressed into the rotor. Upon rocket ignition, the acceleration causes the "g" weight to move down and free the rotor. The rotor, being unbalanced, rotates toward the armed position at a rate that is governed by the escapement and rocket acceleration. At the end of the prescribed arming time, the rack on the rotor disengages the escapement, and the rotor rotates to the armed position either by sustained acceleration or by action of a cam surface on the returning "g" weight after motor burnout. It is locked in the armed posi-

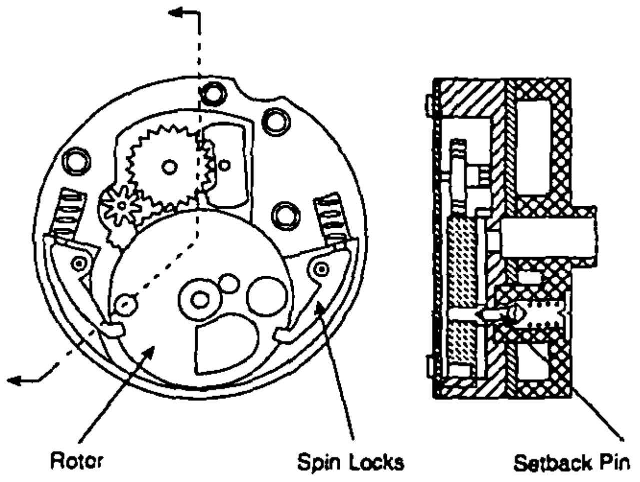


Figure 2-5. Typical Setback Pin and Spin Locks on a Projectile Fuze S&A Mechanism

tion by a spring-biased detent. A safety feature of this design is its ability to discriminate against a short-burning rocket motor. If acceleration is not sustained long enough for the rotor pin to reach a commit point (minimum flight velocity), the safing cam surface of the returning "g" weight will engage the pin and rotate the rotor back to the safe position.

Modern rocket fuzes, as well as bomb fuzes, have used ram air as an environmental energy source to perform arming functions and to supply electrical energy for electronic timing of fuzes and functioning of electroexplosive devices. Fig. 2-7 illustrates the fluidic generator used in the M445 rocket fuze. Ram air passes through an annular nozzle into a cone-shaped cavity whose opening is concentric with the annular orifice. The airstream impinges on the leading edge of the cavity and creates an acoustic perturbance that triggers air inside the cavity into resonant oscillation. The pulsation of the air within the cavity in turn drives a metal diaphragm, clamped at the end of the cavity, into vibration. The vibratory motion of the diaphragm is transmitted to a reed via a connecting rod. The reed is in the air gap between the poles of a magnetic circuit consisting of a pair of permanent magnets located between a pair of magnetic keepers. The reed, made of magnetic material, oscillates in the air gap at the mechanical resonant frequency of the system. The resultant alternating flux induces an electromotive force in a conducting coil around the reed. The power generated is mainly a function of the rate of change of the magnetic flux density, the magnetic field intensity, and the coil design.

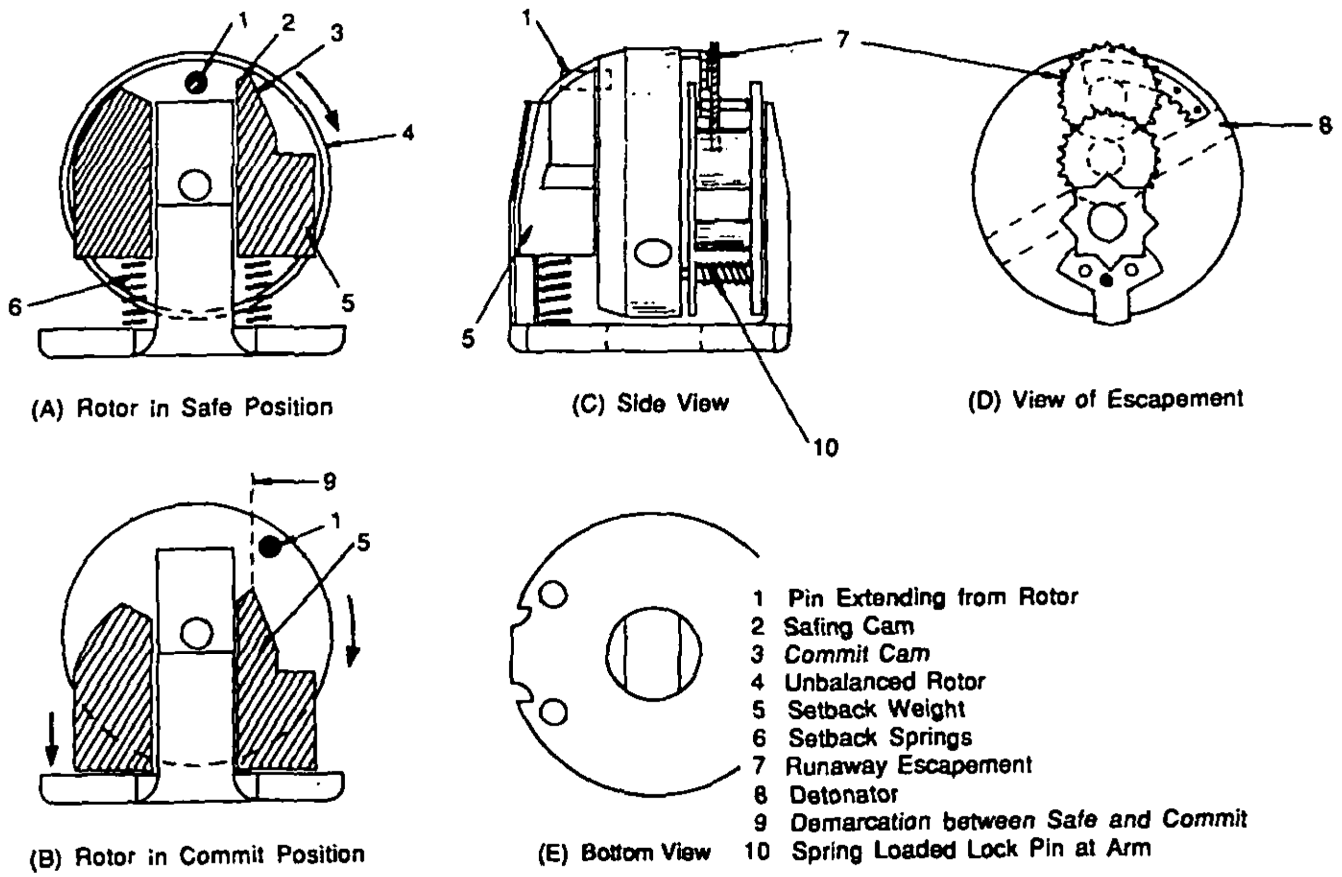


Figure 2-6. Safety and Arming Mechanism for a Rocket Fuze

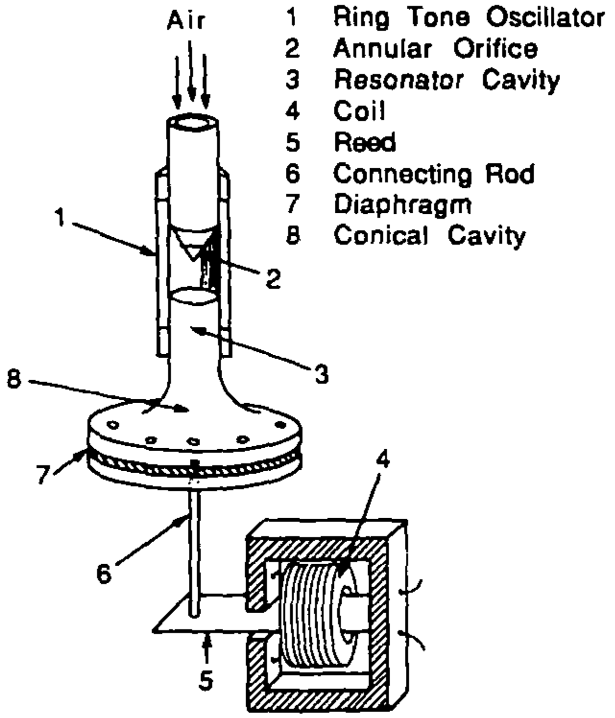


Figure 2-7. Fluidic Generator With Ring Tone Oscillator

The function of the fluidic generator, as a supplier of a second environmental signature for arming, can be provided electrically or mechanically. The output frequency of the generator can be counted by a multistage logic circuit, that provides a firing pulse for a piston motor to unlock an out-of-line mechanism at the prescribed arming time. In the mechanical mode the reciprocating motion of the reed can be converted into rotary motion that can drive a cam to unblock the out-of-line rotor.

In addition to providing a source of power and a second environmental signature, the fluidic generator can serve as an oscillating time base for an electronic timer and can provide a firing signal caused by the disruption of the airflow as the projectile impacts the target (Ref. 27).

2-11 MINE FUZE

The Army, Navy, and Air Force currently deploy a family of scatterable antiarmor and antipersonnel mines with quick emplacement capabilities through air, artillery, special ground vehicle, and hand-emplacement techniques. These mines are enabled for arming by various means depending on the delivery mode and are armed some predetermined time after ground impact. Although the S&A mechanism must satisfy differing conditions of deployment, a number of parts have been designed for commonality with more than one mine S&A mechanism. These fuzes and their power sources must be capable of withstanding severe launch environments, i.e., fired from artillery, launched from a towed dispenser, or air-dropped from high-speed jet aircraft or helicopters. A brief description of each type of dispensing system and the techniques used to arm fuzes are provided in the paragraphs that follow:

1. *Area-Denial Artillery Munition (ADAM).* ADAM is an artillery-delivered, antipersonnel mine delivered from a M483 155-mm howitzer projectile. The fuze uses the forces of spin and ejection (setback) from the projectile for proper arming.

2. *Remote Antiarmor Mine (RAAM).* RAAM is an artillery-delivered, antiarmor mine delivered from a modified M483 155-mm projectile (Fig. 1-48). When the round is fired, the S&A mechanism senses the forces of spin and mine ejection to enable the arming mechanism. (See par. 1-11.2 for more details.)

3. *Ground Emplaced Mine Scattering System (GEMSS).* GEMSS mines are deployed by a towed M128 mine dispenser. Mine density is controlled automatically by a rotating drum, which dispenses the mines radially. This system can dispense both antipersonnel (M74) and antitank (M75) mines. The arming and functioning sequence for the M75 follows. The S&A mechanism undergoes rotation of approximately 53 revolutions per second (rps) in the rotating drum. This rotation causes two centrifugal detents to move out to unblock and remove one lock on the slider. When the mine exits the launcher, a magnetic coupling coil in the mine picks up an electrical pulse, which fires an electric battery primer. The primer output activates the reserve battery, breaks two shorting bars, and moves the lock plate in the S&A mechanism forward to lock out the centrifugal locks. The S&A mechanism is now committed to arm. After ground impact, the electronics generates a firing pulse which initiates a piston actuator that disengages the slider release pin and allows the spring to move the slider to the armed position. Detonation of the mine occurs either by sensing a proper armored vehicle (antiarmor mine M75) or by disturbance of a trip line (antipersonnel mine M74). Both mines self-destruct after a predetermined time if they do not sense a target.

4. *Aerial Delivered Mines.* GATOR and VOLCANO are aerial delivered mines dispensed from high-speed jet aircraft and helicopters, respectively. These systems contain a combination of antitank and antipersonnel mines. Fuze arming is initiated by electrical energy received from a magnetic coupling device identical to that described for GEMSS, which

a. Unlocks the bore rider safety feature

b. Activates the battery.

After impact, a two-minute pyrotechnic timer releases the bore rider, and the electronics sends a signal to a piston actuator to allow the S&A mechanism to move in-line and mechanically arm the fuze.

2-12 GRENADE FUZE

Ideally, an ammunition fuze should arm only when it experiences forces unique to the launch environment. At all other times, i.e., during storage, transportation, and handling, the fuze should remain safe. Unfortunately, a hand grenade does not experience any unique forces at the time it is thrown or while it is in flight. Therefore, arming must occur as a result of some action or event prior to the time the grenade is thrown. Additionally, it is desirable for all fuzes to have an explosive train with the primary explosives physically separated from the lead and booster by a barrier to interrupt the explosive path and thus prevent detonation of the munition until after arming occurs. Because there are no unique forces to use for arming, MIL-STD-1316 (Ref. 2) is not applicable. Instead MIL-STD-1911 (Ref. 3), which requires the use of a different action performed in a specific sequence to enable each safety feature, must be used.

Current and past techniques* for providing safety to the thrower of grenades are to require some positive action to be performed in order to initiate functioning. In Fig. 1-22 the firing pin is restrained by the safety lever, which is itself restrained at one end by the safety pull ring and cotter pin assembly and by a T-lug at the other end. The fuze becomes enabled when the thrower pulls the safety pin while holding the lever in place. Only the pressure of the thrower's hand on the safety lever prevents initiation of the fuze. When the grenade is thrown, the lever is released and is forced out of the way by the spring-driven firing pin assembly. The firing pin strikes the primer and thereby initiates the explosive train of the fuze. Typically, initiation of the main charge in the grenade is delayed 4.5 to 5.0 s to provide protection to the thrower. A major concern to the designer of grenade fuzes is to eliminate the possibility of premature function or bypass of the delay column. Strict quality control for the explosive delay mix and loading procedures must be demanded. Inspection procedures for elimination of excessive porosity in the die-cast housing must also be specified to preclude bypass of the delay column via this path.

On the other hand, launched grenades have both spin and setback forces, which can be used to provide the S&A function. Table 2-2 lists the range of setback, spin, and muzzle velocities for the 40-mm grenade. These grenades can be launched from standard handheld launchers as shown in Fig. 1-24. Par. 1-12.2 describes the arming and functioning of a typical launched grenade fuze, M551. Some earlier 40-mm grenade fuzes used a dynamically unbalanced ball rotor to achieve delayed arming versus the current use of an escapement.

*Because MIL-STD-1911 has only recently been published, no hand grenades have been designed with its requirements.

2-13 SUBMUNITION FUZE

Typical submunition fuzing uses sensing of only a single environment to achieve arming. Both spin and aerodynamic environments have been used to provide forces to remove locks on the S&A mechanism. The M223 fuze described in par. 1-13 and illustrated in Fig. 1-51 uses spin induced by the 155-mm projectile to unscrew a pin blocking a spring-operated slider. When the submunition is placed in the projectile, additional safety is provided by limiting the travel of the slider by the method of stacking within the projectile.

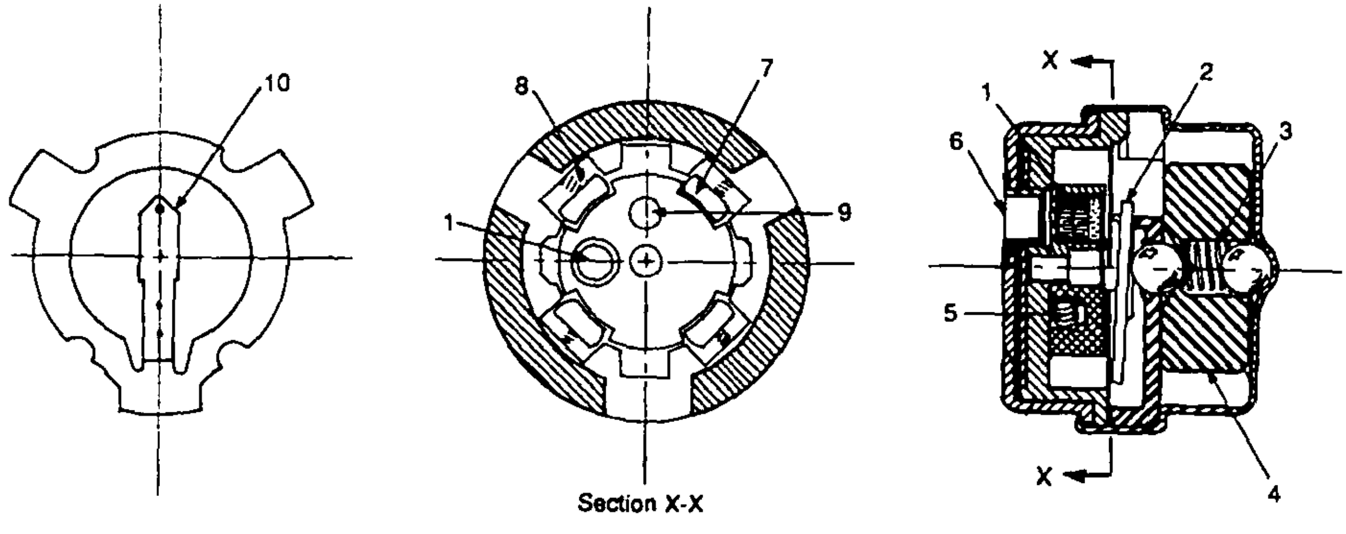
Navy designed submunition fuzes (FMU-88/B and MK1 Mod 0) for air-launched cluster bombs use the aerodynamic forces of the wind stream to operate a flutter arming mechanism (See par. 6-7.2 for detailed discussion.) or rotate a vane to perform fuze arming functions. In addition, both of these fuzes contain a velocity discrimination feature, which provides protection in the event of accidental bomb release on takeoff and landing.

An example of a spin armed submunition fuze is the M219 fuze depicted in Fig. 2-8. The spin used to arm this fuze is derived from flutes on the BLU 26/B submunition. The BLU 26/B is spherical, and the flutes engage the air-stream to cause rotation. This submunition provides a rotational velocity of approximately 45 rps to the fuze and causes four centrifugally operated detents to disengage from the out-of-line rotor. The rotor, being spring loaded, rotates to the armed position. On impact the weight moves laterally and cams the lower ball into the cantilevered firing pin to initiate the stab detonator. The detonator fires an explosive lead, which in turn detonates the submunition.

Projectile-launched submunitions and submunition fuzes must be rugged enough to withstand the forces of launch and the expulsion acceleration forces.

2-14 MORTAR FUZE

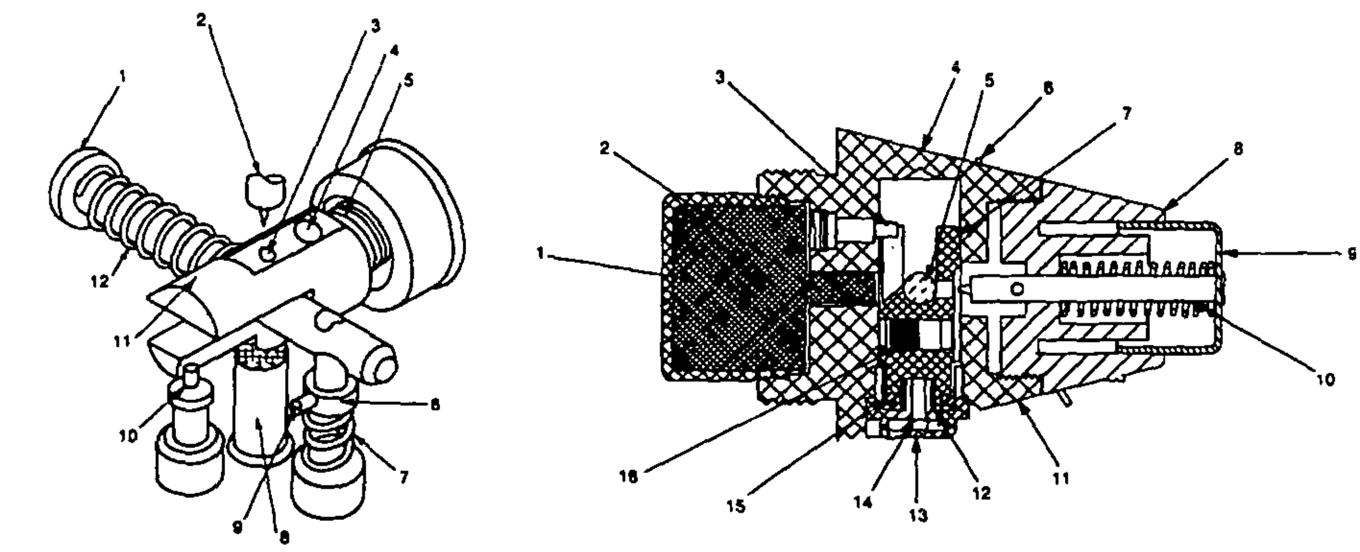
60-mm and 81-mm caliber mortar ammunition are launched from smooth-bore tubes and experience setback forces (See Table 2-2.) in the tube and ram air aerodynamic forces during flight. The M734 60-mm mortar fuze, described in par. 1-6.3 and illustrated in Fig. 1-38, uses both of these induced environments to effect arming. Earlier mortar fuzes used a bore rider pin and a delayed arming mechanism in addition to setback to achieve an acceptable level of bore safety. Fig. 2-9 illustrates a fuze that uses this principle. In-bore safety is provided by a spring-biased bore riding pin that locks the slider in the out-of-line position. A safety pull wire restrains a spring-biased setback pin, as shown in Fig. 2-9(A), that locks the bore riding pin. Setback force from weapon firing moves the setback pin rearward against the pin spring and releases the bore riding pin. The bore riding pin then contacts the bore of the mortar and is allowed further movement when the cartridge leaves the muzzle. The final movement of the bore riding pin unlocks the slider. The slider, like the bore rider pin, is moved by a



(A) Firing Pin Assembly | (B) Rotor and Detent Assembly | (C) Fuze, Shown in Armed Position

1 Stab Detonator in Rotor
2 Firing Pin Assembly
3 Weight-Centering Spring
4 Inertia Firing Weight
5 Rotor Arming Spring
6 Lead
7 Rotor Detent (4)
8 Conical Detent Spring (4)
9 Recess for Firing Pin Point
10 Firing Pin on Cantilever Spring

Figure 2-8. Grenade Fuze M219A1



(A) Arming Action

(B) Cross Section of Fuze

(A):
1 Safety Pin
2 Firing Pin
3 Blank Hole
4 Detonator
5 Slider Spring
6 Setback Pin
7 Setback Pin Spring
8 Lead Charge
9 Cotter Pin
10 Guide Pin
11 Slider Interrupter
12 Safety Pin Spring

(B):
1 Booster Charge
2 Lead Charge
3 Guide Pin
4 Body
5 Bore Riding Pin
6 Pull Wire
7 Slider
8 Head
9 Striker
10 Firing Pin
11 Tape
12 Spring
13 Plastic Disk
14 Orifice
15 O-Ring
16 Detonator

Figure 2-9. Arming Action for Fuze, PD M717

compressed spring, and because of an O-ring seal, a vacuum is created behind the slider. The vacuum is relieved gradually by the air bleed orifice. The metered pressure relief through the orifice provides a 1.5- to 6-s delay before the slider completes the movement necessary to align the detonator with the firing pin and arm the fuze. On impact the striker and firing pin are depressed rearward to fire the detonator. Detonation is superquick through the explosive lead charge and booster charge.

Mortars of 4.2-in. caliber have rifled barrels, which induce spin to the projectile. This large caliber mortar uses the same fuzes as major caliber artillery projectiles since the induced setback and spin levels are large enough to arm these fuzes.

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CHAPTER 3
PRINCIPLES OF FUZE INITIATION

The principles of fuze initiation are explained in this chapter. It begins with a discussion of the means by which the fuze senses the presence of the target: contact, influence, or when a preset functioning delay expires.

Under contact initiation various mechanisms used to sense and react to the target are discussed and illustrated. The means of obtaining superquick response, inertial response, and delayed response functioning are described.

The use of radio frequency, induction, electrostatic, magnetic, electro-optical, capacitive, seismic, acoustic, and pressure sensing is explained and illustrated along with the advantages of each.

Methods of mechanical initiation—including stab, percussion, adiabatic compression, shock, and friction—are discussed and illustrated. Electrical initiation also is described, and its advantages and disadvantages are discussed.

Electrochemical and electromechanical power sources are described in detail together with the advancing power source technologies that offer potential for future fuzing applications.

3-1 INTRODUCTION

A fuze is a device used to cause terminal functioning of a munition at a desired time or place. To accomplish this task, the fuze must become armed, sense the target—by either proximity or impact—or measure time, and then initiate the desired action. The desired action may be detonation of the munition (either instantaneous or delayed), expulsion of submunitions or mines, and/or expulsion and ignition of canisters containing chemicals, smoke, or pyrotechnics.

Arming is the shift in status of a fuze from a safe condition to an enabled condition, i.e., able to function. This consists of the removal of the safety locks from the explosive train interrupter and alignment of the explosive elements in the explosive train. Basic fuze-arming actions are discussed extensively in Part Two.

After arming, the fuze must sense the target and, when the proper target stimulus is received, initiate the first element in the explosive train. Fuze functioning starts with initiation of the first explosive element and ends with the detonation or ignition of an explosive output charge or with some other action such as closure of electrical switches.

3-2 TARGET SENSING

Different munitions are assigned specific tasks. Some are designed to detonate as they approach their targets, others are expected to detonate upon impacting the target, and still others are meant to detonate only after penetrating the target.

In some cases, the fuze must provide for optional actions. Some fuzes are required to destroy the munition if no target is sensed within a given time interval or flight distance. Other munitions, such as mines, are expected to lie dormant for indefinite periods and then to function when a suitable target moves into their effective range. In every instance, however, the fuze must first sense the target at the proper time or distance so that its subsequent actions may be initiated. This problem is usually solved in one of four ways: (1) sensing by contact of munition and target, (2) influence sensing with no contact of munition and target, (3) presetting, in which the functioning delay of the fuze is set before launching or emplacement, or (4) command, in which functioning occurs on a remote signal generated externally after emplacement or launch.

3-2.1 SENSING BY CONTACT

Fuzes that are initiated by contact with the target are the simplest and offer the most direct solution to many fuzing problems. All functioning actions start when some part of the munition touches the target (or the target touches some part of the munition). When properly designed, contact fuzes can be used to produce a detonation of the explosive output charge in any desired location—from a short distance in front of the target to several feet or more within the target.

The electrical or mechanical systems of such fuzes are usually activated by some mechanical action—such as moving a firing pin, closing a switch, or stressing a piezoelectric transducer—that results from contacting the target.

Contact sensing is applied in a variety of ways, namely,

1. *On the Surface of the Target.* The most straightforward use of contact sensing is to have a munition detonate on the front surface of the target. When the fuze touches the target, action starts at once, and detonation occurs as a direct consequence of the sensing.

2. *Behind the Target.* A typical example is a munition designed to detonate within the structure of an aircraft. Methods of extending functioning time or delaying detonation of the bursting charge after first contact are discussed in par. 4-4.1.

3. *In Front of the Target.* An example is that of detonating a shaped-charge warhead some distance in front of the target by using an extended probe. This distance in front of the target is known as the "standoff distance". Standoff

initiation is required for all shaped-charge and fuel-air-explosive (FAE) munitions for maximum effectiveness. For shaped-charge munitions the standoff distance is usually 2 to 3 times the cone diameter because of aerodynamic considerations (Ref. 1), and existing FAE munitions require standoff distances from 1 to 3 m (4 to 9 ft) (Ref. 2).

3-2.1.1 Superquick Functioning

"Superquick" (SQ) is defined as functioning upon contact with the target with a minimum delay consistent with maximizing the damaging effects of fragmentation, jet formation, and/or blast. Functioning time on the order of 20 to 50 μs can be achieved by stressing a piezoelectric crystal or by closing electrical switches (See par. 1-7.). SQ fuze action is required with all shaped-charge rounds to preserve the standoff distance required for optimum penetration.

3-2.1.1.1 Protruding Firing Pin

In the days of World War I fabric-covered aircraft, it was considered necessary for sensitivity reasons to use a firing pin or firing pin striker that protruded from the tip of the projectile. There were many variants, but two general types were employed: (1) a permanently extended pin and (2) a telescoped pin releasable as setback force ceased just beyond the gun muzzle. Two means of extending the pin were (1) to use ram air energy and (2) to use stored spring energy, which is more reliable. The telescoped system protected the pin during the automatic feed cycle of the gun and also allowed use of the pin as a setback lock. Fig. 3-1 shows several types of protruding firing pins.

Better methods of achieving fuze sensitivity without the attendant problems of sealing and potential damage during handling have made the protruding firing pin obsolete.

3-2.1.1.2 Wad Cutter

The generally accepted method of contact sensing of the target by a stab firing pin is the wad cutter system, shown in Fig. 3-2. The forward tip of the fuze ogive cuts out a portion of the target, which drives the firing pin into the detonator.

In earlier designs an effort was made to present a near-knife-edge to the target. This was found unnecessary for sensitivity, and a rounded lip formed by a rolled crimp is now used and is a more economical method.

Most wad cutter systems are sealed with a thin metal diaphragm 0.076 to 0.127 mm (0.003 to 0.005 in.) thick that is crimped in place and sealed with varnish or liquid latex.

Some problems are encountered with premature detonation in-flight caused by heavy rain; however, the present practice is to address this problem only in fuzes for the larger caliber rounds of 75 mm (3 in.) and larger. Fuzes for these rounds employ the crossbar-type raindrop disintegrator located under the closing disk shown in Fig. 1-31. Some Navy point-detonating (PD) fuzes, such as shown in Fig. 1-43, in these calibers use an integral nose bulkhead to circumvent the problem. This bulkhead actually forms a very thick closing disk of approximately 1.3 mm (0.05 in.), which is about 10 times that of small caliber fuze closing disks. Some sensitivity is lost; however, targets for these larger rounds do not require as high a level of sensitivity as those for smaller caliber rounds because the targets are of heavier construction.

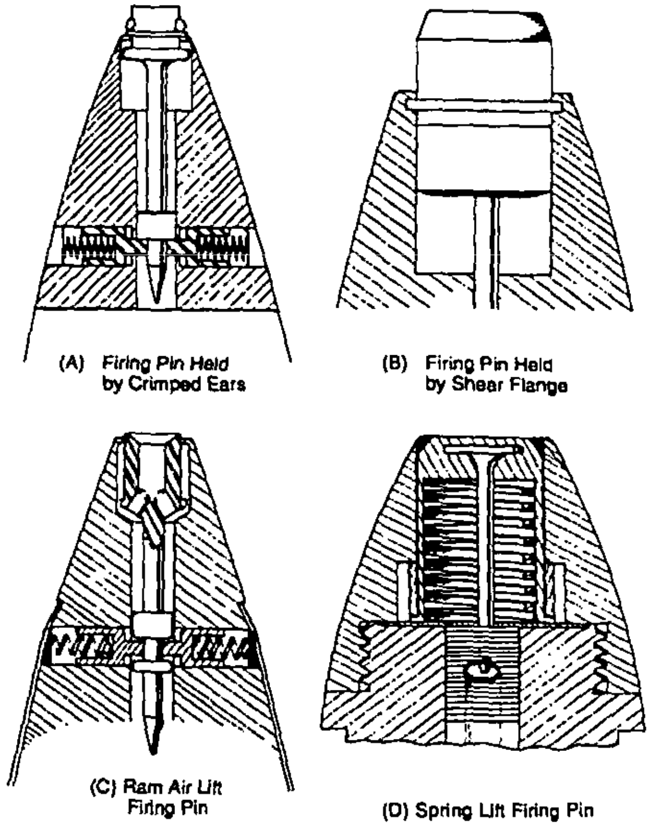


Figure 3-1. Protruding Firing Pins

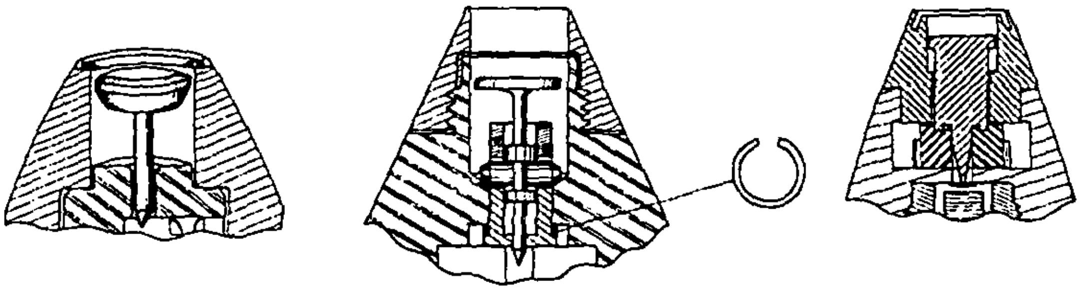
3-2.1.1.3 Deformable Diaphragm

The MK 27 PD Fuze was, perhaps, the first supersensitive fuze to eliminate a closing disk by using a nominal 1-mm (0.04-in.) thick diaphragm closure cast integrally with the aluminum alloy die-cast fuze body. The very light firing pin assembly, i.e., plastic striker and aluminum firing pin, enables the fuze to respond very rapidly to target impact, even though on light targets the nose closure dishes rather than shears through.

The integral closures illustrated in Figs. 3-3(A) and (B) also serve as rain shields as do those in Figs. 3-3(C) and (D), which are more recent developments.

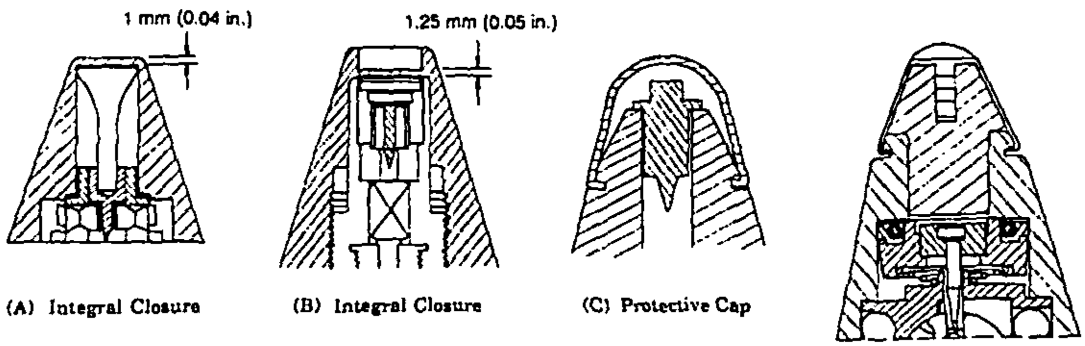
3-2.1.2 Nondelay Functioning

The reaction time of the firing mechanisms, Figs. 3-4(A) and (B), in nondelay systems—as distinguished from SQ



(A) Diaphragm Seal Crimped over Washer (B) Steel Wad Cutter System (C) Diaphragm Seal Crimped Directly Into Nose Piece

Figure 3-2. Wad Cutter Arrangements



(A) Integral Closure (B) Integral Closure (C) Protective Cap (D) Plastic Striker

Figure 3-3. Deformable Systems

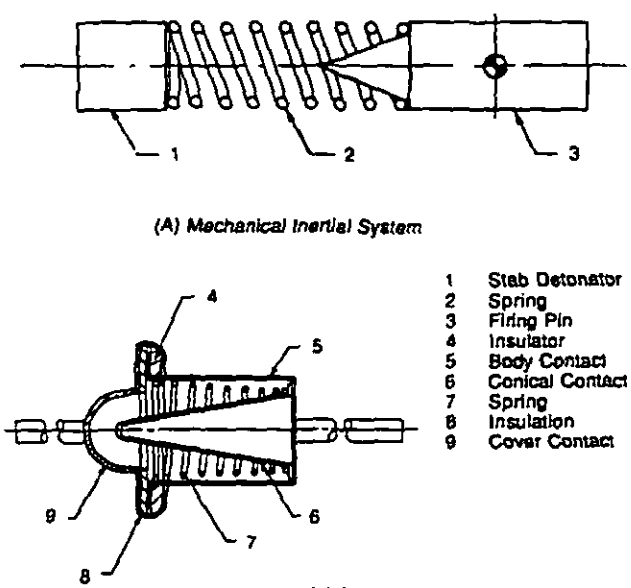


Figure 3-4. Inertial Delay Systems

systems—is controlled by the inertia inherent in responding to the deceleration of the munition. Although the reaction time produces a delay, it is not by design intent; however, use can often be made of this inherent delay.

Most electric fuzes use spring-mass switches—described further in par. 7-2.1—to effect initiation. These switches provide very fast response times, i.e., <1 ms, to high-*g* impacts and can cause detonation of the munition before any appreciable penetration occurs. Response times can be appreciably slower for low-*g* impacts. Reaction times of mechanical inertial systems are usually longer than those of electrical switch systems because the elements that trigger initiation usually travel a greater distance to develop sufficient kinetic energy to initiate a stab or percussion primer.

3-2.1.3 Delay

Many tactical situations require a time delay between initial input stimulus and detonation. This kind of action is necessary for targets having protection or resistance to penetration, i.e., armor (tanks, armored personnel carriers (APC), and ships), concrete or brick (pillboxes and buildings), and sandbags or logs (bunkers). When used against aircraft, small caliber ammunition also requires penetration prior to detonation for maximum effect.

There is a variety of methods available for obtaining the requisite delay times. These methods can be broadly categorized as inertial, pyrotechnic, or electronic. Each method is discussed.

3-2.1.3.1 Inertial Delays

A simple inertial delay of one type can be a firing pin, primer, or switch mounted in a mass that moves in response to a sudden axial deceleration of the warhead during target penetration. The mechanism is encased in the fuze and does not make direct contact with the target. Parameters that control the delay time are the magnitude and duration of the deceleration, the inertia of the system, the distance of travel of the mass, and the friction of the system.

Fig. 3-4(A) illustrates a typical inertia firing pin and detonator assembly that uses an anticreep (antidrag) spring.

Mechanical inertia systems of this type basically are simple and economical. Generally their usefulness is limited to obtaining a partial penetration of the target with a full warhead length probably being the upper limit.

Inertial delays can also be arranged transversely and when unlocked by target impact, can use centrifugal force to move a firing pin into a primer and thus produce a delay independent of the ramming effect of the target. Such delays can effectively place the projectile up to three lengths into the target (Ref. 3).

3-2.1.3.2 Pyrotechnic Delays

Pyrotechnic delays are used extensively in fuzes. A pyrotechnic delay element consists of a metal cup with an initiator (primer) at one end, a delay column in the middle, and a relay or other output charge (Ref. 4). Various internal mechanical baffling and shock-mitigating features are often used to prevent the initiation shocks and primer output from disrupting or bypassing the delay column. Pyrotechnic delays can be used for target penetration, delayed arming, and self-destruction. Times can vary from a few tenths of a millisecond to hundreds of seconds, but times of less than 1 s are especially difficult to achieve.

The harmful effects of moisture make sealed delay elements desirable in all cases. Gasless delay powders are used almost universally because they are well-suited to sealed designs. The accuracy of functioning times for pyrotechnic delays can be expected to be on the order of ±25% for the military operational range of temperatures, −54° to 71°C (−65° to 160°F).

There is additional information on pyrotechnic delays in par. 4-4.1.

3-2.1.3.3 Electronic Delays

Electronic delays for functioning after impact currently are used in Navy and Air Force electric bomb fuzes. These delays are achieved by resistor-capacitor (RC) networks (See Chapter 7 for a discussion of RC networks.) and are generally much more accurate than pyrotechnic delays. Accuracy is a function of the tolerance limits of resistance and capacitance, or the frequency stability of the oscillator, as well as the applied voltage. The RC delays for electric bomb fuzes are in the millisecond range; the longest delay is 200 ms. The limit to the length of time delay is established by the leakage of the capacitor, which in most cases makes the RC network inadequate for delays of more than several minutes (Ref. 5).

3-2.1.4 Void Sensing

Fuzes with fixed time delays designed to effect penetration of barriers in front of targets can fall short of this goal if the barrier is excessively thick or is of such a nature as to slow the warhead unduly. These barriers can be extra layers of sandbags or logs placed to defeat a known delay in the adversary's warhead.

One solution is to design a fuze delay mechanism that measures the thickness of the target, and if the thickness is such that the kinetic energy of the round is insufficient to cause complete penetration, the fuze mechanism detonates the round when it comes to a stop in the target.

The fuze M739A2, shown in Fig. 3-5, contains an impact delay module (IDM) that is designed to operate when it senses a void after impact.

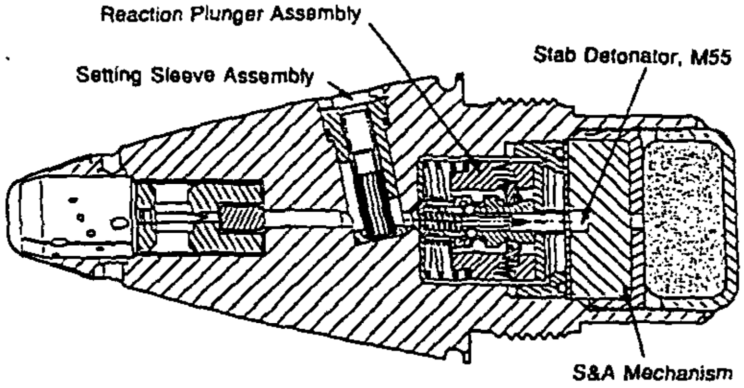


Figure 3-5. Fuze, M739A2 With Impact Delay Module (IDM)

Figs. 3-6(A), (B), (C), and (D) depict the actions in the IDM. Fig. 3-6(A) shows the IDM at time of firing. When fired from an artillery weapon that imposes a suitable spin rate and upon cessation of setback, the spring-loaded spin detents move radially outward from centrifugal force and unlock the plunger assembly, as illustrated in Fig. 3-6(B). Upon impact with a target the plunger overcomes the plunger spring force and moves forward, thus removing the restraint from the two slider balls marked "1". The slider balls are then moved by spin into a cavity within the plunger Fig. 3-6(C). At this point, the firing pin is held in place by the firing pin balls marked "2" and the slider that is being kept in the forward position by the deceleration force.

Reduction of deceleration due to projectile breakout into a void, or reduction in deceleration below 300 g, permits the slider to be driven aft by the slider spring and thus unlock the firing pin balls. The firing pin spring is now free to drive the firing pin through its stroke (Fig. 3-6(D)) and into the detonator located in the safety and arming (S&A) mechanism to initiate the explosive train of the fuze.

The fuze will also function on graze at low angles of impact (≈3 deg) and in a superquick mode. When set for the superquick option, the nose detonator flashes by the firing pin in the IDM by virtue of flats on the tubular part of the pin that intersect the hollow center.

Reaction plungers—i.e., those reacting to deceleration as herein discussed—have been used in the past, and their

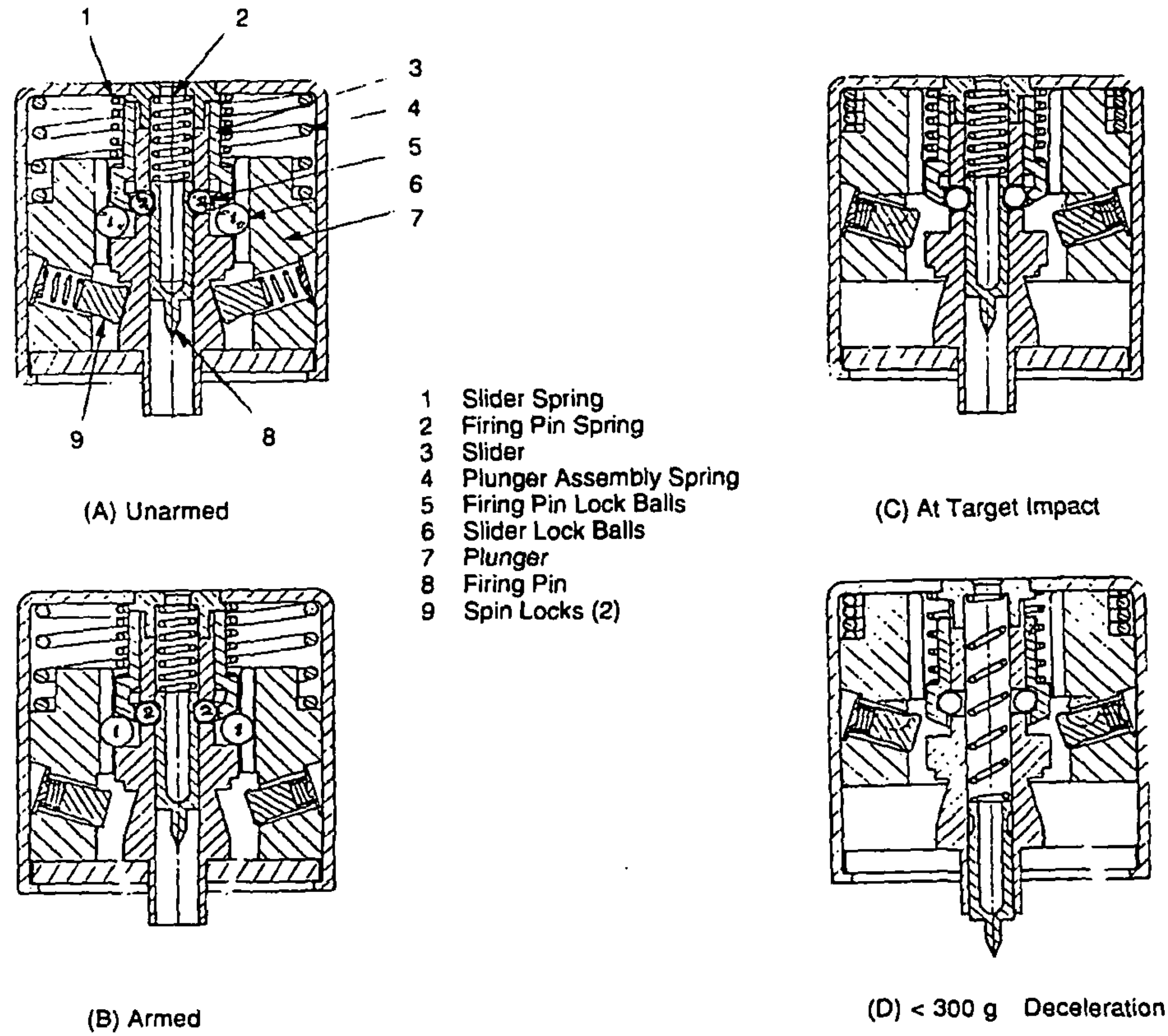


Figure 3-6. Reaction Plunger of Fuze M739A2

limitations are documented. On very hard targets—such as armor plate and to a lesser extent on heavily reinforced concrete—structural damage to the mechanism can prevent firing after impact. Accordingly, significant protection should be provided the IDMs by locating them in a base fuze or within a steel—preferably hardened—ogive when they are in the nose position. Another problem is that the plunger may elastically rebound on severe impact and cock to cause nearly instantaneous initiation. Some shock-mitigating material, such as lead, foamed aluminum, or a similar energy absorber, can be used forward of the IDM plunger to mitigate such rebound.

3-2.2 RADIO FREQUENCY (RF) SENSING

This sensing mode causes detonation of the bursting charge in the vicinity of the target. It is useful in a number of tactical situations to obtain optimum dispersion of fragments, flechettes, or submunitions. Since a direct hit is not necessary, the net effect is that of having an enlarged target. The best example of this type of influence-sensing fuze is the radio proximity type. Originally, such fuzes were called "VT" (variable time) fuzes, but the term "proximity" is now preferred.

A simple, radio-type proximity fuze contains a continuous wave transmitter, an antenna, a receiver, a power source, and a safety and arming (S&A) mechanism. When the emitted waves strike a target, some of the energy is reflected back to the antenna of the fuze. Because of the relative motion between fuze and target, the reflected-wave frequency differs from the original emitted frequency, and the difference in frequency (the Doppler effect) is detected and amplified in the receiver. When the signal reaches a certain value, an electric detonator is initiated that causes the explosive train to function.

The receiver compares the two signals—the reflected and a portion of the transmitted—by amplifying the beat frequency note produced by the two signals. The amplitude of this note depends upon the amplitude of the reflected signal, which is a function of target range. In this way fuze initiation is controlled by projectile-target distance. Proximity fuzes are the subject of other Engineering Design Handbooks listed in the bibliography.

Refinements of influence sensing become especially important for air-to-air and surface-to-air guided missiles. The missile sometimes must sense the target both to follow it and to initiate the fuze action. There are several methods for doing this. Detectors sense the heat or noise of the target, transmitted radio waves sense the location of the target, or independent commands may artificially cause target sensing. These missile guidance systems compensate for changes in target position. Once the missile has come into target range, it senses the exact position of the target by other means and initiates fuze action.

3-2.3 INDUCTIVE SENSING

This method of target sensing is a nonradiating proximity system that is sensitive only to metallic objects; consequently, it can penetrate trees and will not trigger on ground proximity. It can provide standoff for high-explosive antitank (HEAT) ammunition with minimum degradation at high obliquities. The performance is independent of closing velocity and immune to practical electronic countermeasures (ECM). The fuze is applicable to cannon and missile ammunition and offers a simple, low-cost, proximity capability.

The system, shown in Fig. 3-7, is comprised of three coils in tandem that are mounted on a nonconductive ogive. The middle coil is an active alternating current (ac) drive coil that sets up an inductive field encompassing the two sense coils. When in near proximity to a conducting target, this field induces eddy currents, which, in turn, produce an imbalance in the sense coils that results in a firing signal.

An electronic processor circuit is designed to amplify the change in voltage on the sense coils caused by interaction with a target and then to fire a detonator when a threshold has been reached. This circuit functions as a direct current (dc) balancing circuit since the ac signals from the sense coils are rectified and filtered to dc levels before being applied to the inputs of a differential amplifier. The automatic gain control (AGC) nulling amplifier is used along with a variable attenuator buffer stage to equalize the signal levels from the sense coils and eliminate the need to adhere to very tight design or manufacturing tolerances. The signal through the AGC feedback loop responds very slowly to an unbalanced condition, but the signal through the high-gain differential-amplifier (diff-amp) responds to a rapidly changing signal in the target engagement band pass.

This circuit design has many advantages including low cost, no necessity for factory adjustments, and no requirement for tight tolerances. Other circuit designs being considered include phase detection and "ac balancing", which could improve sensor performance by increasing standoff. If production volumes justify the initial investment, the circuit functions could be integrated on one or two monolithic integrated circuits.

3-2.4 ELECTROSTATIC SENSING

A proximity fuze for antiaircraft projectiles can function by sensing the electric field surrounding an aircraft in flight. This field is caused by a charge accumulated by two processes on the airframe. The first process is a triboelectric (friction-generated) effect in which an electrostatic charge is developed when the airframe strikes dust and precipitation particles. Of lesser magnitude is an engine-charging current, which is developed during the combustion process. These currents are typically in the tens of microamperes. For example, an F4D fighter is charged to 50 kV within 0.5 s after takeoff. Experiments have shown that aircraft at these potentials are easily detected at several meters with a small, projectile-mounted electrostatic probe (Refs. 6 and 7).

An implementation of a short-circuit longitudinal probe design is shown in Fig. 3-8. The probe is formed by splitting the projectile electrically into small fore and aft sections. The effect of short-circuit loading is achieved by connecting the fore probe electrode to the inverting input of an operational amplifier and by connecting the aft electrode to the noninverting input. When the projectile approaches a positively charged target, free electrons on the projectile tend to flow to the forward probe to maintain zero tangential electric field on the projectile surface. If it is assumed there is good insulation between the two electrodes, the only path available for the charge is through the amplifier feedback resistor.

The charge that settles on the forward probe electrode is proportional to the field applied in the direction of the projectile axis and is a function of time as the projectile approaches the target. The time derivative of the charge gives the current in the feedback resistor. It follows that the amplified output *V* of the probe is proportional to the time derivative of the voltage.

Experimentation with this configuration has indicated that simulated aircraft targets can be detected and that, with proper signal processing, the concept can discriminate between signals generated by targets and electrostatically charged trees and raindrops.

3-2.5 MAGNETIC SENSING

Magnetic sensing (electromagnetic induction) can occur when an electromotive force is induced in an electric circuit by changing the magnetic field about that circuit.

This principle can be useful in antitank mines. The magnetic field of the earth is shifted by the iron tank so that the magnetic flux of the earth, which threads a coil in the fuze or is connected to the fuze, is changed as the tank passes over the mine. The electric voltage induced in the coil actuates a sensitive switch or relay, which closes the detonator firing circuit.

Design refinements can be made to ensure that the tank or other type of vehicle is in optimum relation to the mine. One significant design problem is battery life during long-term emplacement.

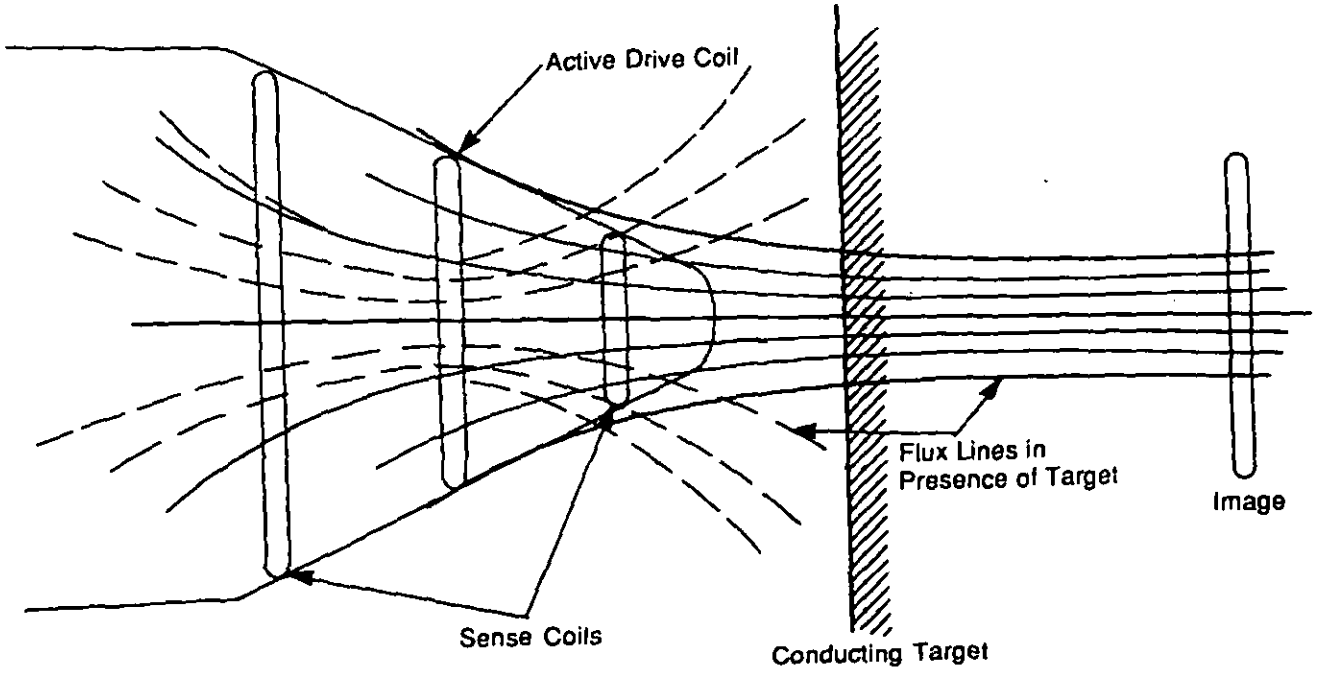


Figure 3-7. Inductive Sensing

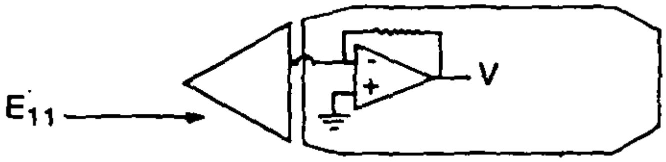


Figure 3-8. Short-Circuit Longitudinal Probe Configuration for Electrostatic Fuze

3-2.6 ELECTRO-OPTICAL (EO) SENSING FOR FIRING

This mode of sensing is particularly applicable to the infrared (IR) emissions from jet engines. Sensors (photodiodes) are located behind a lens system in the nose of a fuze. Through a signal-processing circuit, these sensors enable the fuze to locate the target and fire when within lethal range.

Passive, solid-state, IR technology is a major advance in proximity-fuzed projectile antiaircraft effectiveness because of its accurately controlled burst positions and improved reliability. There is no degradation of effectiveness when fired close to the surface of the earth, and it is essentially immune to countermeasures when used in the antiaircraft role. This immunity is sufficient reason to supplement RF proximity fuzes with the EO system.

The design of an EO system for a passive IR proximity fuze is determined primarily by considerations of the expected spectral character of the target and its background radiation. The fuze should be capable of discriminating between these two radiating sources.

The optical system of a typical fuze consists essentially of three parts: (1) a band-pass filter (synthetic sapphire with an optical filter on the back side and an optical absorption filter deposited on the front side) for isolating target energy within the atmosphere absorption band, (2) a thick lens (silicon), and (3) a detector (lead selenide (PbSe), which is optically cemented to the rear surface of the lens).

The detector is made up of four 50-deg annular sectors connected electrically to form a bridge. The lens-detector system is designed so that the field of view seen by the four segments of the detector is composed of four sections of a cone whose half-apex angle corresponds to the desired look angle. The electrical signal generated by the detector then consists of a series of 50-deg pulses or 55% duty cycle caused by the rotation of the projectile. The detector functions as a transducer and converts IR energy into electrical energy. The detector material is chemically deposited PbSe operating at ambient temperatures. PbSe is a photoconductive material, and when IR energy is focused on the PbSe, the electrical resistance of the detector decreases. Since the detonator is in a bridge configuration, any change in the resistance of one detector leg causes an unbalance in the dc voltage divider action of the bridge. This change occurs rapidly enough to allow the signal to be capacitively coupled to the preamplifier stage.

Fig. 3-9 shows a block diagram of the signal processing circuitry and a schematic diagram of the firing circuits. The amplifier is one-half of an integrated circuit operational amplifier (OpAmp), which has a differential input that sums the detector output signals. The OpAmp has a single-ended output and a gain of 20. A solid-state coherent detector demodulates the IR detector signals.

This monolithic phase-lock loop (PLL) and detector system exhibits a high degree of frequency selectivity and, due to its coherent nature, offers a higher degree of noise immunity than noncoherent peak detection modulators. The PLL is a frequency feedback system consisting of a phase comparator, a low-pass filter, an error amplifier in the forward path, and a voltage-controlled oscillator (VCO) in the feedback path.

Whenever the two inputs to the phase detector are synchronized, there is an output signal from the phase detector. This output is filtered by the envelope detector and integrator and eventually reaches a threshold level that operates a comparator circuit. The step function output of the comparator provides the trigger pulse for the gate of the silicon-controlled rectifier (SCR). A schematic diagram of the firing circuits is shown in Fig. 3-9(B).

The described IR sensing and signal processing technology is that used in the Navy's MARK 404 passive IR proximity fuze (Ref. 8).

3-2.7 MILLIMETER WAVE (mmw)

Recent advances in solid-state circuitry have made working at millimeter wave (mmw) frequencies practical. The mmw range has been defined as 40 to 300 GHz (Ref. 9). Other terminology includes "near-millimeter waves" for frequencies from approximately 100 to 1000 GHz and "submillimeter waves" from about 150 to 3000 GHz.

The use of these higher frequencies has a favorable potential for fuzing in the following areas:

1. *Antenna Performance*. Narrower bandwidths and higher attainable gain for a given aperture will reduce multipath effects.
2. *Electronic Countermeasures (ECM)*. High free space attenuation means low vulnerability to ECM and extremely low side lobe detectability.
3. *Fog, Cloud, Rain, and Snow Immunity*. Low-loss atmospheric propagation characteristics of millimeter waves, as shown in Fig. 3-10, enhance immunity to obscurants.
4. *Size and Weight*. Components scale with wavelength, thus reducing packaging volume and weight.

The recent advances in technology are attributable to the availability of solid-state components of higher power and frequency. The development of injection-locked impact avalanche and transit time (IMPATT) amplifiers, frequency-doubled microwave (Gunn) oscillators, and frequency-stabilized or phase-locked sources has permitted advances in fuzing performance against new threats, such as supersonic and low over-the-terrain or -water missile targets, as well as increased immunity to ECM and obscurants (Ref. 10).

3-2.8 CAPACITIVE SENSING

The XM588 fuze, shown in Fig. 3-11, was designed as a low-cost proximity fuze with near-surface-burst (NSB) capability. It is capable of sensing nonmetallic surfaces and is intended for use with 81-mm mortar projectiles. The system has a very limited sphere of influence, which results in a high resistance to ECM.

The capacitive method increases round effectiveness by avoiding the smothering effects experienced when rounds with PD fuzes are fired into soft terrains, such as marsh grass, thick shrubbery, and snow. Detonation occurs approximately 50 mm (2 in.) before contact with most terrains. Over clear terrains—such as mud, water, or dirt—a lesser but positive improvement is obtained with the NSB fuze. Similar performance occurs at all approach angles including graze. In marsh grass 2 m (7 ft) tall, lethal areas approximately three times greater than for ground bursts are

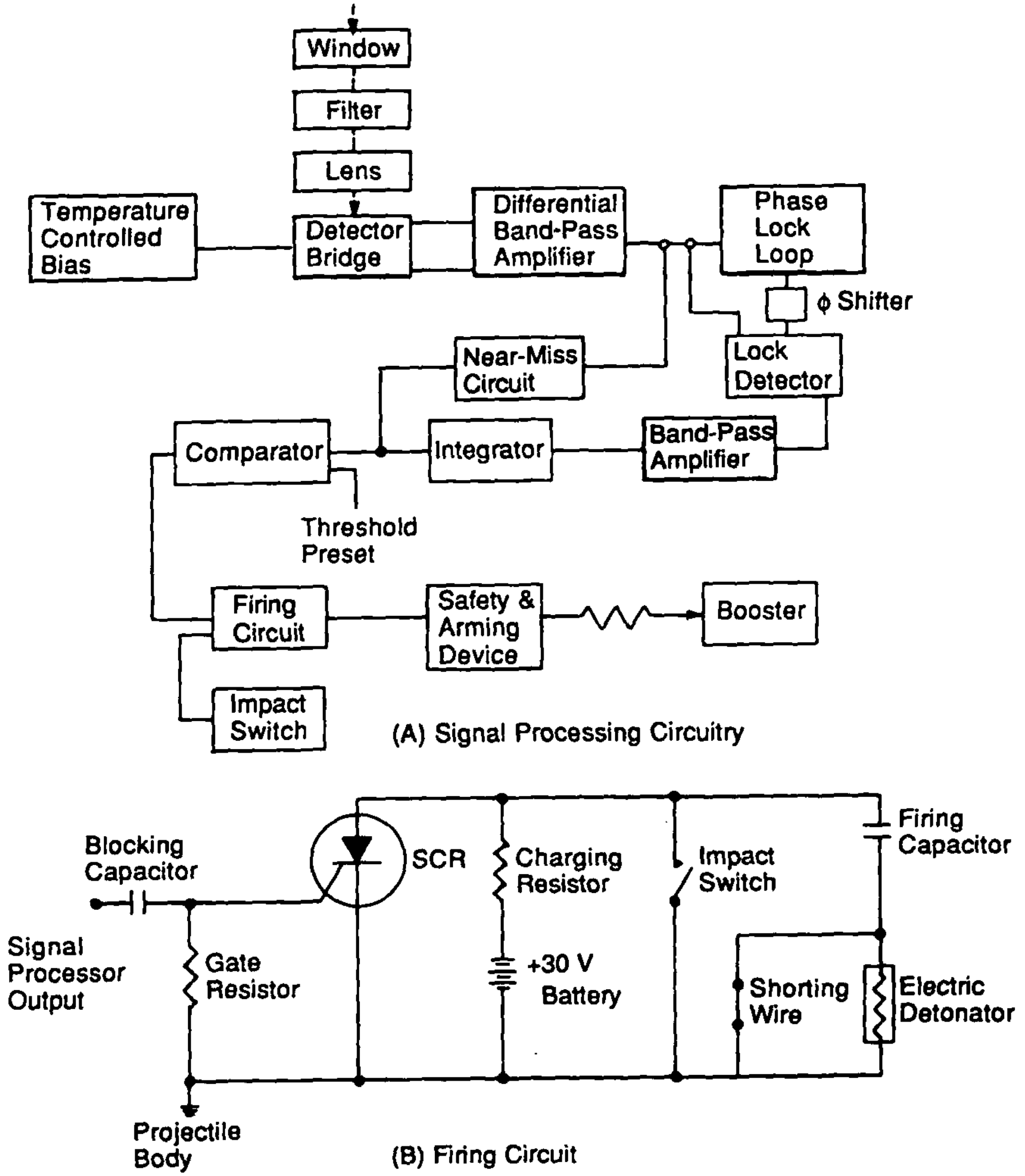


Figure 3-9. Schematic Diagrams of Signal Processing and Firing Circuitry of MK 404 Fuze

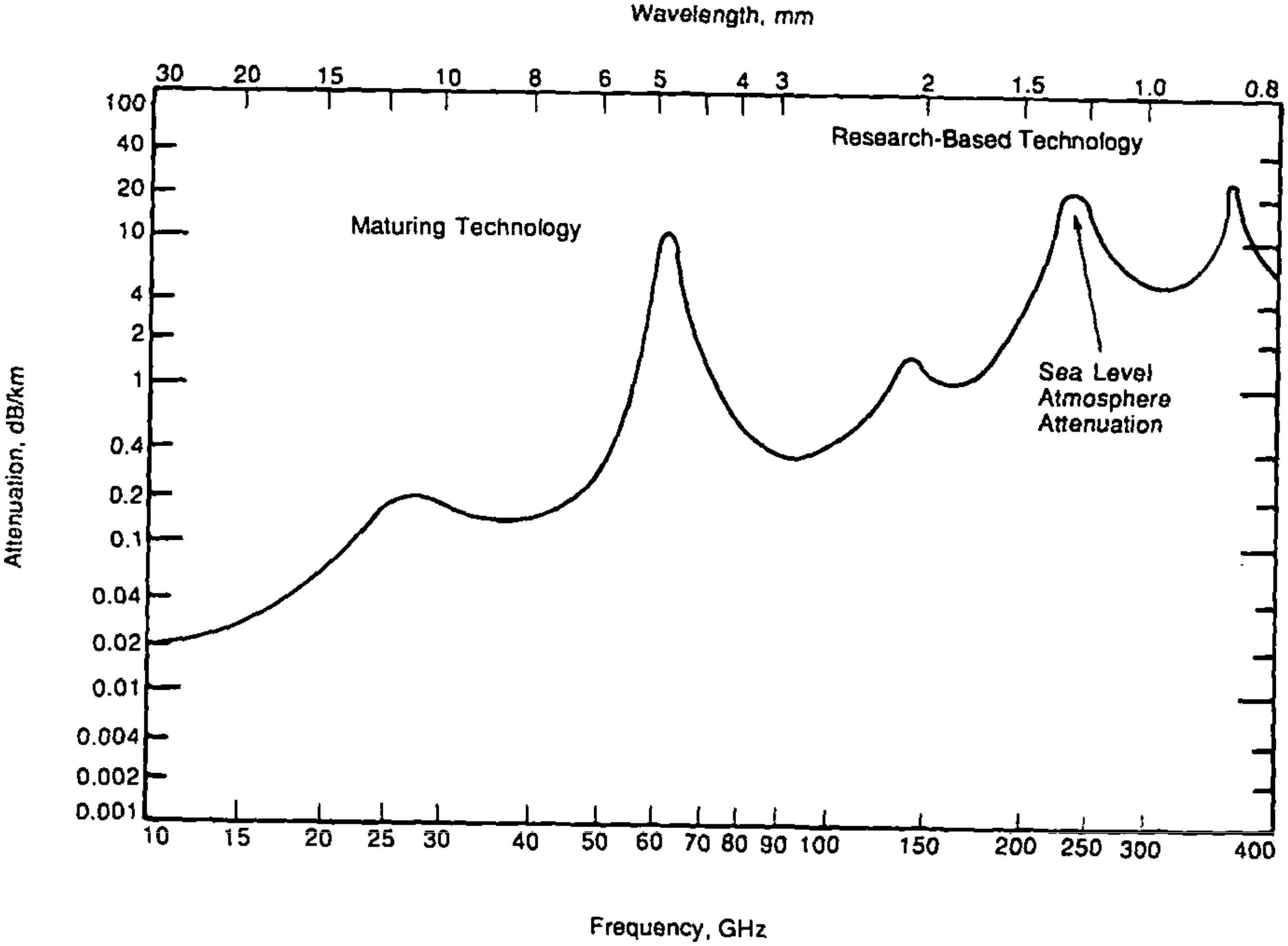


Figure 3-10. Atmosphere Attenuation Windows

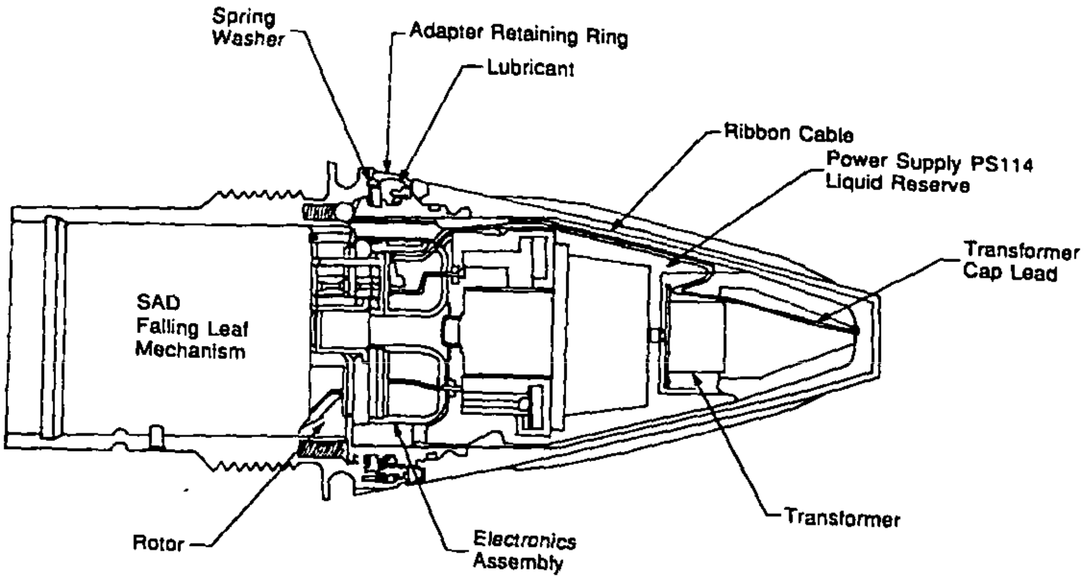


Figure 3-11. Fuze, XM588, Proximity

predicted for the NSB against standing or prone troops, and lethal areas eight to thirteen times greater are predicted against troops in foxholes.

This capacitance fuze contains a dc-to-dc converter and a single integrated circuit (IC). The IC consists of an oscillator, a receiver, a firing circuit, a temperature compensator, and a voltage regulator. The power supply is a single-cell, liquid-reserve battery. There is an oscillator cap electrode and an electric field shield. The oscillator consists of a transformer that, in conjunction with the transistors on the IC, provides not only the required electromagnetic field but also the required voltages for the receiver and firing circuits.

The oscillator and receiver, each of which has a very limited sphere of electrical influence, are separated by a shield that reduces the free space capacitive coupling and thereby increases fuze sensitivity. The oscillator is connected to the nose cap electrode, and the receiver input is electrically connected to the fuze sleeve and projectile body. The shield acts as a battery common ground and ground reference for all of the electronic circuitry. The dc-to-dc converter furnishes 14 V to the firing circuit and 7 V to the detector circuitry, as shown in Fig. 3-12.

When the projectile approaches any object, the amount of capacitive coupling between the caps and the receiver electrodes (projectile body) is increased. This stronger signal initiates the firing circuit. The voltage versus standoff is dependent on the target dielectric constant and ground cover density. All measured target types (clear ground to dense cover) produce signals from 6 to 50 mm (0.25 to 2 in.) from nose contact.

Discriminatory circuitry in the receiver assures that the firing signal must have a rate of rise compatible with the approach velocities of the 81-mm mortar shell. Additional circuitry prevents a firing signal until the voltage of the firing capacitor has reached a predetermined level. This prevents firing before the first 6 s of flight time.

3-2.9 SEISMIC SENSING

This mode of sensing can be employed to respond to earth vibrations caused by vehicular traffic. Sensitivity requirements for antipersonnel applications are probably such as to invite premature detonation from other vibrations, such as exploding projectiles. This would be a convenient means of nullifying the minefield based on this type of sensor.

One design consideration would be to build in sufficient intelligence to determine when a vehicle is at an optimum position relative to the mine. This would prevent distant vehicles from triggering the system. Use of a trembler switch would necessitate a battery power source, but the use of a piezoelectric system would eliminate this requirement. The piezoelectric system can fire the mine or alert a locating radar that triggers the mine at the optimum time. These devices offer the additional advantage of the ability to discriminate between a spurious signal and a proper vehicular signal.

Presently, emphasis is being placed on the piezoelectric method; however, it is currently not in use.

3-2.10 ACOUSTIC SENSING

Acoustic sensing is being employed in the development of Mine, AT, XM84, an off-route land mine system designed as a hand-emplaced antivehicular mine. The acoustic sensing system alerts (turns on) a search radar acquisition and firing circuit. The radar determines when the target is in an optimum position relative to the mine. There is also a variant system that uses IR acquisition.

The acoustic sensor must be able to distinguish between a nearby projectile burst and the vehicle noise signature, or it must alert the radar at each significant noise level and rely on the radar to reset the system if the search does not disclose a vehicle.

3-2.11 PRESSURE SENSING

This basic method of target sensing is the oldest used in firing land mines and booby traps. It is simply a convenient method of triggering an explosive charge by the application of weight. A great advantage is gained in that the target is in an optimum, or near optimum, position to realize maximum damage effects.

The antivehicular mine responds to a triggering force of 890 to 3335 N (200 to 750 lb), which provides some selection of targets. The antipersonnel mine is usually set for 111 N (25 lb).

The usual firing mechanism employs a stab firing pin held safe by a Belleville spring, which is forced over dead center for rapid motion to drive the firing pin into the detonator. Par. 12-2.2 illustrates the action of a Belleville spring and presents the design equations. Fig. 3-13 shows a pressure-sensing mechanism in the form of a fuze incorporating the Belleville spring.

3-3 MECHANICAL FUZE INITIATION

3-3.1 THE INITIATION MECHANISM

After the fuze receives information that it should start target action, a number of complex mechanisms may be put into operation. The necessary power to operate the fuze must be made available immediately. This power must then activate any time delays or other necessary features prior to initiation of the first element of the explosive train.

In a mechanical fuze, contact sensing (impact) or presetting (time) is converted directly into the mechanical movement of a firing pin, which in turn is driven either into or against the first element of the explosive train. Functioning delays can be obtained by inertia (See par. 3-2.1.3.1 for further discussion.) or by pyrotechnic devices, which are an integral part of the explosive train. (See par. 4-4.1 for further discussion.)

The simplest means of initiation is to use the forces of impact to crush the nose of the fuze and thereby force the pin into the primer. In a base fuze the pin or primer may move forward when relative changes in velocity occur. Springs are also used to provide relative motion between pin and primer, typically in time fuzes for which inertial forces from impact are not available.

Firing pins for stab initiation are different from those for percussion initiation, as explained in the paragraphs that follow. Typical firing pins are shown in Fig. 3-14. Initiation by adiabatic compression of air does not require a firing pin at all. (See Fig. 3-15.)

3-3.2 METHODS OF INITIATION

3-3.2.1 Initiation by Stab

When a firing pin punctures the disc or case of the sensitive end of a primer or detonator, its kinetic energy is

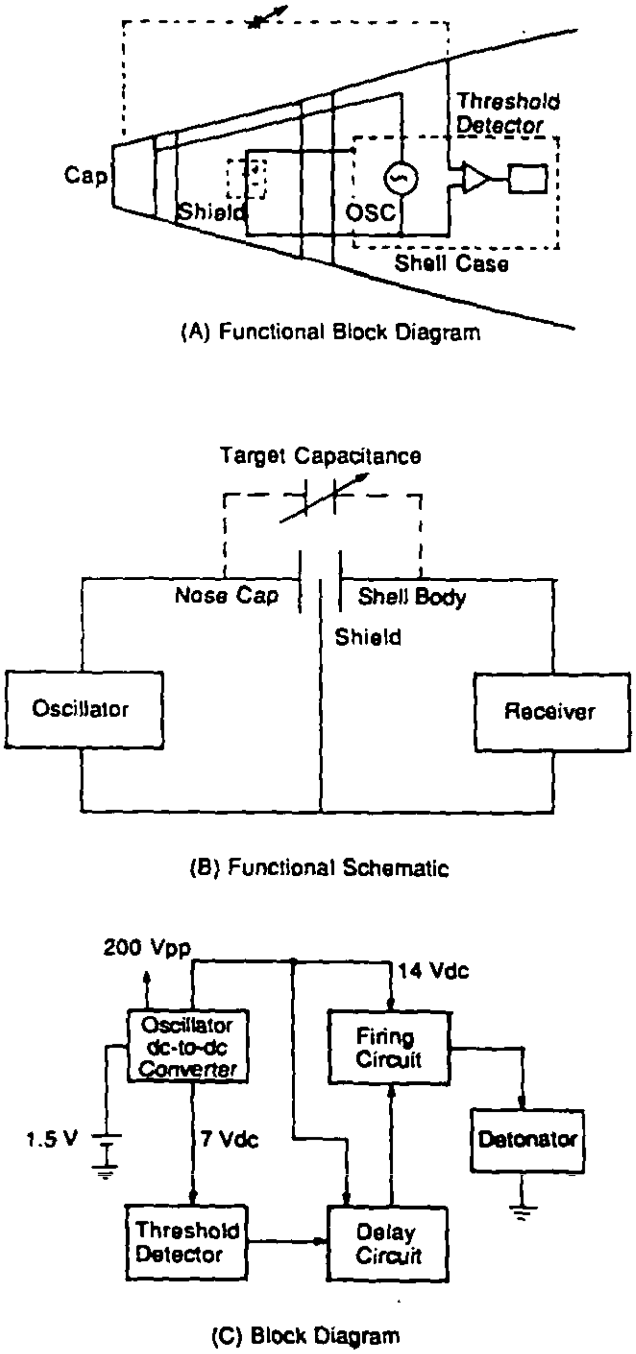


Figure 3-12. Schematics of Circuitry of Fuze XM588

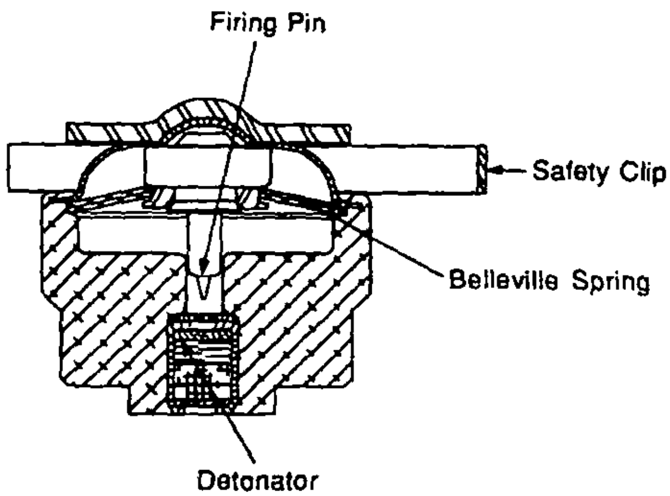


Figure 3-13. Pressure-Sensing Mechanism

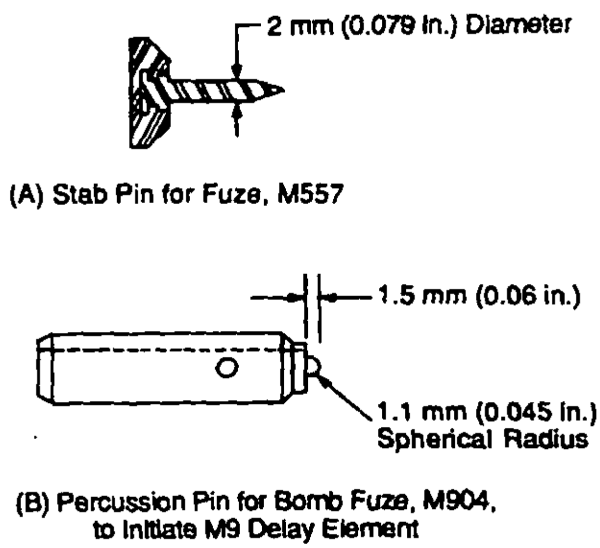
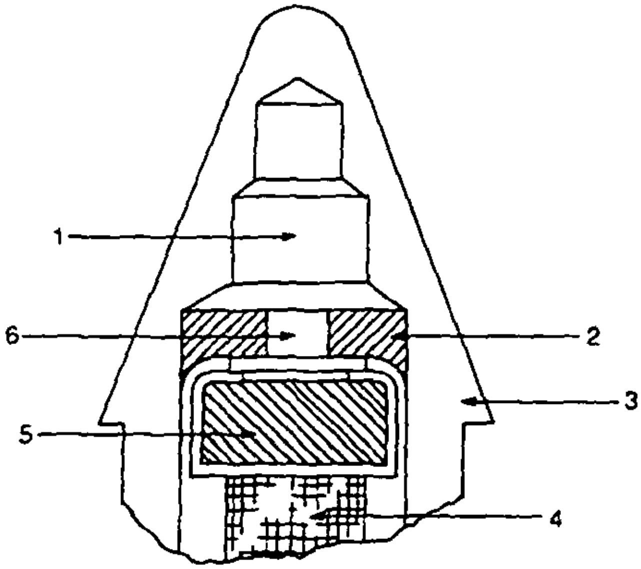
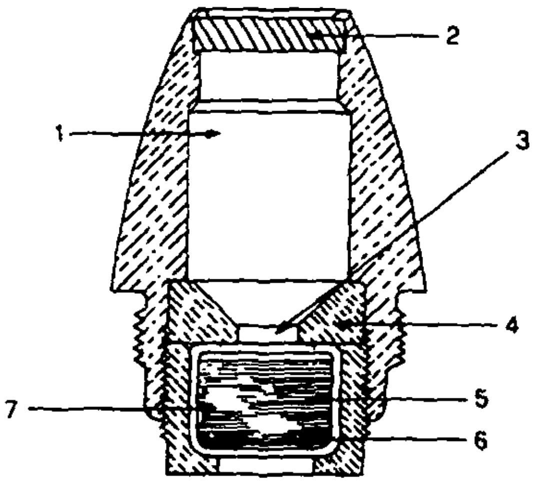


Figure 3-14. Typical Firing Pins



(A) Fuze, PD, M75

1 *Air Column*
2 Aluminum Washer
3 Fuze Body
4 High-Explosive Booster
5 Detonator
6 Air Passage



(B) Fuze, PD, Mk 26

1 Air Column
2 Heavy Closing Disk
3 Air Passage
4 Funnel Washer
5 Azide
6 Tetryl
7 Detonator

Figure 3-15. Initiation by Adiabatic Compression

dissipated into heat, which ignites the explosive material. (Crushing or cracking crystals of explosive material may also cause initiation.) This process is referred to as "stab initiation". The standard firing pin for stab initiators is a truncated cone, as shown in Fig. 3-16 (Ref. 4). To achieve greater sensitivity, special firing pins with reduced flat diameters have been employed occasionally. Because the firing pin is a critical component of the initiation assembly, it must be tested to verify the reliability of the system. Unless otherwise specified, the standard tip should be used.

Both steel and aluminum alloys are in common use as firing pin materials. Tests indicate a slight sensitivity advantage for steel, but the difference is not sufficient to eliminate use of aluminum alloys or other materials. Alignment of the assembly is critical because misalignment can decrease sensitivity.

In general, the higher the density of the stab-sensitive explosive mix, the greater the sensitivity of the stab initiator. Because the denser explosive offers more resistance to the penetration of the firing pin, the kinetic energy of the moving mass dissipates over a shorter distance. Thus a smaller quantity of explosive is heated to a higher temperature.

3-3.2.2 Initiation by Percussion

As in stab initiation, the function of the firing pin in percussion initiation is to transform kinetic energy into heat. In contrast to the stab initiation process, the firing pin does not puncture the case in percussion initiation. Instead the firing pin dents the case and pinches the explosive between an anvil and the case. This preserves obturation, or sealing, of the explosive element. Energy must be supplied at a rate

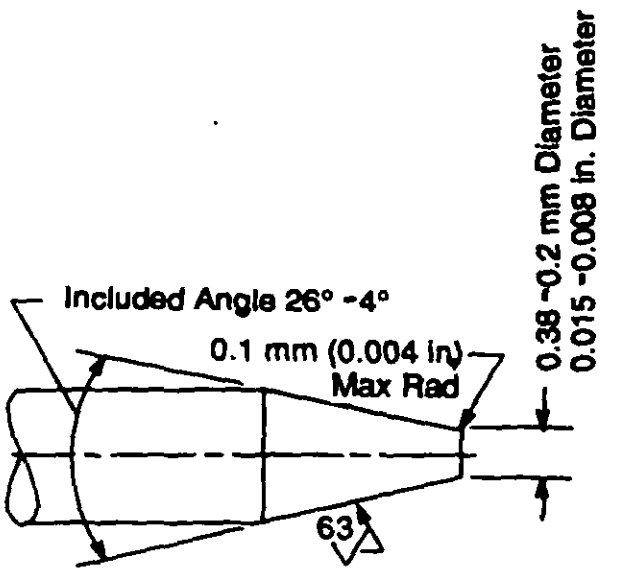


Figure 3-16. Standard Firing Pin for Stab Initiators

sufficient to fracture the granular structure of the explosive. Percussion primers are discussed more fully in par. 4-3.1.2.

Criteria for percussion firing pins have not, as yet, been refined to the same degree as those for stab pins. Studies, however, have been made of the effect of the firing pin contour on the sensitivity of specific primers. It was found that a hemispherical tip provides greater sensitivity than a flat tip and that little effect on primer sensitivity results from changing the tip radius. A full investigation of the sensitivity relationships with respect to cup, anvil, charge, and pin has indicated that sensitivity variations appear to originate in the nature of primer cup collapse rather than in the detonation phenomenon itself.

A study of the effect of firing pin alignment on primer sensitivity indicates that there is little effect if the eccentricity is less than 0.51 mm (0.02 in.). Above this eccentricity, sensitivity decreases rapidly because of anvil construction. Sensitivity also decreases as the rigidity of the primer mounting is decreased.

3-3.2.3 Initiation by Adiabatic Compression and/or Shock

If a column of air in front of an initiator could be compressed rapidly enough, its temperature would rise due to adiabatic compression to a value that could ignite the primary explosive. The force of target impact could be used to crush the nose of a simple fuze; thus an adiabatic compression mechanism would be used. Fig. 3-15(A) illustrates this concept. Undoubtedly, the crushed hot fragments from the nose contribute to the initiation process. Although fuzes using this type of initiation are economical to produce, they are neither as sensitive nor as reliable at low velocities or for thin targets as firing pin mechanisms. Hence this technique is rarely used.

The theory of initiation by adiabatic compression was partially disproved in tests of an early and now obsolete 20-mm fuze design shown in Fig. 3-15(B). When the funneled disk was replaced by a solid disk, initiation of the fuze still occurred. In this case, it was suspected that initiation was caused by shock phenomenon. It is a well-established fact that detonation of even secondary explosives can be effected by a shock wave transmitted across a barrier. This technique is known as through-bulkhead initiation (Ref. 4).

3-3.2.4 Initiation by Friction

The heat generated by friction can be sufficiently high to initiate an explosive reaction. Friction initiation is used in the Firing Device, M2, illustrated in Fig. 3-17, in which a wire coated with a friction composition is pulled through an ignition mix. Because the heating time cannot be closely controlled, friction initiation is used only in firing devices that are not fuzes.

Creation of situations in which explosives are subjected to inadvertent frictional forces should be carefully avoided.

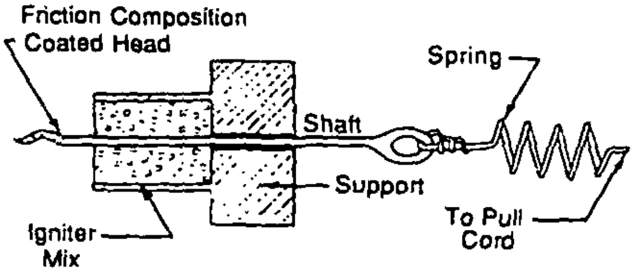


Figure 3-17. Firing Device, M2

Premature detonation has been ascribed to explosive material adrift in projectile fuze threads (Ref. 11).

3-4 ELECTRICAL FUZE INITIATION

Why should the designer use an electric fuze? First, the electric fuze can operate within a few microseconds after target sensing, and the sensing can occur before target contact. Second, the electric fuze can be initiated from remote places. For example, in a point-initiating, base-detonating (PIBD) fuze, sensing occurs in the nose, whereas detonation proceeds from the base of the munition. Third, electric fuzes provide a much higher degree of accuracy for timing functions in time fuzes and for functioning delays after impact. Fourth, the use of electric power sources, electronic logic functions, and electric initiation affords vastly increased versatility in performing both safety and functioning operations.

3-4.1 ELECTRIC FUZE OPERATION

The first step in the operation of electric fuzes is to activate the power source. This is usually accomplished by using the induced environments of launch such as setback or spin, by an electric input to activate a battery, or by using ram air to turn a turbine or activate a fluidic generator. The second step is to perform logic and/or timing functions relative to the arming process and thus ready the fuze for functioning. The third step is to sense the target by impact, proximity, or command. These actions culminate in initiation of the first element of the explosive train at the desired time and place. See Chapter 7, which discusses electric arming.

3-4.2 INITIATION OF THE FIRST EXPLOSIVE ELEMENT

Whereas design details of electrical explosive elements are discussed in par. 4-3.1.4, consideration must be given here to their initiation. Hot bridgewire electric initiators are the simplest and the most widely used as the first element in the explosive train of an electric fuze. MIL-HDBK-777 provides design information on the input and output characteristics of numerous procurement-standard electric initiators that are suitable for use in fuzes. In general, it is desirable to keep the input energy requirements for electric initiators as high as possible, consistent with the power source and other circuitry requirements. This leads to increased safety in handling and loading and to decreased susceptibility to spurious electromagnetic or static electricity environments.

Several other types of initiation mechanisms are commonly employed, namely, conductive mix, graphite bridge, spark gap, exploding bridgewire (EBW), and exploding foil initiator (EFI). The two latter mechanisms are used in uninterrupted explosive trains. See pars. 4-3.1.4 and 4-3.1.5.

After deciding upon a suitable power source, the designer must first ascertain what fraction of its energy can be used to fire the electric initiator. Then the designer must choose an initiator that can be initiated reliably when the minimum available energy is applied and that has an output consistent with reliable initiation of the next element in the explosive train.

3-5 SELF-CONTAINED ELECTRICAL POWER SOURCES

A major class of ammunition fuzes requires electrical power for the functioning of electronic components and/or the initiation of electroexplosive devices (EED). In some applications the electrical power can be provided on the launch platform prior to or during launching of the munition and used to charge a capacitor or initiate a battery within the fuze. These types of fuzes are discussed in Chapter 1.

In the majority of Army ammunition fuze applications, considerations of nonavailability, safety, and/or fuze power requirements preclude the use of external power sources. Thus it is necessary to employ an electrical power source within the munition. For some munitions, such as large guided missiles, the electrical power for the fuze may be available from the on-board power sources used for guidance and control functions. When other electrical power sources are not present or are not suitable for fuze use, however, a self-contained power source within the fuze is required. The process used to determine the characteristics of a power source needed for a fuzing application involves consideration of

1. Voltage limits as needed for current or resistance requirements
2. Activation time and discharge life
3. Storage and operating temperature limits
4. Size and weight limits
5. Factory-to-function environmental sequence.

3-5.1 ELECTROCHEMICAL POWER SOURCES (BATTERIES)

The most widely used self-contained electrical power sources in Army fuzes are electrochemical devices (batteries). Batteries used in this application are defined in three classes—reserve, primary, or secondary—with various types within each class. Table 3-1 lists the classes and types used in fuzes and their areas of application.

3-5.1.1 Liquid Reserve Batteries

The most prevalent type of projectile fuze power supply is the liquid reserve battery, which is also referred to as a "reserve energizer" (Ref. 11). In this device the electrolyte is packaged in an ampoule within the battery. Upon launching of the projectile, the ampoule is crushed or punctured, and the electrolyte released for distribution into the cells between the electrodes. Breaking of the ampoule is usually the result of the setback force or, occasionally, the initiation of a small explosive charge. Generally the electrolyte is distributed centrifugally as a consequence of projectile spin, but in some instances, distribution is accomplished by gas pressure from an explosively initiated gas generator.

The most common chemical systems used in modern liquid reserve batteries are

1. Lead/fluoroboric acid/lead dioxide
2. Zinc/potassium hydroxide/silver oxide
3. Lithium/thionyl chloride/carbon
4. Lithium/lithium hexafluoroarsenate-methyl formate/vanadium pentoxide.

Although chemical Systems 3 and 4 are listed in Table 3-1 as primary, they can also be used as reserve batteries.

A typical spin-dependent reserve battery is shown in Fig. 3-18. The electrode stack is arranged in a series configuration so that the voltage output of the stack is the cell voltage (1.0 to 1.5 V) multiplied by the number of cells. A copper ampoule is located in the center of the stack and contains the electrolyte. The ampoule-cutting mechanism is a dashpot arrangement that is capable of discriminating between the forces of firing setback and those of rough handling.

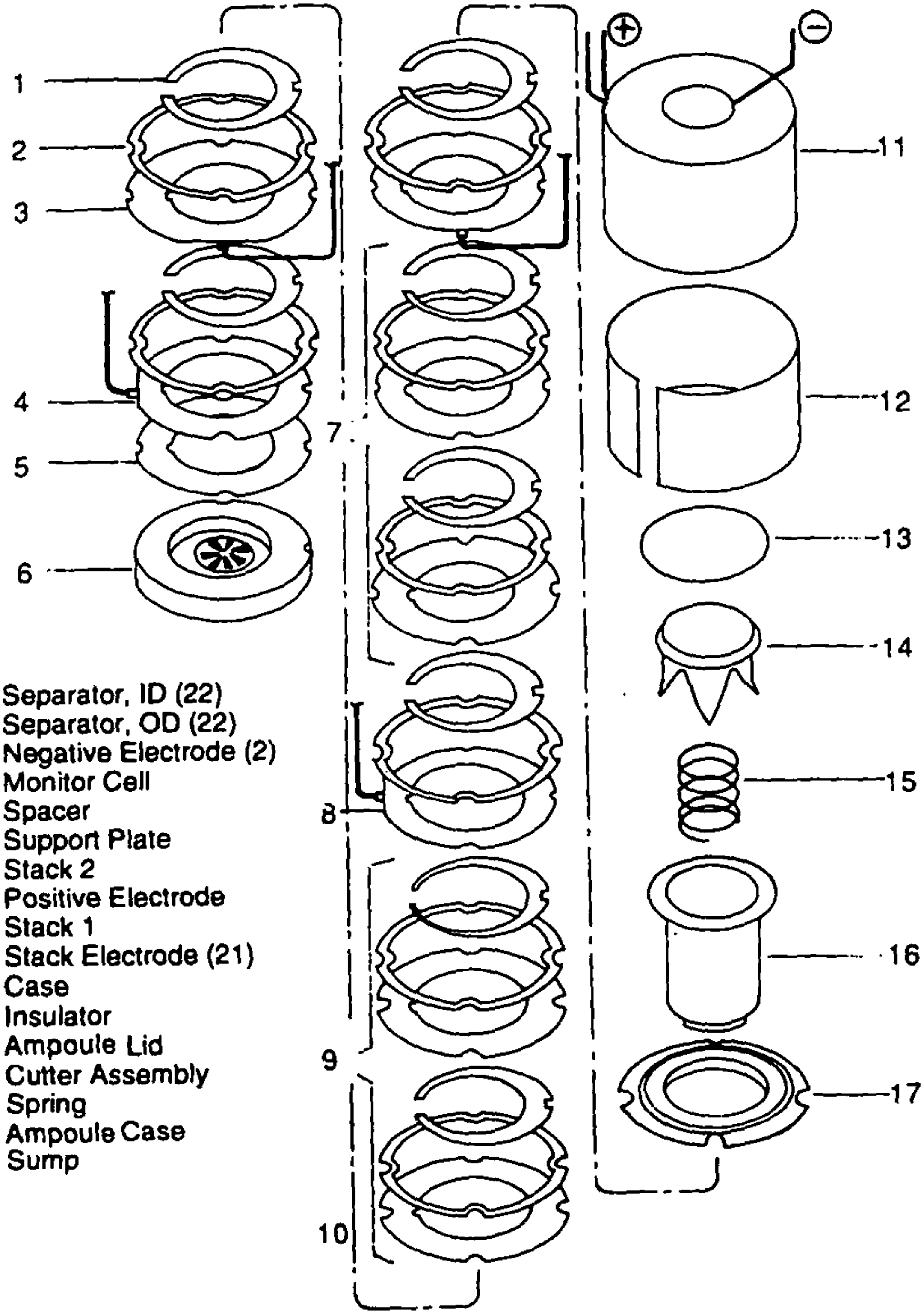
Liquid reserve batteries of the lead/fluoroboric acid type generally are limited to short-time applications not exceeding three minutes. Table 3-1 provides some of the other operating characteristics.

The advent of the new family of scatterable mines generated a requirement for a liquid reserve battery with a considerably longer life. This challenge was met by the development of a lithium anode liquid reserve battery, shown in Fig. 3-19. The cell incorporates an absorbing separator between the electrodes, which enables retention of the thionyl chloride electrolyte within the cell. This design feature and the long wet-stand capability of the lithium-base electrolyte allowed development of reserve batteries with acceptable performances. Prior to this, liquid ammonia batteries with a two-week active life were used; however, they had a much lower current density and problems in long-term storage. The discharge curves for a lithium/thionyl chloride liquid reserve battery at a current density of 50 mA/cm^2 (323 $mA/in.^2$) are shown in Fig. 3-20.

TABLE 3-1. FUZE BATTERY SYSTEM CHARACTERISTICS

CLASS	TYPE	SYSTEM			NOMINAL VOLTAGE, V	ENERGY DENSITY, W·h/kg	DISCHARGE LIFE	APPLICATIONS	STATUS/REMARKS
		ANODE	ELECTROLYTE	CATHODE					
Reserve	Liquid	Pb	HBF_4	PbO_2	2.0	80	<5 mon	Gun and spin projectiles	Primary Army/Navy fuze PS*
		Li	$SOCl_2$	C	3.5	150	~1 h	Spin projectiles and land mines	In development
		Zn	KOH	AgO	1.6	90	1-3 d	Scatterable land mines	Developed
	Thermal	Ca	$LiKCl_2$	$CaCrO_4$	2.6	10-30	~10 mon	Military ordnance	Obsolete
		Mg	$LiKCl_2$	V_2O_5	2.7	10	~5 mon	Military ordnance	Obsolete
		Li	$LiKCl_2$	FeS_2	2.1	29-75	<1 h	Military ordnance	In production
Primary	Long Life	Zn	KOH	Ag_2O	1.4	90	1-3 yr	Moderate ED** and life	In production
		Cd	KOH	HgO	0.8	100	1-3 yr	Moderate ED and life	In production
		Mg	KOH	MnO_2	2.5	150	1-3 yr	Moderate ED and life	In production
		Li	SO_2	C	2.9	280	2-5 yr	High ED and life	In production
		Li	$SOCl_2$	C	3.6	300	2-5 yr	High ED and life	In production
		Li	$LiClO_4$	$(CF)_x$	2.8	200	2-5 yr	High ED and life	In production
		Li	$LiClO_4$	CuS	2.1	135	2-5 yr	High ED and life	In production
		Li	$LiAsF_6$	V_2O_5	3.5	270	2-5 yr	High ED and life	In production
	Solid	Li	LiI	I_2	2.8	250	10 yr	Long-life heart pacers	In production
Secondary	–	See Long-Life Primary			–	–	–	Mostly commercial	Not used in fuzes

*PS = power source
**ED = energy density



1 Separator, ID (22)
2 Separator, OD (22)
3 Negative Electrode (2)
4 Monitor Cell
5 Spacer
6 Support Plate
7 Stack 2
8 Positive Electrode
9 Stack 1
10 Stack Electrode (21)
11 Case
12 Insulator
13 Ampoule Lid
14 Cutter Assembly
15 Spring
16 Ampoule Case
17 Sump

Figure 3-18. Spin-Dependent Reserve Battery, PS 416

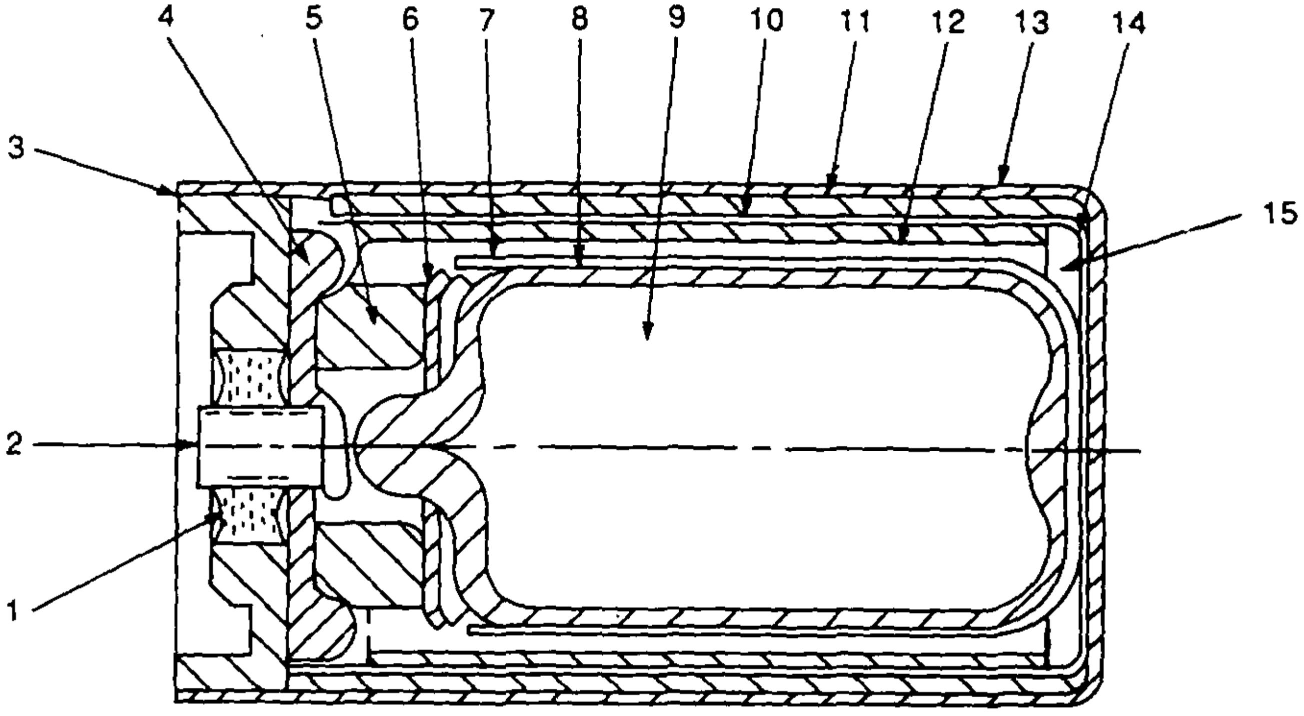


Figure 3-19. Lithium/Thionyl Chloride Reserve Cell

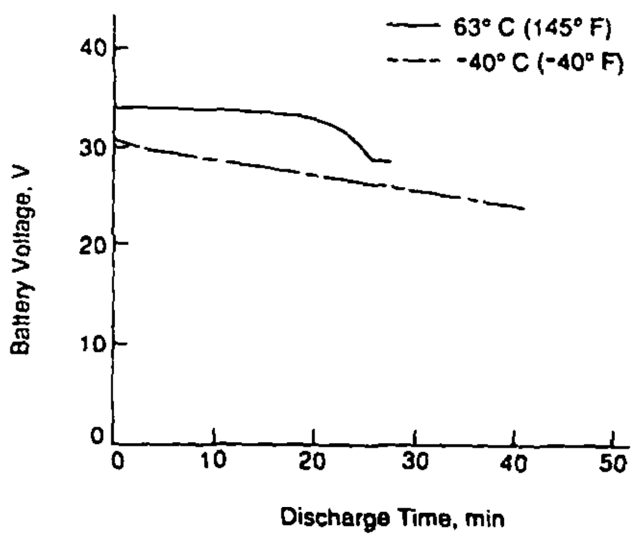


Figure 3-20. Discharge Curve of a Lithium/Thionyl Chloride Reserve Battery

3-5.1.2 Thermal Batteries

Thermal batteries were developed specifically for use in ordnance systems in which spin forces are not available to distribute the electrolyte (Ref. 11). In this type of battery the electrolyte is placed between the electrodes when the battery is built and is a solid under storage conditions. Upon launch of the ordnance, a pyrotechnic chemical distributed within the battery is ignited, causing the initially solid electrolyte to melt and become conductive.

Three component compositions have been employed in thermal batteries:

1. Magnesium/potassium chloride-lithium chloride/silver
2. Calcium/potassium chloride-lithium chloride/calcium chromate
3. Lithium/potassium chloride-lithium chloride/iron.

Anodes for thermal batteries may be simply punched from rolled stock of the desired metal. For calcium anodes, rolled sheet may be pressed and staked against an iron substrate with a grate configuration, or the metal may be vacuum deposited directly onto an iron or nickel-plated sheet. The approaches to the use of lithium are many. Lithium may be impregnated into a porous metal matrix, or it may be mixed with powdered metals, such as iron, and pelletized or rolled together.

Cathodic materials in powder form may be distributed in the electrolyte to make a homogeneous pellet of electrolyte, binder, and cathode. The cathode material ultimately is discharged, or reduced, on the surface of a metallic cathode collector.

Two forms of pyrotechnic materials generally are employed in thermal batteries. One consists of a mixture of zirconium powder and barium chromate, or other chromates, fabricated into a "heat paper" from a water slurry that also contains fibers of glass, asbestos, or other refractories. "Heat paper" is readily ignited and burns with a very hot flame. The other is a pellet pressed from a mixture of iron powder and potassium perchlorate. Layers of pyrotechnic material, in either paper or pellet form, are interspersed between cells to provide a uniform distribution of heat upon battery initiation. The pyrotechnic material can be ignited by an electric match, by percussion, or by friction primers. The choice is dictated by the characteristics of the munition.

Because a thermal battery can function only as long as the electrolyte remains molten and conductive, it has been necessary to wrap the battery stack with insulating material to keep it from cooling prematurely. Asbestos, insulating fibers, and asbestos-substitute insulating materials are generally used. Work is ongoing on room temperature thermal batteries; however, none are currently in production.

Recent advances in thermal battery technology have shown that these batteries can function in high axial spin environments. This feature, combined with the other advantages of thermal batteries, makes them a primary candidate for future projectile fuze applications in which long life, high-power density, ruggedness, and high reliability are paramount. Fig. 3-21 shows an exploded view of a modern thermal battery, and Fig. 3-22 shows typical axial spin performance curves.

3-5.1.3 Long-Lived Active Batteries

Active batteries have been considered for ammunition fuzes since World War II, but their limited shelf life and active power hazard have limited their use in these applications. During the past decade, significant improvement has been achieved in the shelf life of some of the more promising active systems, i.e.,

Anode	Electrolyte	Cathode
zinc	KOH	silver oxide (primary)
cadmium	KOH	mercuric oxide
magnesium	KOH	manganese dioxide

and particularly, the following lithium batteries:

Anode	Electrolyte	Cathode
lithium	sulfur dioxide	carbon (C)
lithium	thionyl chlride	carbon (C)
lithium	sulfuryl chloride	carbon (C)
lithium	lithium perchlorate	carbon monofluoride $(CF)_x$
lithium	lithium perchlorate	copper sulfide (CuS)
lithium	lithium perchlorate	copper oxide (CO)
lithium	lithium hexaarsentate	vandium pentoxide (V_2O_5).

The lithium anode batteries, because of their high-energy density and long shelf life (> 5 yr in the reserve mode), have recently been reviewed for use in fuze applications. Table 3-1 is not all-inclusive but does compare the performance characteristics of the most promising systems. Their high-energy capabilities, however, can cause a corresponding decrease in safety, especially when the low-melting—186°C (367°F)—lithium anode is combined with sulfur chloride, thionyl chloride, and sulfuryl chloride cathodes. Too often, these batteries have vented, ruptured, and even exploded when discharged under low-impedance loads (external or internal) or they have overheated (as in a fire). Some reduction in hazards can be obtained by using pressure-release vents, thermal disconnect switches, electrical fuses, and other safety measures. The improvements in safety, however, often do not meet weapon needs but do result in reduced reliability.

3-5.1.4 Solid Electrolyte Batteries

Two types of the solid electrolyte battery have been considered for weapon use, i.e.,

1. Those employing silver anodes, modified silver iodide as the electrolyte, and metallic or organic iodides or iodine-bearing complexes as cathodes
2. Those employing lithium anodes, lithium iodide as the electrolyte, and iodine-bearing compounds or complexes as cathodes.

The silver types have the advantage of relatively high-electrolyte conductivities and, therefore, reasonably high current capability. They tend, however, to degrade in high-temperature storage and inherently yield low per-cell potentials, i.e., 0.6 V. Conversely, the lithium-type cells produce as much as 2.8 V, but the low conductivity of lithium iodide restricts their current output to the microampere range, particularly at low temperatures.

3-5.1.5 Secondary (Rechargeable) Batteries

Rechargeable batteries have no application in current fuzing systems. Access to the batteries and their incompatibility with the rapid firing requirements of battlefield conditions are the principal reasons for their lack of acceptance. Recently a new concept has emerged that has considerable appeal. The concept involves the use of rapidly charged secondary batteries for canister-dispensed submunitions. These batteries would be charged in flight or prior to launch

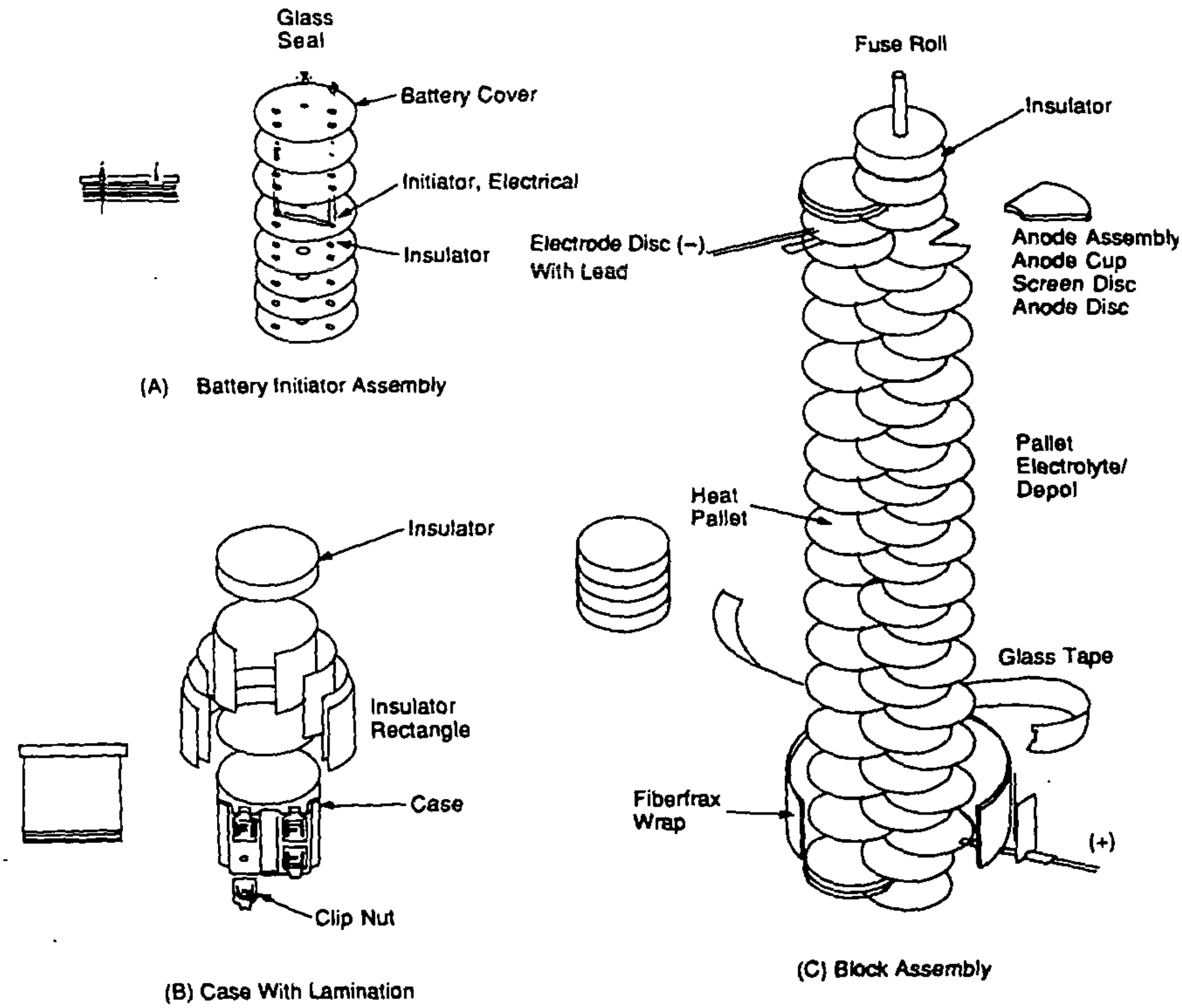


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Figure 3-21. Generic Thermal Battery

from a master power source. The chemical system proposed employs (1) zinc and silver chloride electrodes and (2) an aqueous or alcoholic solution of zinc chloride as the electrolyte. Preliminary effort has demonstrated the characteristics that follow:

1. Small size—approximately 9.5 mm (0.375 in.) in diameter by 9.5 mm (0.375 in.) in height
2. Low unit cost—in sufficiently automated production
3. Fast charging—10 to 20 s depending on power requirements
4. Typical power—15 V and 20 mA.

3-5.2 ELECTROMECHANICAL POWER SOURCES

Electromechanical power sources are becoming more prevalent in fuzing applications. They possess a number of advantages over electrochemical power sources particularly in the areas of cost, shelf life, testability, and the ability of the wind-driven types to provide an arming force based on an environmental stimulus. Electromechanical power sources are generally of two classes, i.e., wind-driven generators and pulse-driven generators. Wind-driven generators are of two types, i.e., turboalternators and fluidic generators. These devices develop power as a result of their response to ram air pressure. The two types of pulse generators most commonly used in fuzing are piezoelectric transducers and electromagnetic generators. These devices develop power as a result of setback or impact.

The characteristics, advantages, disadvantages, and areas of application of each of the types of electromechanical power sources are discussed in the paragraphs that follow.

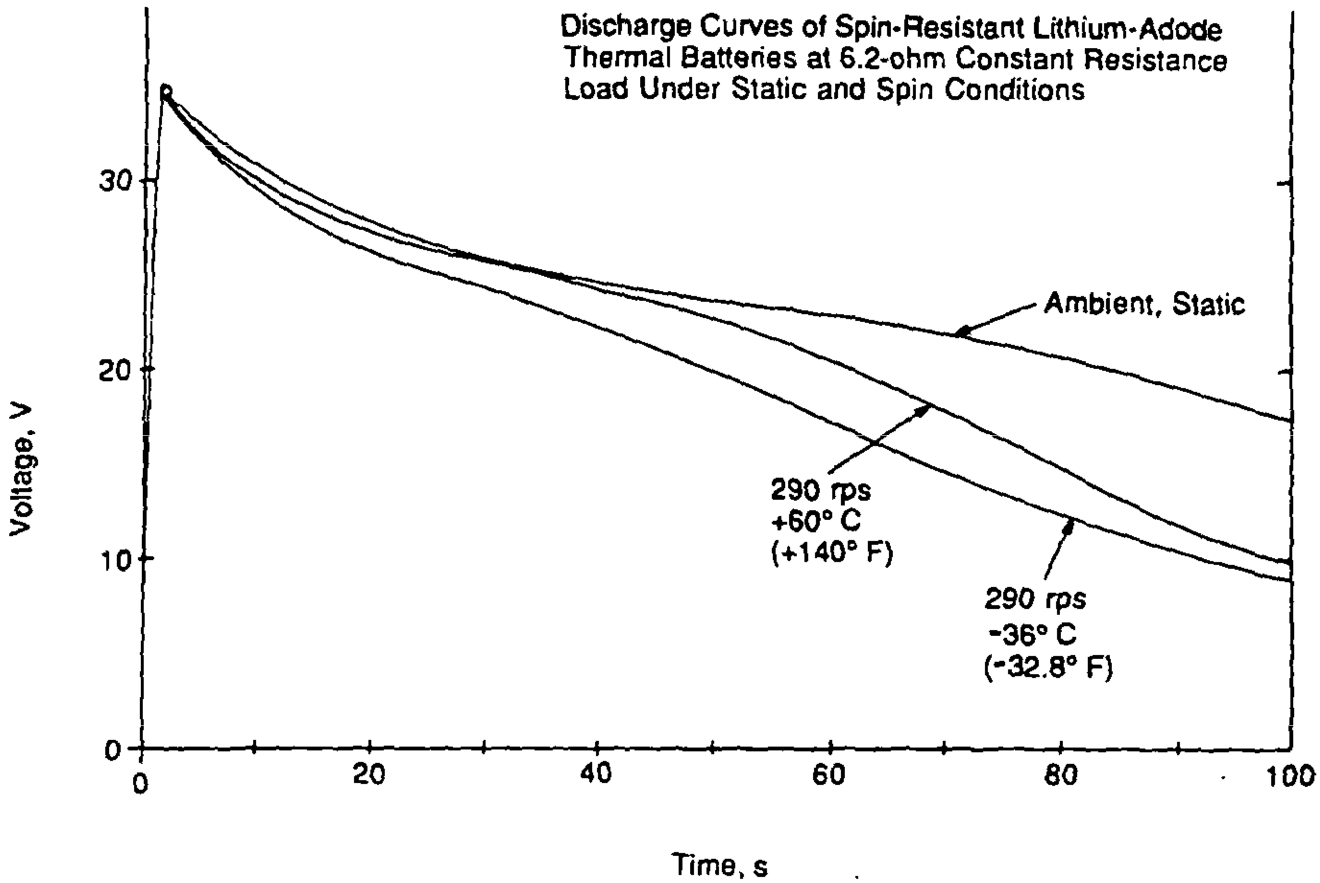

Figure 3-22. Discharge Curve of a Spin-Resistant Lithium-Anode Thermal Battery

3-5.2.1 Turboalternators

One of the most innovative designs to occur in fuze power sources is the reintroduction of the wind-driven turboalternator, which is vastly improved over the older types of such devices. It has the following advantages over electrochemical power sources (Ref. 12):

1. Almost limitless shelf life
2. Simple technology
3. Low cost
4. Nondestructive testability
5. Second environmental arming signature for nonspin munitions, such as mortars, rockets, and bombs.

The key elements of the turboalternator are a turbine, a permanent magnet mounted on a shaft, two bearings, a coil assembly, and a stator-housing assembly, as shown in Fig. 3-23. In order to reduce bearing wear and to preclude centrifugal damage to the rotating magnet, the molded nylon vane has undercut blade tips, which can flex radially under the influence of centrifugal force. This flexing reduces the turbine speed by reducing the turning angle of the air passing through the blade channels. The kinetic energy of the air is converted to mechanical rotational energy and causes the rotor to rotate between the poles of a magnetic stator, thus inducing an electromotive force (emf) in the armature windings. The output of the shaft also can be used to perform mechanical arming functions.

The magnetic rotor is sintered Alnico, magnetized to have six poles. For every 120 deg of rotation, the induced emf completes one electrical cycle as shown in Fig. 3-24. A low-cost bearing consisting of tiny balls captured in a stamped retainer serves as the outer race; the inner race is provided by a controlled surface on the shaft. The coil assembly consists of a nylon bobbin with tabs that align the stator pole pieces. The resistivity and number of turns of wire are tailored to match the impedance of the electrical circuit of the fuze.

The stator-housing assembly is stamped from sheet permalloy into a can and matching end plate, each with three integral pole pieces spaced 120 deg between their centers. When the two parts are assembled, the separation between centers of any two adjacent poles is 60 deg.

Performance characteristics of a turboalternator are given in Fig. 3-25, which shows the electrical power output and shaft rotational speed of the reduced-cost alternator over the velocity range of the 60-mm lightweight company mortar system.

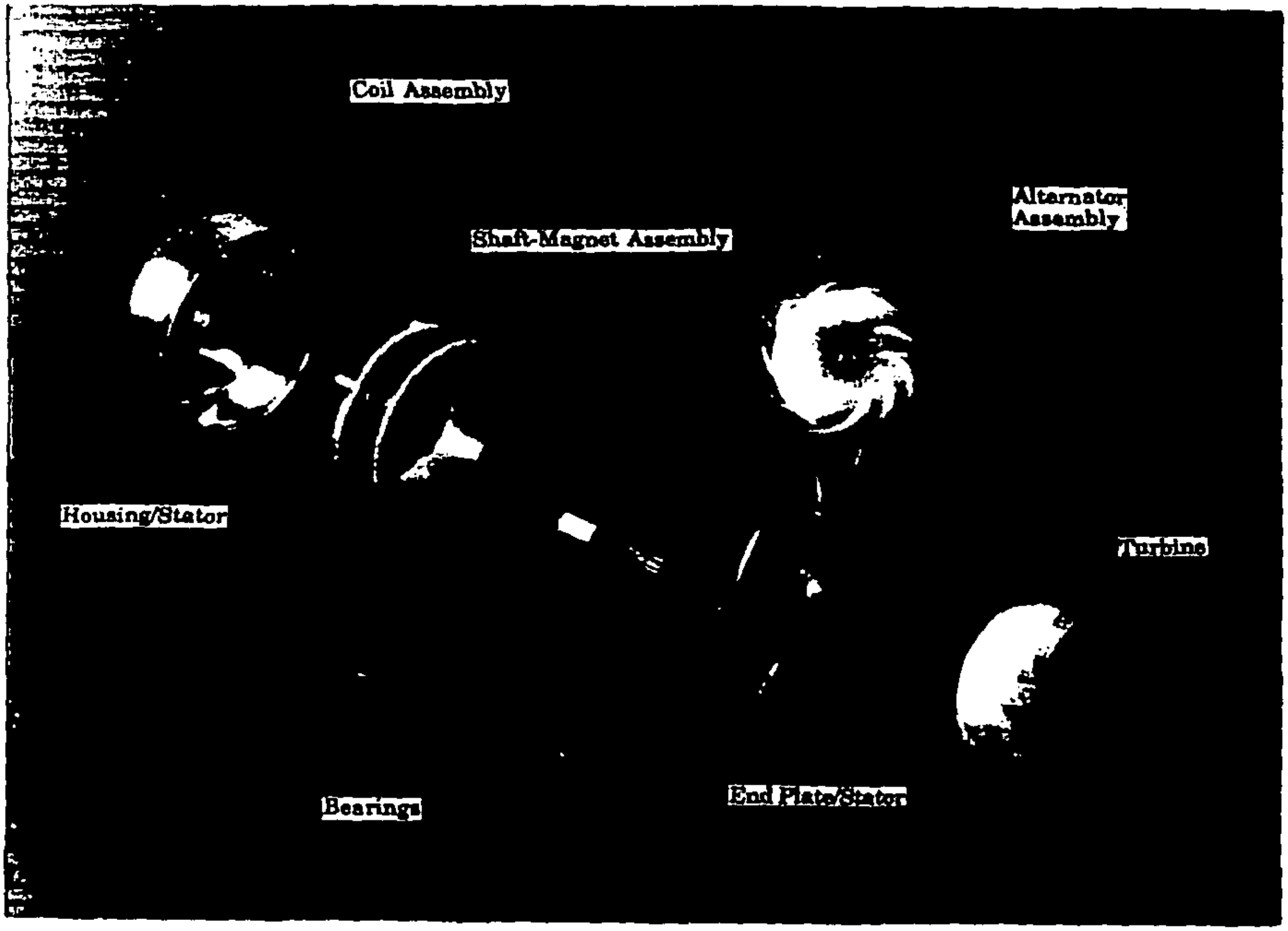

Figure 3-23. Key Elements of a Turboalternator

3-5.2.2 Fluidic Generators

The application of fluidic generators as a power source for fuzes has been discussed in pars. 1-9.2 and 2-10, and the principle was illustrated in Figs. 1-46 and 2-7. As previously described, the basic elements of the fluidic generator are an annular orifice or nozzle, a resonator with a ring-shaped leading edge and cavity, a diaphragm, a connecting rod, an iron reed, and a coil magnet assembly (Ref. 12).

The geometry of the nozzle and the resonator cavity are critical to establishing an air-column oscillation of the desired frequency.

The diaphragm is stamped from N_i-Spac C (an alloy of nickel, chromium, and titanium), which has a negligible coefficient of thermal expansion. This property makes its resonant frequency insensitive to changes in temperature. The resonant frequency is dependent on the diameter, mass, and stiffness of the diaphragm.

The power produced is a function of the physical size of the generator. An increase in the diaphragm diameter results in an increase in displacement and, therefore, an increase in power. Similarly, an increase in the size of the resonator or the magnetic transducer—i.e., larger surface area and/or higher energy product of the magnet—also results in a greater power output. Fig. 3-26 displays the frequency and power output for a fluidic generator as a function of input pressure.

The fluidic generator produces less power than the turboalternator per unit volume; however, it has the capability of operating at higher airspeeds. The turboalternator is limited to the lower speeds by bearing life and structural problems inherent with the rotating magnet.

3-5.2.3 Piezoelectric Transducers

When a piezoelectric element is stressed mechanically, a potential difference exists across the element and causes a charge to flow in the circuit. A piezoelectric control-power supply is shown in Fig. 3-27. One common method of manufacturing such transducers is to form a polycrystalline piezoelectric material into a ceramic. These ceramics can be formed into any desired shape, e.g., a disk. For actual use in a circuit, the faces of the ceramic body are usually silver coated to form electrodes. In general, the voltage across such an element is proportional to the product of stress and element thickness, but the charge per unit area is

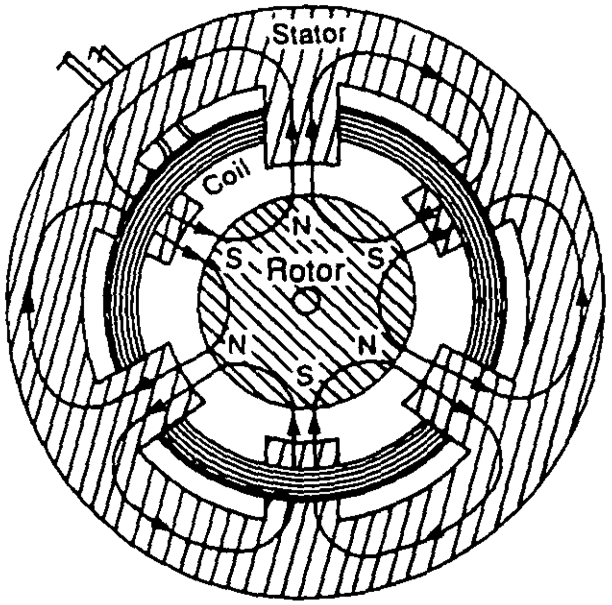

Figure 3-24. Magnetic Circuit of Six-Pole Alternator Showing Flux Path

proportional to the applied stress. The voltage is developed immediately when the element is stressed. Voltages as high as 10,000 V can be obtained and suitable insulation must be provided.

A straightforward use of a piezoelectric transducer is to place it in the nose of a projectile in those applications where the fuze must function a very short time after impact. The signal is transmitted immediately upon impact. In HEAT projectiles, for example, the main explosive charge must be detonated before appreciable loss of standoff results from crushing of the ogive or before deflection from the target occurs at high angles of obliquity. This necessitates a fuze function time of 200 μs or less after impact.

The M509A2 PIBD Fuze used a piezoelectric crystal in the nose of the 105-mm M456AIE2 projectile, which on impact initiated an electric detonator. An earlier version of the Navy's MK118 Bomblet used a piezoelectric crystal that was stressed by the shock wave of a stab detonator. The principal reason for this method was the low terminal velocity of the bomblet, which was insufficient to produce the required energy by crushing when soft targets were hit.

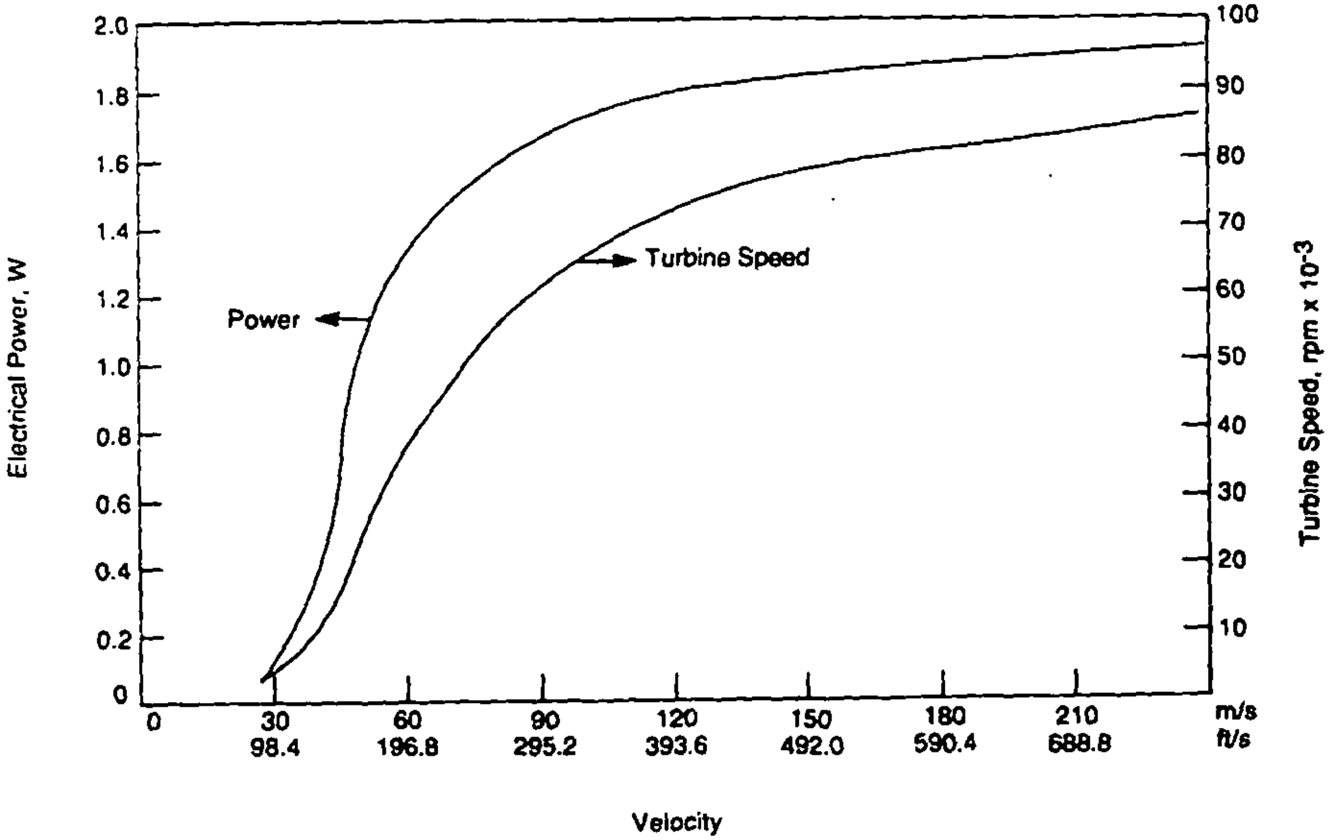

Figure 3-25. Performance Characteristics of Turboalternator

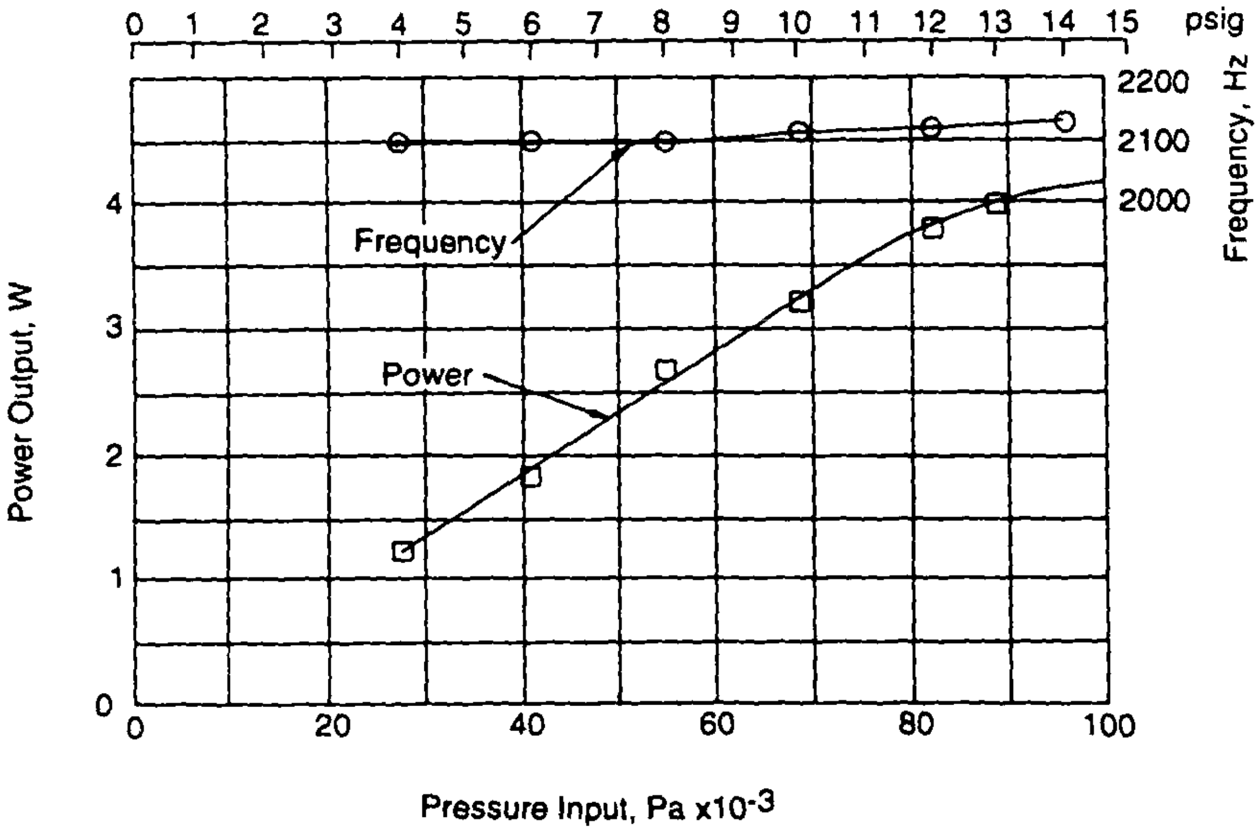

Figure 3-26. Frequency and Power Output of Fluidic Generator (Ref. 13)

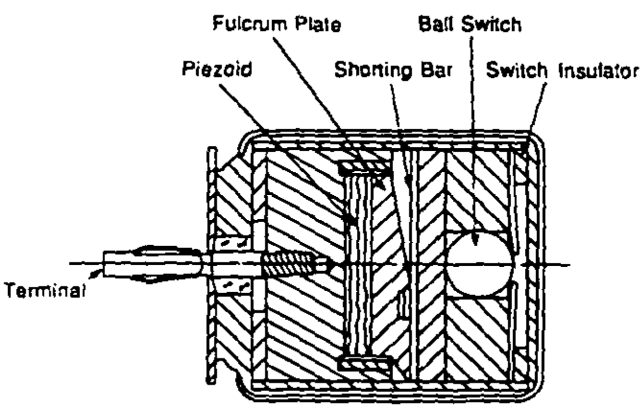

Figure 3-27. Piezoelectric Control-Power Supply, XM22E4 (Ref. 12)

3-5.2.4 Electromagnetic Generators

A magnetic setback generator uses impact or setback forces to introduce an air gap in its closed magnetic system and thereby to change the reluctance of the system (Ref. 12). This change in reluctance manifests itself as a change in magnetic flux, which in turn induces an emf in a coil or wire. This emf stores a charge in a capacitor.

The M509A2El fuze uses a moving magnet setback generator, as shown in Fig. 3-28. The generator is composed of six basic parts—armature, bobbin and coil assembly with terminals, armature plate, magnet, shear disk, and cover with stamped insert. The bobbin and coil assembly fits inside the armature, and the magnet, armature plate, and armature form a closed magnetic circuit. This construction helps "keep", i.e., preserves the flux density of, the magnet. During setback, the magnet moves through the armature plate and away from the armature. Lines of flux from the magnet cut through the coil of wire and induce a voltage in the coil. This output is approximately 100 V on a 0.56-μF capacitor, or 0.028 J, which is more than sufficient to fire an M69 electric detonator reliably.

These generators are well-suited to artillery environments and have the virtue of long shelf life as well as the safety advantage of no stored energy. Unlike wind-driven generators, they require no direct access to the outside of the projectile and therefore can be sealed within the fuze. On the other hand, the output of such generators is of short duration, so they generally must be coupled with energy storage devices, such as capacitors, to allow the energy to be applied over a longer time period. This requirement for additional components obviously has some space and cost penalty. The total energy output of pulse generators tends to be substantially lower than that of continuous power

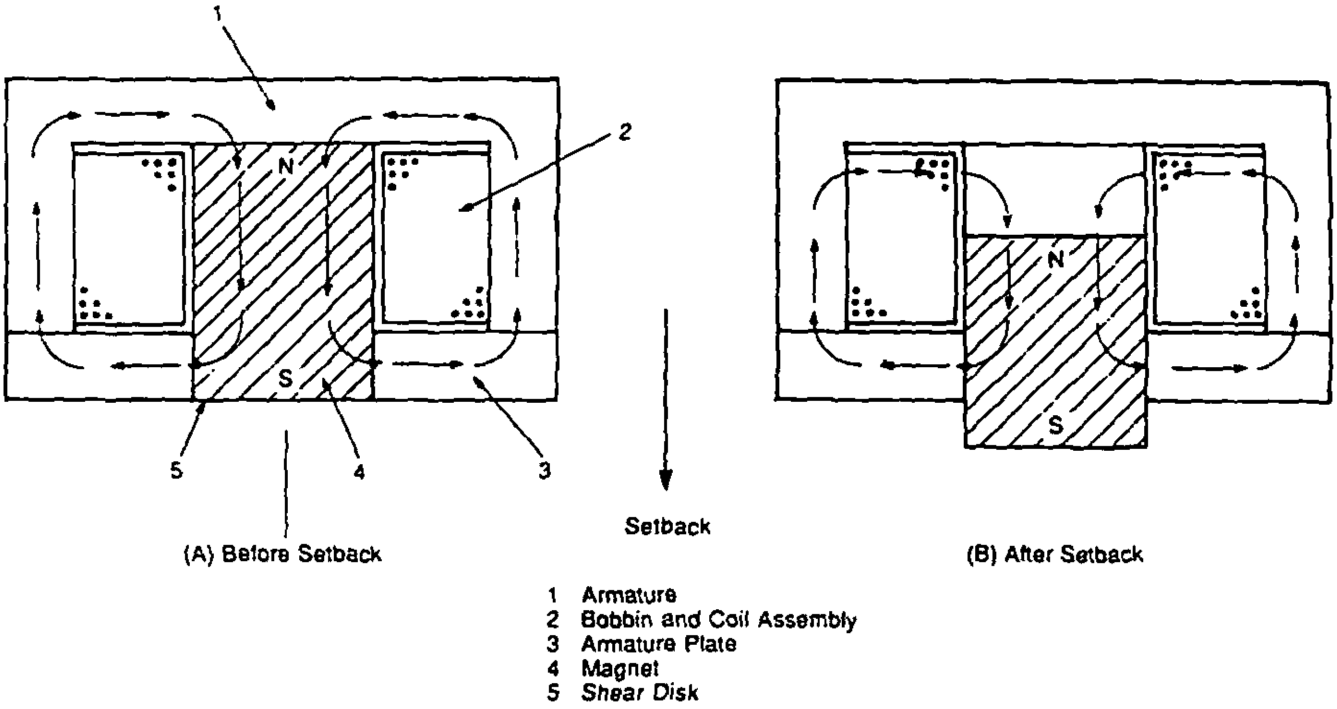

Figure 3-28. Setback Generator, M509

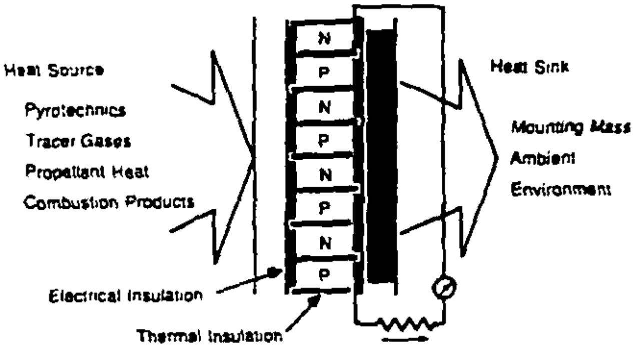

Figure 3-29. Operating Principle of Thermoelectric Module

sources, such as batteries or wind-driven devices. Therefore, pulse generators are limited in their application to short pulse functions, i.e., firing of detonators, or low-power circuitry.

3-5.3 THERMOELECTRIC POWER SOURCES

In its simplest form, a thermoelectric generator may be a thermocouple or an array of thermocouples (Ref. 12). It is well-known that couples of common metals or alloys produce only a very small amount of electrical energy and therefore are virtually limited to the measurement of temperature. Only in recent years, as a result of the development of more efficient thermoelectric materials, has significant thermoelectric power generation become a reality.

The thermoelectric phenomenon is based upon the fact that a temperature gradient across any material tends to drive charge carriers from the hot side to the cold side and produce a voltage proportional to the temperature difference. The proportionality constant, the Seebeck coefficient, is a characteristic of the material. For an efficient device, materials with high Seebeck coefficients, low electrical resistivities, and low thermal productivities are required. A variety of semiconductors—among them bismuth telluride, lead telluride, germanium telluride, and silicon germanium—have evolved with such characteristics.

Thermoelectric modules are usually made with a number of thermoelectric couples, which combine a "P"-type (positive) material and an "N"-type (negative) material electrically connected in series. Fig. 3-29 shows a schematic diagram of a thermoelectric module made up of a number of thermoelectric couples. The individual elements of the couple are separated from each other by electrical (and thermal) insulation and are connected on the hot and cold surfaces to form a series circuit. The module is connected thermally to, but isolated electrically from, the heat source and heat sink. As heat flows through the module, a temperature gradient is established, and a voltage potential is created at the terminals by the Seebeck effect. When a load is applied to the terminals, current flows through the system and produces dc electric power.

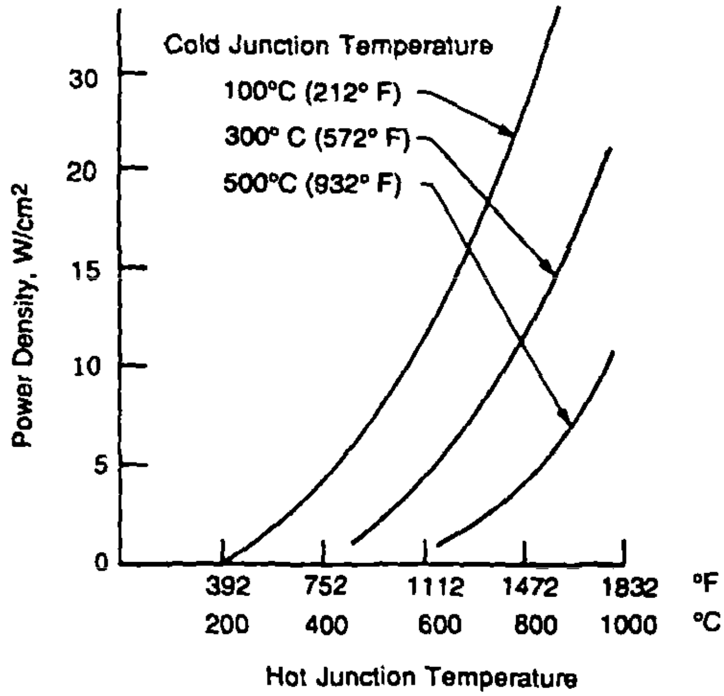

Figure 3-30. Power Density versus Hot Junction Temperature

The power output from thermoelectric power supplies is a function of the amount of heat that passes through the module and the temperature difference achieved. A large, thick module or a small, thin module could provide the same power output, depending on the quality of the heat source and the heat transfer characteristics of the system. Fig. 3-30 displays the curve of power density versus hot junction temperature for a 1.0-mm (0.039-in.) thick module made of silicon germanium thermoelectric material. Power density varies inversely with module thickness. The limit on power density is the ability of the system to transfer heat at the rate required to maintain the required temperature differences.

As previously stated, thermoelectrics require both a heat source and a heat sink to operate. Among the heat sources proposed for the operation of thermoelectrics in ordnance fuzing or arming applications are breech or muzzle blast, aerodynamic heating, and pyrotechnics (such as in thermal batteries). Some of the problems that have inhibited the use of thermoelectrics in such applications are

1. The transfer of blast or aerodynamic heat to the hot junction of the device
2. The persistence of an adequate source of heat throughout the required mission
3. The maintenance of a cold junction
4. The need for a large number of couples to provide the necessary level of voltage and current
5. The series and parallel connections between these couples
6. The cost.

Progress in miniaturization and manufacturability indicates that some of the problems can be overcome. For example, powdered metallurgy techniques that allow base materials to be pressed directly into elements, and ultimately into a modular matrix, promise the elimination of hand assembly and costly machine slicing of billets. Photoetching and vapor deposition techniques also can be employed.

The advantages claimed for thermoelectric power supplies are small size, solid-state reliability, long shelf life, no stored energy, environmental stability, and potential for low cost in mass production.

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CHAPTER 4
THE EXPLOSIVE TRAIN

The purpose, geometry, and design constraints of the fuze explosive train are addressed in this chapter. The purpose of the explosive train as a means of turning a small, initial energy impulse into one of suitable energy to detonate the main charge of the munition in a controllable manner that satisfies the requirements of safety is explained. The explosives acceptable for use are described by their physical properties (sensitivity, stability, and output), the means of encapsulation into components suitable for use in the fuze, and their compatibility with other fuze components.

The various tests used to determine the characteristics of the explosives are explained along with the safety precautions required for handling, storage, and transportation.

Individual explosive components, such as primers, detonators, delays, leads, boosters, actuators, fuse cords, and detonating fuses, are described as to their use, construction, and output abilities. A compendium of stockpiled explosive components is referenced.

Of specific note is the description of in-line-explosive trains with the safety restrictions imposed on them and the explosive logic system that can be designed with the explosive trail method of loading.

Problems encountered in the design of explosive trains are presented, and solutions are recommended.

4-0 LIST OF SYMBOLS

A, B = constants, dimensionless
D = diameter, m (ft)
G_r = reference gap, m (ft)
G_t = observed gap, m (ft)
K = sensitivity of an explosive to initiation, $MPa^2 \cdot s$ ($lb \cdot s/ft^2$)
L = length, m (ft)
P = pressure applied in initial pulse, MPa (lb/ft^2)
t = pulse duration, s
X = stimulus, DBg

4-1 INTRODUCTION

An explosive train is an assembly of combustible and explosive elements inside a fuze that are arranged in the order of decreasing sensitivity. Its function is to accomplish the controlled augmentation of a small impulse into one of suitable energy to cause the main charge of the munition to detonate. This chapter covers the description and characteristics of explosives and explosive elements and the principles of explosive train design. Safe practices in the handling of explosive materials are also discussed.

The reader is urged to study the Engineering Design Handbook on explosive trains (Ref. 1). This reference contains both theoretical and practical data pertaining to explosives and explosive trains in far more detail than can be included within the scope of this handbook.

4-2 EXPLOSIVE MATERIALS

Explosive materials used in ammunition are metastable compounds that can be made to undergo a rapid chemical change with or without an outside supply of oxygen and with the sudden liberation of large quantities of energy and gases at high temperature and pressure. Certain mixtures of fuels and oxidizers can be made to explode, and these are considered to be explosives. A fuel that requires an outside source of oxidizer can also be made to explode under the proper conditions, but the fuel is not considered to be an explosive.

In general, explosives can be divided into two classes, pyrotechnic explosives (sometimes called low explosives) and high explosives, and each is characterized by the rate of advance of the chemical reaction zone.

Many types of explosives are found in fuzes. Each one has its own characteristics and must be tailored to its intended use. Although the fuze designer need not know the chemistry of explosives, he should have a good working knowledge of what explosives to use and how these explosives perform.

4-2.1 PYROTECHNICS

A pyrotechnic is an explosive for which the rate of advance of the chemical reaction zone into the unreacted explosive is less than the velocity of sound through the undisturbed material. When used in a normal manner, pyrotechnics burn or deflagrate rather than detonate. The burning rate depends upon such characteristics as the degree of confinement, area of burning surface, temperature, and composition.

As shown in Fig. 4-1, burning starts at the point of initiation "0" and travels along the column of explosive as indicated. The products travel in every direction away from the burning surface. As a result, pressure is built up within the space of confinement. The velocity of propagation increases with pressure until it becomes constant.

Pyrotechnics are divided into two groups: (1) gas-producing explosives, which include propellants, certain primer mixtures, igniter mixtures, black powder, photoflash powders, and certain delay compositions and (2) nongas-pro-

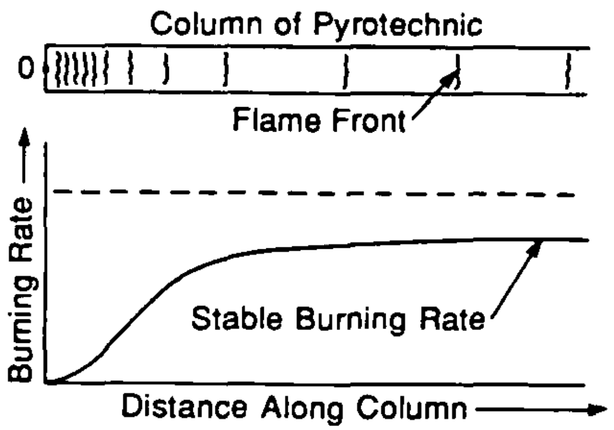


Figure 4-1. Burning Pyrotechnic

ducing explosives, which include the gasless-type delay compositions.

4-2.2 HIGH EXPLOSIVES

An explosive is classified as a high explosive if the rate of advance of the chemical reaction zone into the unreacted explosive exceeds the velocity of sound through the undisturbed explosive. This rate of advance is termed the detonation rate for the explosive under consideration. High explosives are also divided into two groups: primary and secondary.

The detonation velocities of high explosives are illustrated in Figs. 4-2 and Fig. 4-3. Fig. 4-2 shows a column of high explosive that has been initiated at "0". When the reaction occurs properly, the rate of propagation increases rapidly, exceeds the velocity of sound in the unreacted explosive, and forms a detonation wave that has a definite and stable velocity.

Fig. 4-3 shows the rate of propagation of a reaction front under ideal conditions (upper curve) and poor conditions (lower curve). The reaction starts and becomes a detonation if the proper conditions exist. If the initiating stimulus is

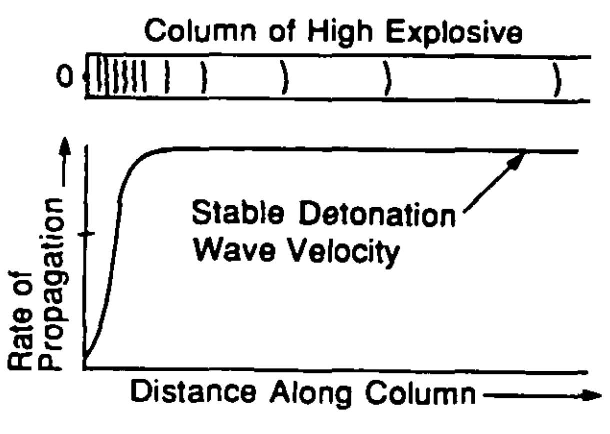


Figure 4-2. Detonating High Explosives

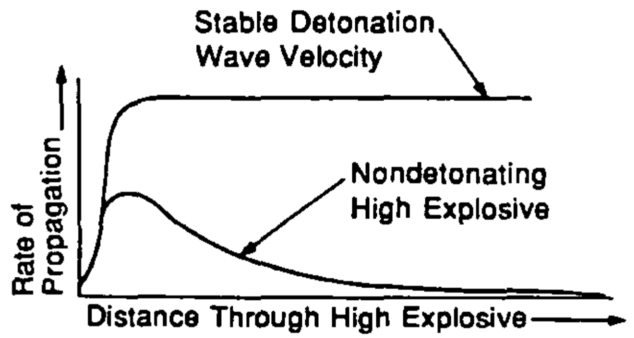


Figure 4-3. Examples of Good and Poor Detonations

insufficient or if the physical conditions (such as confinement or loading density) are poor, however, the reaction rate may follow the lower curve. The front may then travel at a much lower speed, and this speed may even fall off rapidly.

The growth of a burning reaction to a detonation is influenced considerably by the conditions of density, confinement, and geometry as well as by the vigor of initiation, particle size, amount of charge reacted initially, and other factors.

4-2.2.1 Primary High Explosives

Primary high explosives are characterized by their extreme sensitivity to ignition by heat, shock, friction, and electrical discharge (Ref. 2). Ignition leads to high-order detonation of the material, even for milligram quantities. The primary high explosives, such as azides and styphnates are generally used as initiating and output materials for low-energy squibs, primers, and detonators.

4-2.2.2 Secondary High Explosives

Secondary high explosives are not readily initiated by heat, mechanical shock, or electrostatic discharge. Ignition requires an explosive shock of considerable magnitude, which is usually obtained from a primary high explosive. Small, unconfined charges even though ignited do not transmit easily from a burning reaction or deflagration to a detonation. Materials such as tetryl, CH6, RDX, TNT, and compositions A3, A4, and A5 are considered secondary high explosives.

For safety, MIL-STD-1316 requires an interruption in the explosive path between the primary and secondary explosives. (See par. 9-2.2.)

4-2.2.3 Characteristics of High Explosives

Some of the most important characteristics are sensitivity, stability, detonation rate, compatibility, and destructive effect. Although these properties are the ones of most interest to the fuze designer, they are unfortunately difficult to measure in terms of an absolute index. Standard laboratory tests, empirical in nature, are still used to provide relative ratings for the different explosives. Hence the designer must rely upon these until more precise methods of evaluation are devised.

Input sensitivity refers to the energy stimulus required to cause the explosive to react. A highly sensitive explosive is one that initiates as a result of a low energy input. All explosives have characteristic sensitivities to various forms of stimuli such as mechanical, electrical, or heat impulses.

The relative sensitivities of common fuze explosives according to standard laboratory tests are given in Table 4-1. The fact that results obtained by various procedures differ does not necessarily mean that one result is right and another is wrong or that one is necessarily better. Each may be a completely valid measurement of the sensitivity of an explosive under the conditions of the test.

Impact tests determine the sensitivity of an explosive by the dropping of a weight from different heights onto a small test sample. The Picatinny Arsenal (PA) test uses a 19.6-N (4.4-lb) weight. Sensitivity is defined as the least height at which one out of ten tries results in an actuation (Ref. 3). Another impact test is the one employed by Lawrence Livermore National Laboratory (LLNL) (Ref. 2). In this test a 24.5-N (5.5-lb) weight is dropped onto a small sample (84 mg (1.3 gr)) and the height in meters at which a 50% probability of reaction occurs is calculated.

Gap tests are also used as a measure of sensitivity. The wax gap test introduces wax between the donor 100 g (0.22 lb) and acceptor charges and the length of the gaps at which there is a 50% probability of initiation is determined. A refinement of this test incorporates Lucite between the donor (165 mg (2.55 gr) RDX) and acceptor, and a steel dent block is added to determine the output (Ref. 4). The data are analyzed by the gap decibang (DBg) method, which is calculated from the transformation function of

$$X = A + 10B\log(G_r/G_t), \text{DBg} \qquad (4\text{-}1)$$

where

X = stimulus, DBg
A, B = constants, dimensionless
G_r = reference gap, m (ft)*
G_t = observed gap, m (ft).

The sensitivity K of an explosive to initiation can also be expressed by

$$K = P^2 t, \text{MPa}^2\,\text{s}\left(\frac{\text{lb}^2\cdot\text{s}}{\text{ft}^4}\right) \qquad (4\text{-}2)$$

where

P = pressure applied in initial pulse, MPa (lb/ft^2)
t = pulse duration, s.

Explosives with a large K value are less sensitive. Note also that pressure is more effective in producing initiation than is pulse duration.

*Although inch is a more convenient unit to use with fuzes, foot is used to simplify the equations.

Stability is the measure of the ability of an explosive to remain unaffected during prolonged storage or by adverse environmental conditions (pressure, temperature, humidity). The vacuum stability test is the most widely used for explosives. A 5.0-g (77-gr) sample (1.0 g (15 gr) for primary high explosives), after being thoroughly dried, is heated in a glass tube for 40 h in a vacuum at the desired temperature (100°C (212°F)), and the volume of gas evolved is measured. Direct comparison of test values between different explosives is not always possible.

Compatibility implies that two materials such as an explosive charge and its container, do not react chemically when in contact with or in proximity to each other, particularly over long periods of storage. Incompatibilities can produce either more sensitive or less sensitive compounds or affect the parts that touch the incompatible materials. If the metal container is incompatible with the explosive, coating or plating it with a compatible material will often resolve the difficulty. The compatibility of two materials can be determined by storing them together for a long time under both ordinary and extreme conditions of temperature and humidity. Table 4-2 lists compatibility relations between various metals and common explosive materials. The blank spaces indicate no definite results to date.

Of the reactions of explosives with metals, that of lead azide with copper or copper-bearing alloys deserves special comment. Although this reaction is relatively slow even in the presence of moisture, some forms of copper azide are extremely sensitive and have the potential to create a serious safety hazard. For this reason primer and detonator cups of aluminum and stainless steel are now used exclusively where lead azide is a component. The azide material is sealed inside the cup. Azides also react with other metals, such as zinc and cadmium.

Table 4-3 lists several physical properties of high explosives. Other properties are found in standard reference books (Refs. 1 and 2).

4-2.3 PRECAUTIONS FOR EXPLOSIVES

No explosive materials are completely safe, but when handled properly, nearly all of them are relatively safe. The first requisite for safe handling of explosives is to cultivate respect for them. The person who learns only by experience may find that his first experience is his last. The potentialities of all common explosives should be learned so that any explosive can be handled safely.

4-2.3.1 General Rules for Handling Explosives

Prior to conducting of any explosive handling operation or fuze assembly or breakdown, a standard operating procedure (SOP) should be prepared and submitted to cognizant safety personnel for review. The SOP is a step-by-step procedure, which must be judiciously followed during the explosive-handling operation.

TABLE 4-1. RELATIVE SENSITIVITIES OF FUZE EXPLOSIVES

EXPLOSIVE	IMPACT TESTS PA mm	IMPACT TESTS PA in.	IMPACT TESTS LLNL 50%* m	IMPACT TESTS LLNL 50%* in.	GAP TESTS Wax 50% mm	GAP TESTS Wax 50% in.	GAP TESTS Lucite 50% mm	GAP TESTS Lucite 50% in.	GAP TESTS Air mm	GAP TESTS Air in.	GAP TESTS Lucite DBg	LOADING PRESSURE MPa	LOADING PRESSURE ksi	DENSITY kg/m³	DENSITY lbm/in.³
Black Powder	406.4	16												1882.23	0.068
CH6	304.8	12					8.4	0.332			4.79			1605.43	0.058
Comp A3	406.4	16	0.81	31.9	43.2	1.7								1605.43	0.058
A4	—	—	0.37	14.6										1605.43	0.058
A5	203.2	8													
	304.8	12									4.616	110	16	1605.43	0.058
RDX	203.3	8	0.28	11			11.9	0.47	8.1	0.32	3.283	69	10	1550.07	0.056
(cyclonite)											5.069	262	38	1743.83	0.063
DIPAM	—	—	0.85	33.5							7.54	441	64		
HMX	22	9	0.32	12.7							8.71			1909.91	0.069
HNS	203.2	8	0.54	21.26							5.18				
Lead	7.62 Pure										−0.303			3072.47	0.111
Azide	12.7 Dex-5													4373.42	0.158
Lead															
Styphnate	203.2	8												3017.11	0.109
Octol			0.35	13.8							3.4	28	4		
	457.2	18	0.52	20.5							7.086	441	64	1799.19	0.065
PETN	152.4	6	0.16	6.3					11.9	0.47	6			1577.75	0.057
Tetryl	203.2	8	0.37	14.6	51.1	2.01	11	0.434	4.6	0.18	7.8			1577.75	0.057
TNT	355.6	14									16.5			1577.75	0.057
	381.0	15	1.48	58.3	20.8	0.82	5.3	0.21			4.635		6	1411.67	0.051
											6.114		19	1577.75	0.057

PA = Picatinny Arsenal
LLNL = Lawrence Livermore National Laboratory
*50% = 50% Probability of Firing— <0.25 m (9.8 in.) = relatively sensitive to impact
0.25 to 0.71 m (9.8 to 28 in.) = moderate sensitivity—can be handled by standard procedures
>0.76 m (30 in.) = relatively insensitive to impact

TABLE 4-2. COMPATIBILITY OF COMMON EXPLOSIVES AND METALS

	LEAD AZIDE	LEAD STYPHNATE	PETN	RDX	TETRYL
Magnesium	N		B,S		
Aluminum	A,N	A,N	A,VS	A,VS	A,N
Zinc	C,N			A	B,VS
Iron	N			A	B,S
Steel	C,N		B,VS	A,S	C,H
Tin	A,N			A	A,N
Cadmium	C				A
Copper	D,N	A	B,VS	A,S	A,N
Nickel	C			A	A,N
Lead	N			A	A,N
Cadmium-plated steel	C		B,S	VS	A,N
Copper-plated steel	D,N		B,VS	B,VS	A,VS
Nickel-plated steel	N		B,VS	A,S	A,N
Zinc-plated steel	N		B,VS	A,S	A,N
Tin-plated steel	N			A	B,VS
Magnesium aluminum	VS		B,S		
Monel metal	C,N				
Brass	D,N		B,S	A,S	B,VS
Bronze	D,N			A	A,VS
18-8 Stainless steel	A,N	A	A,N	A,N	A,N
Titanium	N			N	N
Silver	N			N	N

CODE
A = no reaction
B = slight reaction
C = reacts readily
D = reacts to form sensitive materials
H = heavy corrosion of metals
VS = very slight corrosion of metals
N = no corrosion
S = slight corrosion of metals

Some general rules concerning the safe handling of explosives or explosive-loaded fuzes follow:

1. Consult the safety regulations prescribed by the military agency and by the local and Federal Governments.
2. Conduct all experiments in the prescribed laboratory space, never near storage spaces of bulk explosives.
3. Experiment with the smallest sample of explosive that will serve the purpose.
4. Keep all work areas free from contaminants.
5. Avoid accumulation of charges of static electricity.
6. Avoid flame- and spark-producing equipment.
7. Keep to a minimum the number of personnel at work in the same area, but one person should never work alone.
8. Be sure that the chambers for "loading" and "testing" are well-shielded electrically and mechanically.
9. Some explosive materials are stored wet, some dry, and some in special containers. Ensure that the special instructions for each type are carefully and completely followed.
10. Wear safety glasses at all times.
11. Scrupulously avoid all explosive dust in threaded joints where high pressures can develop from a pinching action.

TABLE 4-3. PHYSICAL PROPERTIES OF FUZE EXPLOSIVES

EXPLOSIVE	CRYSTAL DENSITY		MELTING POINT		DETONATING VELOCITY				LOADING PRESSURE		DENSITY	
					Density Used		Velocity					
	g/cm^3	$lb/in.^3$	°C	°F	g/cm^3	$lb/in.^3$	m/s	ft/s	MPa	ksi	g/cm^3	$lb/in.^3$
Lead									34	5	2.71	0.098
Azide*	4.80	0.173	Decomposes		4.0	0.144	5180	16,995	103	15	3.07	0.111
Lead									34	5	2.23	0.080
Styphnate*	3.02	0.109	Detonates		2.9	0.105	5200	17,060	103	15	2.51	0.090
Black Powder*	2.0	0.072			1.91-1.95	0.070	1300	4265				
Comp A3**	1.672	0.060	200	392	1.65	0.059	8270	27,132	69	10	1.61	0.058
A4			200	392	1.67	0.060	8470	27,788			1.61	0.058
A5	1.757	0.063	200	392	1.70	0.061	8600	28,214			1.61	0.058
CH6†	1.75	0.063	200	392	1.61	0.058	8600	28,214			1.61	0.058
PBXN-301	N/A	N/A	140	284	1.53		7090	23,262			1.556	0.056
PBXN-5	N/A	N/A	250	482	1.84-1.86		8760	28,740			1.90	0.068
PBXN-6	N/A	N/A	No Data		1.767		8440	27,690			1.81	0.065
DIPAM	1.79	0.065	304	579	1.76	0.064	7400	24,277				
HNS	1.74	0.063	315	599	1.60	0.057	6800	22,309				
Tetryl									34	5	1.47	0.053
	1.73	0.062	130	266	1.73	0.061	7170	23,523	103	15	1.63	0.059
PETN*									34	5	1.48	0.053
	1.76	0.064	141	286	1.67	0.061	8300	27,230	103	15	1.71	0.062
HMX*	1.905	0.069	285	545	1.89	0.068	9110	29,888				
RDX*									34	5	1.52	0.055
	1.82	0.066	204	399	1.65	0.059	8780	28,805	103	15	1.65	0.059
TNT*					Cast							
	1.65	0.059	81	178	1.5-1.6	0.057	6640	21,784	34	5	1.4	0.05
					Pressed							
					1.63-1.64	0.059	6825	22,391	103	15	1.52	0.055

*Fuze explosives not approved past the interrupter
**Comp A3 = 91% RDX + 9% wax
A4 = 97% RDX + 3% wax
A5 = 98.5% RDX = 1.5% stearic acid

†CH6 = 97.5% RDX
1.5% Calcium stearate
0.5% Graphite

4-2.3.2 Storage and Transportation of Fuzes

Fuzes like other explosive items are normally stored in special magazines that are usually covered with earth and designed to protect against spreading the effects of a spontaneous detonation or an accidental detonation caused by fire, severe concussion, or impact. The prescribed distances between explosive storage areas must be maintained to minimize the possibility of sympathetic detonation or propagation to other magazines. These distances are defined by the quantity and class of explosive material being stored. These relationships are based on levels of risk considered acceptable for the stipulated exposures and are tabulated in quantity-distance tables found in Army and Department of Defense safety manuals (Refs. 5, 6, and 7).

Although the fuze designer is not usually responsible for the storage of fuzes, the points that follow should be adhered to when storing explosively loaded fuzes or explosive components:

1. Never store primary high explosives in the same magazine with secondary high explosives unless they are contained in fuzes.
2. Loose powder, powder dust, or particles of explosive material from broken or damaged ammunition are not permitted in magazines. Flammable material, such as wooden dunnage, pallets, or boxes shall be reduced to an absolute minimum.
3. Secure all explosive material in magazines with approved locks and/or other appropriate security measures to minimize unauthorized access to these areas.

Transportation of fuzes may be by rail, highway, air, and water. Regulations governing the transportation of all hazardous materials, including fuzes, are given in Refs. 8 and 9. For the purposes of hazard classification, explosives are divided into Classes A, B, and C, depending upon their relative sensitivity, strength, or confinement. In general, fuzes are classified as Class A unless they are packaged such that they will not cause functioning of other fuzes, explosives, or explosive devices in the same or adjacent containers, in which case they are Class C. The three classes are broadly categorized as Class A, detonating or otherwise of maximum hazard; Class B, flammable hazard; and Class C, minimum hazard.

4-3 INITIAL EXPLOSIVE COMPONENTS

4-3.1 GENERAL CHARACTERISTICS

Explosive material fulfills its purpose only if it explodes at the intended time and place. The fuze is the mechanism that senses these circumstances and initiates the explosive reaction in response to a stimulus generated by the target or by a present time. In Table 4-4 common explosive materials and additives are listed opposite the explosive train component in which each is used.

The first element of the explosive train is the initiator. Initiators are classified according to the nature of the stimulus to which they are designed to respond, such as stab, percussion, or electric, and according to their output characteristics as primers, detonators, delays, or squibs.

A primer is a relatively small, sensitive explosive component generally used as a first element in the explosive train. As such, it serves as an energy transducer and converts mechanical or electrical energy into explosive energy. It has a relatively small explosive output, mainly flame, and therefore will not reliably initiate secondary high explosive charges. Sometimes the function of a primer is performed for convenience in fuze design by other components such as a stab or electric detonator.

A detonator is a small, sensitive explosive component capable of reliably initiating high-order detonation in the next high-explosive element in the explosive train. It differs from a primer in that its output is an intense shock wave. It can be initiated by nonexplosive energy or by the output of a primer. Furthermore, it will detonate when acted upon by sufficient heat or by mechanical or electrical energy.

Primers and detonators are commonly placed into two groups, mechanical and electrical. The electrical group includes those initiated by an electric stimulus. The mechanical group includes not only percussion and stab elements, which are initiated by the mechanical motion of a firing pin, but also flash detonators, which are initiated by heat. As a group, electrical initiators are the more sensitive and differ from the mechanical group in that they contain the initiating mechanism, i.e., the bridgewire and ignition charge, as an integral part. The paragraphs that follow describe the common initiator types that comprise part of the explosive train.

4-3.1.1 Stab Initiators

The stab initiator is a rather simple item consisting of a cup loaded with explosives and covered with a closing disk. It is relatively sensitive to mechanical energy. A typical stab detonator is shown in Fig. 4-4(A).

4-3.1.2 Percussion Primers

Percussion primers differ from stab initiators in that they are initiated and fired without puncturing or rupturing their containers. Therefore, they are used in fuzes mainly as initiators for obturated (sealed) delay elements. The essential components of a percussion primer are a cup, a thin layer of priming mix, a sealing disk, and an anvil. Typical percussion primers are shown in Fig. 4-4(B) and 4-4(C). In general, they are less sensitive than stab initiators. A 28-gr (1-oz) weight dropped from 30 cm (12 in.) is a typical condition under which all percussion primers should fire. Percussion primer cups are constructed of ductile metals (commonly brass) to avoid being ruptured by the firing pin.

4-3.1.3 Flash Detonators

Flash detonators are essentially identical in construction to stab initiators with the exception of priming mix, which is usually omitted in the flash detonators. They are sensitive to

TABLE 4-4. COMMON EXPLOSIVE MATERIALS AND ADDITIVES

COMPONENT	NORMALLY USED	ACCEPTABLE FOR MIXES	USED IN SPECIAL CASES
Primer (including priming mix in detonator)	Lead azide Lead styphnate	Antimony sulfide Barium nitrate Corborundum Ground glass Lead sulfocyanate Lead thiocyanate Nitrocellulose Potassium chlorate PETN Tetracene	Diazodinitrophenol Mannitol hexanitrate Nitrostarch
Detonator			
Primary explosive	Lead azide		Diazondinitrophenol Mannitol hexanitrate Nitrostarch
Base charges	Lead azide PETN RDX Tetryl		Diazondinitrophenol Mannitol hexanitrate Mannitol hexanitrate Nitrostarch
Lead or Booster	CH6 Comp A3 A4 A5 DIPAM HNS PBXN-301 PBXN-5 PBXN-6 Tetryl*		Pressed TNT RDX/WAX

*No longer manufactured; exists in some stockpiled ammunition

heat. A typical flash detonator is shown in Fig. 4-4(D). Flash detonators are considered to be initiators for convenience of grouping even though they are not the first element in the explosive train.

4-3.1.4 Electric Initiators

Electric primers and electric detonators differ from stab initiators—they contain the initiation mechanism as an integral part. They constitute the fastest growing class of explosive initiators. (See also par. 4-4.5.2 for further discussion.)

Several types of initiation mechanisms are commonly used in electric initiators: hot wire bridge, exploding bridgewire, film bridge, conductive mixture, and spark gap. Typical electric initiators are shown in Fig. 4-5. Electrical contact is made by two wires, by center pin and case, or occasionally by two pins.

An example of this construction is the wire lead initiator shown in Fig. 4-5(A). Two lead wires are molded into a cylindrical plug, usually of Bakelite®, so that the ends of the wire are separated by a controlled distance on the flat end of the plug. This gap can then be bridged with a graphite film or a bridgewire welded between the lead wires. The bridgewires are typically less than 2.54×10^{-2} mm (0.001 in.) in diameter and 1.016 mm (0.04 in.) long.

Metal parts of squibs are identical to those of electric initiators. A typical squib is shown in Fig. 4-6. Squibs provide an explosive flash charge to initiate the action of pyrotechnic devices. (See also par. 4-4.5.2 for further discussion.)

4-3.1.5 In-Line Initiator Systems

In recent years techniques have been developed that permit direct initiation of insensitive high explosives with electrical energy without the use of initiator explosives. The exploding bridgewire (EBW) detonator, as shown in Fig. 4-5(C), is an example of a device that can initiate high explosives without the use of sensitive primary explosives. In an EBW the small bridgewire is electrically exploded when very high current is forced through it before it has time to melt and disrupt the circuit. The essential components of an EBW system are a high-energy source, a storage capacitor, a trigger circuit, and a matched transmission line to the bridgewire. The energy required to initiate these devices is approximately one joule. The EBW method has been used to initiate directly such explosives as PETN, RDX, and HMX. To initiate less sensitive high explosives requires significantly higher energy levels and therefore is impractical

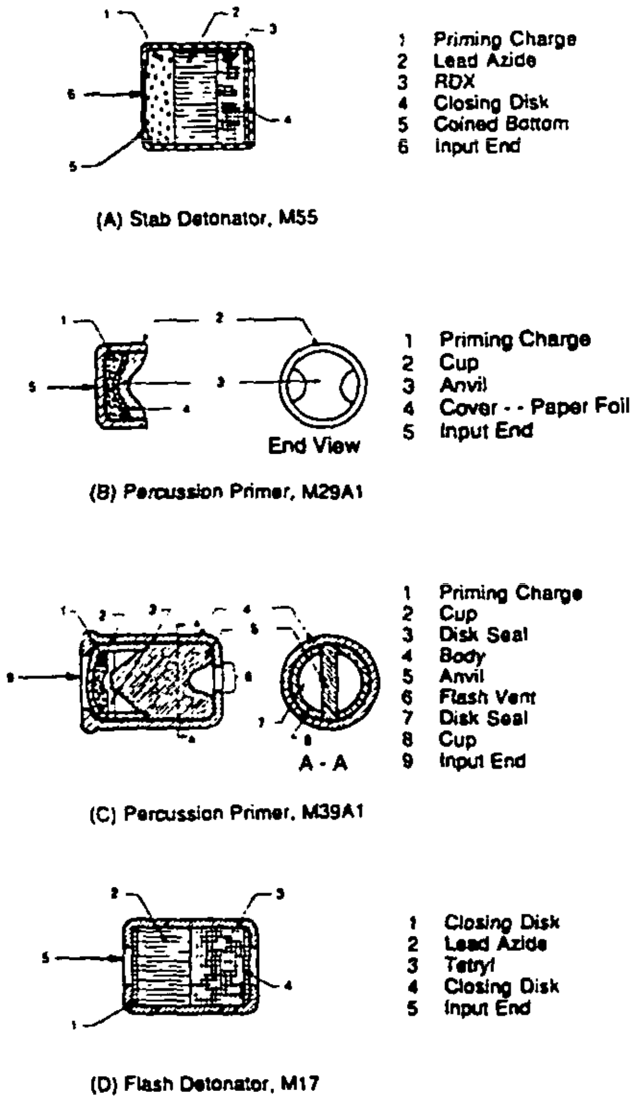


Figure 4-4. Typical Mechanical Primers and Detonators

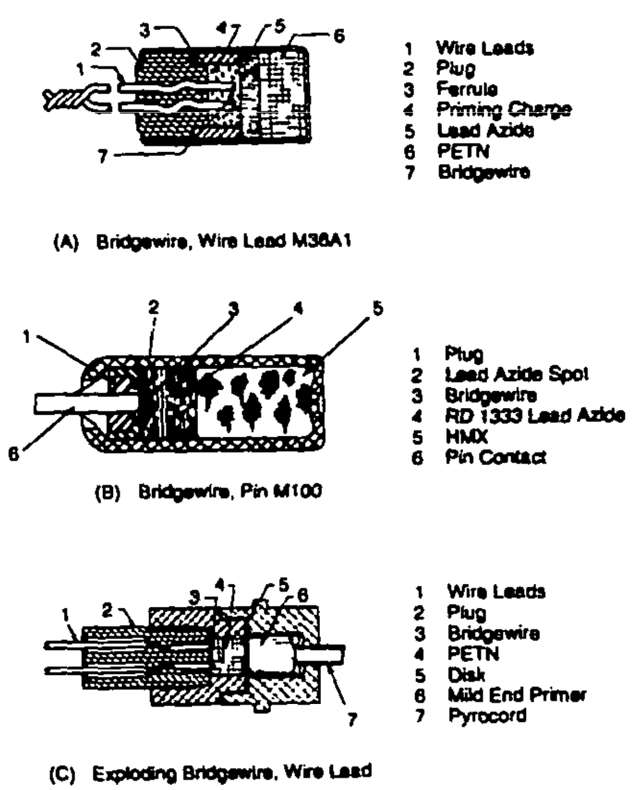


Figure 4-5. Typical Electrical Primers and Detonators

in functional systems. HNS can be initiated from a bridgewire; however, to do so would require in excess of 10 joules. Since none of these explosives, except HNS, are approved for in-line use without interruption of the explosive train, special approval would have to be obtained from the service's safety review board before an EBW could be used in a fuze design.

As a natural extension of the EBW concept, a relatively new concept of high-explosive initiation, the exploding foil initiator (EFI), has been developed.

The EFI concept developed by the Lawrence Livermore National Laboratory (Ref. 10) has several advantages over the EBW detonator. The primary advantages include

1. The metal bridge is completely separated from the explosive by an insulating film and an air gap.

2. The explosive can be loaded to a high (near crystal) density.

3 Approved booster explosives, such as HNS, can be detonated.

4. Much less energy is required for initiation.

Fig. 4-7(A) depicts the basic detonator components of an EFI system. They consist of a high-density explosive pellet (typically HNS), an insulating disk with a hole or barrel in the center, and an insulating flyer material, such as mylar with a metal foil etched on one side. The necked section acts as the bridgewire.

When a high-current firing pulse is applied, the necked down section is vaporized. This then shears the mylar flyer, which accelerates down the barrel and impacts the explosive pellet. This impact energy transmits a shock wave into the explosive and causes it to detonate (Fig. 4-7(B)). Refs. 11, 12, and 13 provide additional information on energy relationships and theory of this concept.

Design criteria for control of the initiating energy source for noninterrupted explosive trains have been promulgated in MIL-STD-1316 (Ref. 14 and par. 4-3.2). In general, two energy interrupters, each operated by an independent safety feature, are required to prevent inadvertent flow of energy to the initiator.

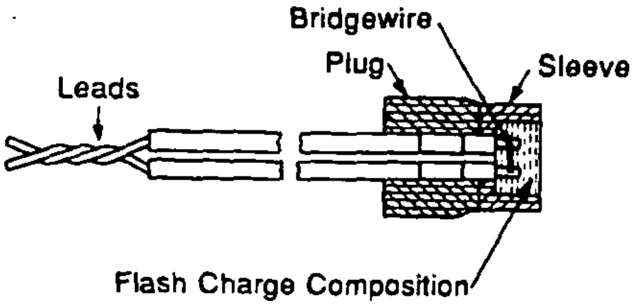


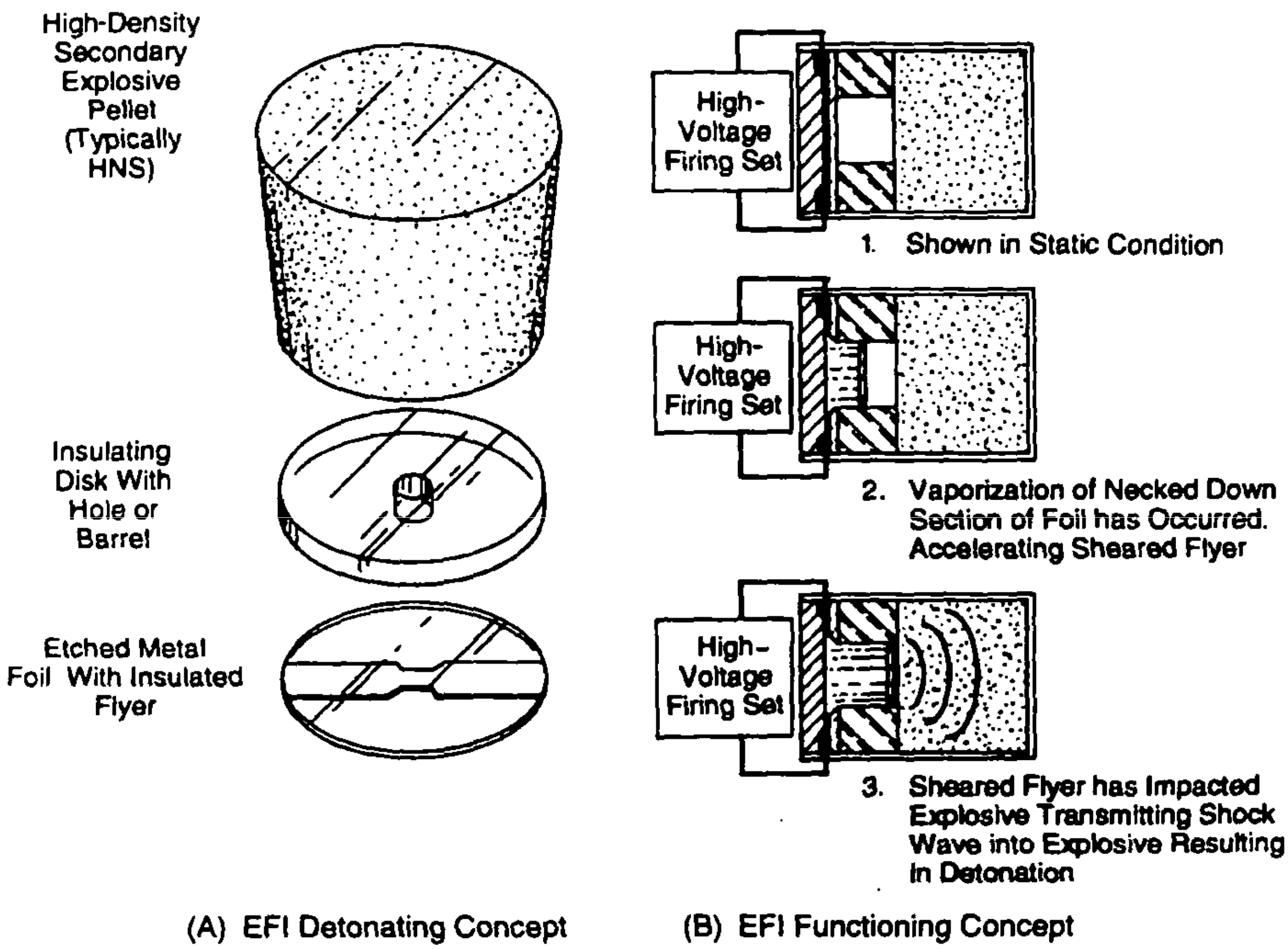
Figure 4-6. Electrical Initiator, Squib M2

4-3.2 INPUT CONSIDERATIONS

The rate at which the energy of an externally applied stimulus is transformed into heat and the degree of concentration of that heat are important in determining the magnitude of the stimulus necessary to initiate a reaction. In stab initiators the energy available is concentrated by the use of small diameter firing pins, and in electrical devices by rapidly dissipating the energy in short and highly concentrated paths.

Two limiting threshold conditions for initiation apply to almost every system: (1) the condition in which the energy is delivered in a time so short that the losses are negligible during this time and (2) the condition in which the power is just sufficient to cause initiation eventually. In the first condition the energy required is at its minimum, whereas in the second the power is at its minimum. These two conditions are represented by the dashed asymptotes in Fig. 4-8. The relation between the energy required for initiation and the rate at which it is applied may be represented by the hyperbolas. In its general terms, the relationship illustrated applies to almost all initiators.

MIL-HDBK-777—discussed in par. 2-5.1—contains information on the input and output characteristics of all procurement standard and development explosive initiators (Ref. 15).



From *Exploding Foil Initiator Ordnance* (Brochure), Reynolds Industries Systems, Inc., Ramon, CA, December 1985.

Figure 4-7. Exploding Foil In-Line Initiator

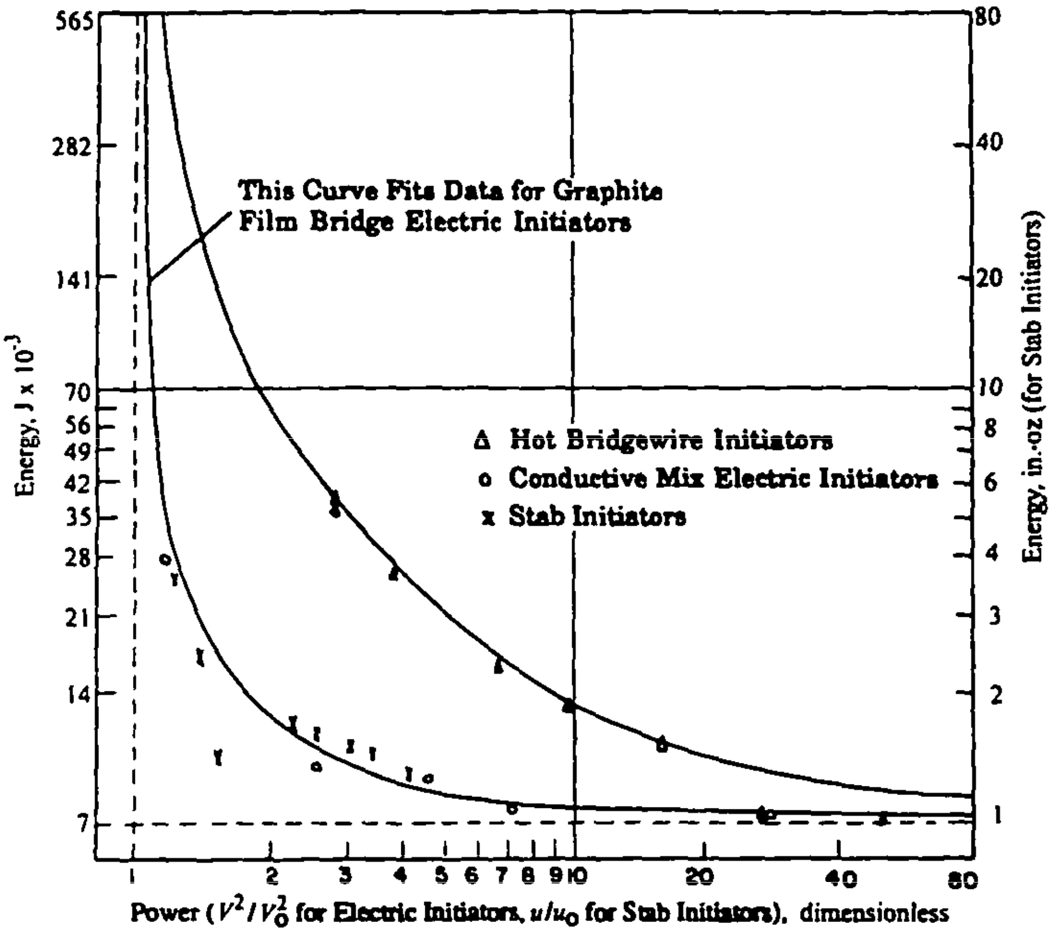


Figure 4-8. Energy Power Relationship for Various Initiators

4-3.3 OUTPUT CHARACTERISTICS

The output of a primer includes hot gases, hot particles, high-speed flyer plates, a pressure pulse, which in some cases may be a strong shock wave, and thermal radiation. Although a number of tests have been used to characterize primer output, no general quantitative relationship of value to a designer has been developed. The design of a primer must be based on precedent and the following generalities:

1. Both gaseous products and hot particles emitted by primers play important roles in ignition.

2. The effectiveness of the gaseous products in ignition increases directly with temperature and pressure. Since the pressure is related inversely to the enclosed volume, an increase in this volume or a venting may call for primers of greater output.

3. Hot particles and globules of liquid are particularly effective in the ignition of materials with high thermal diffusion properties.

4. Hot particles and globules establish a number of reaction nuclei rather than burning along a uniform surface. This action may be undesirable in short-delay columns or in propellant grains designed for programmed combustion.

5. The reproducibility of the time of a delay element is related to the reproducibility of the output of the primer that initiates it. The times of short, obturated delay elements are particularly sensitive to variations in primer output.

As its name implies, a detonator is intended to induce detonation in a subsequent charge. The two features of its output that are useful for this purpose are the shock wave it emits and the high velocity of the fragments of its case. The output effectiveness of current detonators is directly related to the quantity of the detonating explosive and to the vigor of the detonation.

Detonator output is measured by means of gap or barrier tests, sand test, lead disk test, steel plate dent test, Hopkinson bar test (Ref. 1), and in terms of the velocity of the air shock and fragments produced. Like primers, no known measurement technique yields a quantitative measure of the output of an individual detonator which is usable, without reservation, as a criterion of the effectiveness of the detonator in a particular explosive train.

The output characteristics are achieved by means of the explosives used. Primers are loaded with one of a variety of priming compositions. Typical stab detonators have three charges—a priming charge, an intermediate charge, and a base charge—although two of these can be combined. The priming charge is like that of the primer. The intermediate charge is usually lead azide, whereas the base charge can be lead azide, PETN, RDX, or tetryl.

Confinement is an important factor in both the growth of detonation and the effective output of stable detonation. It might be expected that inertia (density) is the only important factor in confining a detonating explosive; however, it is not quite so simple. Only that material affected by the detonation within the reaction time can contribute to the confinement of the reaction. The effectiveness of the confining media therefore becomes a function of the shock velocity (speed of sound in the material) as well. Table 4-5 lists the acoustic impedance (velocity × density) of various confining materials. The critical air gap across which a detonation can be propagated is proportional to the acoustic impedance. It has been found that a fuze which had worked satisfactorily when the lead and booster were housed in a steel or brass container failed because the booster did not detonate reliably when die-cast zinc or plastic containers were used. (Ref. 17) The confinement provided by the zinc may have also been reduced by porosity as well as by its somewhat lower acoustic impedance. Acoustic impedance (Table 4-5) is a good criterion of confinement effectiveness. The object of confinement is to have the greatest mismatch possible between the explosive and the confining media so that as much of the detonation wave as possible is reflected back into the explosive.

In one way or another, gaps, barriers, or spacer materials are components of explosive systems. In some instances, the features are purposely designed into an explosive train; in others, they are inherent in construction just as is confinement. Bottoms of cups are barriers and manufacturing tolerances introduce gaps. In some instances, the combination of gaps and barriers is beneficial. For example, barrier fragments have transmitted detonation over a gap that was sometimes forty times that across which the air blast wave alone could carry it.

4-3.4 CONSTRUCTION

Initiators usually consist of simple cylindrical metal cups into which explosives are pressed and various inert parts are inserted. MIL-STD-320 (Ref. 18) describes design practices and specifies the standard dimensions, tolerances, finishes, and materials for initiator cups. In general, all initiator designs should conform to this standard. It is not, however, the intent of this standard to inhibit the development of new concepts so that an occasional departure may be necessary under special circumstances.

An example of a deviation from standard design is a coined cup, shown in Fig. 4-4(A). This design eliminates the need to seal this end of the cup. Another example of a special purpose shape is the concave bottom of the M100 detonator, shown in Fig. 4-5(B), that was designed to obtain a shaped charge effect.

Most primers and detonators are loaded between 69 and 138 MPa (10,000 and 20,000 psi). Exceptions include percussion and stab priming mixtures, which may be loaded at 207 to 552 MPa (30,000 to 80,000 psi), and the ignition charges of electric initiators, which are "buttered" onto the bridgewire in the form of a paste.

4-3.5 CLOSURE AND SEALING (Ref. 19)

Closure and sealing of explosive components can be accomplished by a variety of processes. Because evidence of explosive powder on the outside of most devices, particularly detonators, is cause for rejection, effective sealing of an explosive unit is a critical manufacturing step.

Various processes to make strong, leak-tight seals may be used. They range from welding and soldering to glass-to-metal sealing and epoxying, and each process is designed to meet specific requirements. Combinations of these processes are also used. Certain specifications, such as shelf

TABLE 4-5. AIR GAP SENSITIVITY RELATED TO ACOUSTIC IMPEDANCE OF ACCEPTOR CONFINING MEDIUM (Ref. 16)

CONFINING MEDIUM OF ACCEPTOR	ACOUSTIC IMPEDANCE OF ACCEPTOR CONFINEMENT $kg/(m^2 \cdot s) \times 10^8$	CRITICAL AIR GAP* mm	CRITICAL AIR GAP* in.
Lucite	0.7	1.6002	0.063
Magnesium	1.4	2.235	0.088
Zinc (die cast)	2.6	2.565	0.101
Babbitt	3.2	3.759	0.148
Brass	3.9	3.886	0.153
Steel (SAE 1020)	4.2	6.604	0.260

*Lead azide to tetryl, 3.81-mm (0.150-in.) diameter columns for 50% reliability of fire life and environmental conditions, may require hermetic sealing, whereas some applications have less stringent criteria. The subparagraphs that follow are a simplified description of the processes, applications, advantages, and disadvantages of the methods most commonly used to seal ordnance devices.

4-3.5.1 Welding

Welding can be simply defined as heating metallic parts and allowing the metals to flow together to form a fusion bond. When ordnance devices are welded, the amount of heat put into a device should be carefully controlled because of the proximity of explosive material. Many methods of welding have been established to seal explosive devices.

4-3.5.1.1 Resistance Welding

Resistance welding is a process in which bonding is attained by heat produced from ohmic heating and by the application of pressure. Resistance welding is somewhat unique because filler material is rarely used and fluxes are not required.

There are three critical parameters in resistance welding. They are (1) the amount of current passing through the work, (2) the pressure transferred by the electrodes to the work, and (3) the amount of time the current flows through the work. The two surfaces being joined provide the maximum resistance in the circuit and, therefore, the location of maximum heating. Pressure applied during heating forces the mated parts to bond.

Although there are many types of resistance welding, this discussion focuses on two with specific applications to sealing ordnance devices, stitch and projection welding.

Stitch welding involves overlapping spot welds to bond two pieces together. It is often used to bond a thin closure disc to a relatively larger header or cup. Stitch welding provides very low heat input, and the equipment is typically simple.

Projection welding is done at the contact points of projections that extend from one of the workpieces. Projection shapes and sizes are usually determined by the thickness of the thinner workpiece and specific application. When possible, projections should be located on the thicker workpiece. If welding dissimilar metals, the projections should be located on the workpiece with greater conductivity. (See Fig. 4-9.)

Projection welding typically decreases the amount of energy necessary to make a weld. This process also improves heat balances when thin materials are welded to thick materials. Projection welding allows several welds, or possibly a complete closure weld, to be made at predetermined locations with one weld pulse.

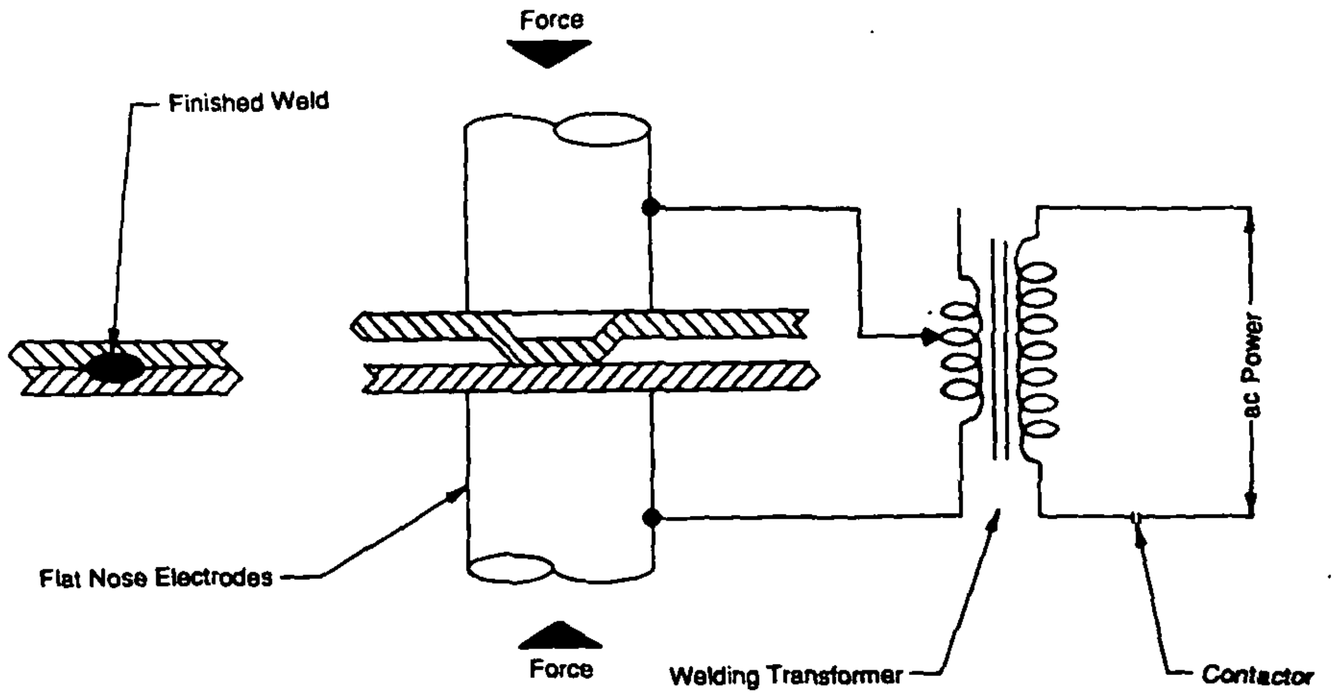


Figure 4-9. Projection Welding (Ref. 19)

4-3.5.1.2 Gas Tungsten Arc Welding

Another method of welding occasionally used to seal ordnance devices is gas tungsten arc welding (GTAW), commonly referred to as TIG welding. TIG welding is a process by which a bond between two metals is formed by heating them with an arc between a tungsten (unconsumable) electrode and the workpiece. Unlike resistance welding, filler metal may or may not be used. An inert shielding gas protects the weld environment and shields the hot tungsten electrode from the oxygen and nitrogen in the air. Most metals and alloys make high-quality welds using this process. Because there is no slag and very little spatter, postweld cleaning is virtually eliminated. TIG welding of explosive devices typically requires the use of heat sinks to dissipate the high heat input characteristic to this form of welding.

TIG welding is commonly associated with low volume and relatively higher initial costs than other forms of arc welding. However, the process offers the capability to weld various thicknesses and in many positions, so it can be justified as a method of sealing.

4-3.5.1.3 Ultrasonic Welding

Ultrasonic welding is a solid-state welding process using high-frequency vibrating energy to bond workpieces held together under pressure. The combination of clamping forces and vibratory forces creates stresses in the base metal and produces minute deformations. These deformations introduce a moderate temperature rise in the base metal at the weld zone. Because the weld is not raised to the melt temperature, no nugget is formed. The high-frequency vibration also aids in cleaning the weld area by breaking up oxides and removing them. The process is typically limited to extremely thin materials; however, most ductile material and many dissimilar materials can be welded ultrasonically.

The high-frequency energy can be delivered to the workpiece in many ways. Contact methods may range from tips similar to spot welding to a wheel configuration like that of roll welding. Although ultrasonic welding is used extensively in the aerospace and electronics industries, individual applications must carefully consider the effect of high-frequency vibrating energy on the workpiece or device.

4-3.5.1.4 Electric Beam Welding

Electron beam welding (EBW) is a welding process in which the metallic bond is formed using heat from a concentrated beam of high-velocity electrons. Heat is generated as these electrons bombard the workpiece, and virtually all of the kinetic energy of the electrons becomes heat. The entire process must take place within a vacuum because electron beams are easily deflected by air. This requires specially designed pumps, motors, and travel mechanisms. Some work has been done with nonvacuum EBW; however, the process is very restrictive.

EBW provides excellent weld penetration. To seal small ordnance devices, tremendous penetration is not usually required; however, precise penetration or "spike" welds are often desired. EBW provides a relatively low heat input and produces a heat-affected zone much smaller than that of an arc weld. This smaller, heat-affected zone is very advantageous when welding explosive devices.

In addition to the reduced heat input, the distortion of an EBW is minimized because of the almost parallel sides of the weld nugget. Cooling rates tend to be higher. Although these rates are good for most metals, they may cause cracking in metals with high carbon content. Most metals can be electron beam welded and very few welds require filler material. Precise weld joint design is important.

Electron beam welding is very often used for hermetic sealing. EBW is a very fast process and is a good candidate for automation. This high rate of productivity aids in justifying the relatively high capital investment required to obtain an electron beam system.

4-3.5.1.5 Laser Welding

In laser beam welding (LBW), metals are bonded by heat from a concentrated light beam impinging upon the work surfaces.

The laser beam, the highest energy concentration of any known source, can be projected with virtually no divergence and can be focused with conventional optics to a precise spot. The beam is coherent with a single frequency; however the beam frequency used varies with the specific application. The most commonly used wavelength for welding is 1.06 μm.

Lasers are particularly useful in applications requiring precise and well-defined welds, such as sealing small explosive devices. Lasers operating at 1.06 μm are easily handled by conventional optics and can be focused to spot sizes on the order of 0.13 mm (0.005 in.) in diameter. Lasers are especially useful in applications requiring weld penetration of 1.5 mm (0.06 in.) or less. Laser welds tend to be more shallow than electron beam welds. (See Fig. 4-10.)

Lasers have many advantages in welding or sealing explosive devices. LBW has many of the same advantages as the EBW process. Laser welding can be done quickly, provides relatively low heat input, leaves a relatively small heat-affected zone, and is more capable of welding dissimilar metals than resistance or arc welding. Also they do not require a vacuum environment, and this facilitates production. Laser welds typically do not require filler material, but accurate joint design is very critical.

The narrow heat-affected zone and the high aspect ratio of that zone minimize distortion and facilitate welding near glass-to-metal seals. However, the narrow heat-affected zone also allows rapid cooling, which produces large thermal differences in the weld metal and base metal. This can cause cracking in some materials, especially carbon steels. Consequently, laser parameters are often tailored to minimize thermal stresses.

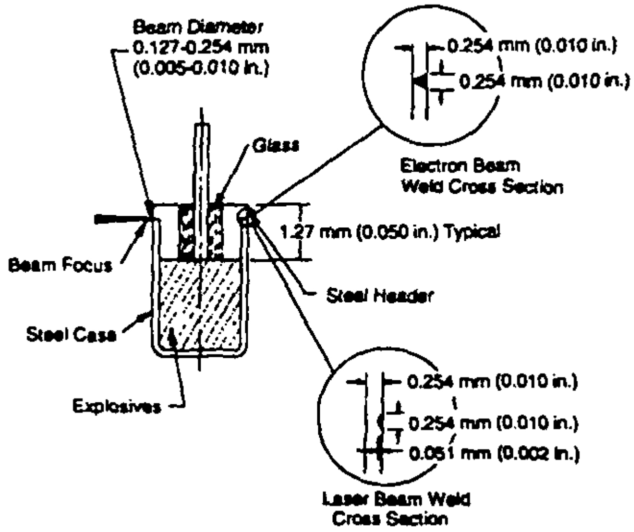


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Figure 4-10. Laser Welding (Ref. 19)

Laser welding is usually performed under atmospheric conditions with the assistance of an inert shielding gas, such as welding-grade argon. The gas provides an inert atmosphere and reduces oxidation at the weld. It also removes plasma created at the weld, which can obstruct the beam path and possibly damage the optics near the workpiece.

Lasers have been used for years to seal heart pacemakers hermetically, as well as to seal lithium batteries used in pacemakers and in wristwatches. One very common source of laser energy to seal these devices is the pulsed neodymium-yttrium-aluminum-garnet (Nd:YAG) laser. A continuous seam is created by overlapping the weld spots. Weld rates are limited by the machine pulse rate, and the acceptable weld overlap (generally 75%). Weld speeds of up to 3 m/min (120 in./min) are possible.

4-3.5.2 Soldering

Soldering is a metallurgical joining method that uses a filler metal with a melting point below 450°C (840°F). Soldering depends upon wetting for the bond formation. Solder is a filler metal that does not require diffusion or intermetallic compound formation to create a bond. Brazing is similar to soldering except that the filler metal melts at a temperature above 450°C (840°F).

Soldering is a very popular way of sealing and is commonly used to secure a header into a cup and provide a hermetic seal. A 63% tin/37% lead composition is widely used in ordnance devices because of its low melting temperature, which allows the solder to flow without heating the explosive mixture to the point of ignition.

Other solder compositions are used depending upon the specific application and materials being joined. In general, solder joints must be very clean prior to the bonding.

The selection and application of flux used to clean and remove oxides from the surface of the metal are critical to the solder operation. Acidic fluxes must be completely removed after soldering to prevent pitting and corrosion in the soldered joint. Solders are also available with flux inside the core. They are often easier to handle and can simplify production.

Soldering is useful for creating hermetic seals. With the proper combinations of joint design, solder, and flux, a relatively low-cost seal can be achieved. Several methods of soldering are applicable to sealing ordnance devices; they differ only in the source of heat to melt the solder.

4-3.5.2.1 Induction Soldering

In induction soldering, the heat required to melt the filler material is obtained from the resistance of a workpiece to an induced electric current. The workpiece is essentially used as the secondary of a transformer converting electric energy into heat. (See Fig. 4-11.)

No contact with the induction source is necessary. The depth of heating of the workpiece is basically controlled by the frequency of the power source and the heating time. In general, smaller parts are heated at high frequencies and larger parts at lower frequencies. Induction coils or plates can be oriented in various positions to achieve desired heating. Plastic inserts are often used inside the coils to hold the workpiece during heating.

Hermetic sealing by this method usually involves the use of a solder preform placed along the joint to be sealed. Flux may be added, or a solder with a flux core may be used. The workpiece and solder preform are then heated to allow the solder to flow and create the desired seal.

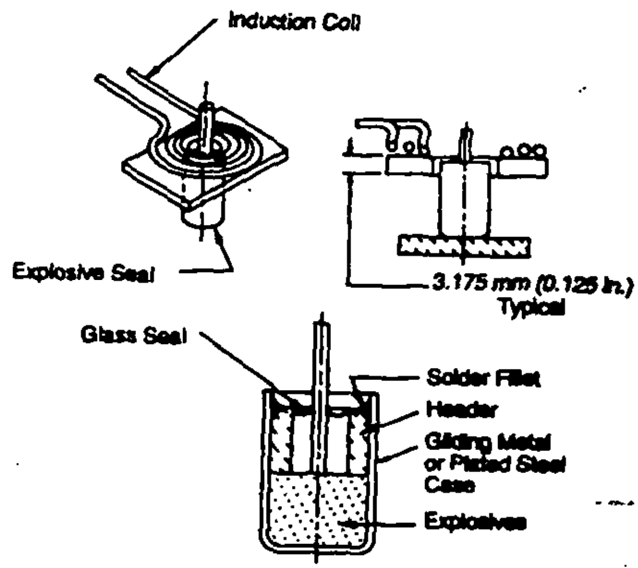

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Figure 4-11. Induction Soldering (Ref. 19)

4-3.5.2.2 Hand Soldering

Hand soldering, or iron soldering, most often involves some type of hand-held iron as the heat source. Various shapes of irons or tips can be used in order to accommodate specific applications.

Although soldering reaction and process are similar to other methods, hand soldering requires more operator talent. This method is often used when workpieces to be sealed may not be uniform and not adaptable to automatic soldering procedures. Hand soldering also allows very localized heating, which can be crucial to the protection of temperature-sensitive devices.

4-3.5.2.3 Infrared Soldering

In infrared soldering, the heat to melt the filler metal and promote wetting to a base metal is obtained through infrared rays. Also only the top layers of the work are heated, so heat input is minimal. Used primarily in electronics and miniature soldering, the infrared method is particularly adaptable to continuous production. Banks of infrared sources can easily be positioned to heat part of a conveyor system to increase productivity.

4-3.5.3 Glass-to-Metal Sealing

Glass-to-metal seals (GTMS) provide a unique way to maintain complete isolation of one environment from another, yet they allow electrical contact between the two. Seal shape and size can vary depending upon the specific application. Seals can be made flush or can be produced and then ground flush. In those ordnance devices in which explosive powder is pressed directly over a bridgewire, a flush surface is required to support the bridgewire during loading.

In making a GTMS, there are basically two types of fusing processes, matched and mismatched. In matched seals the thermal expansions of the glass and metal members are similar, and sealing is achieved by an interface bond between them. Mismatched or compression seals, however, contain glass and metal members with different coefficients of expansion. Thus the seal is created by the compressive pressure induced in the glass by the outer metal member.

Glass-to-metal seals are most often used in combination with another form of closure sealing to form a hermetic seal. For example, a GTMS assembly may be soldered in a cup to complete the hermetic sealing of an explosive device.

4-3.5.3.1 Matched Seals

The most important factor in a matched seal is the interface bond between the glass and metal. Pretreating the metallic components prior to sealing forms oxides that will later interact with the glass to create a strong and hermetic bond. The amount of oxide present on the metal is critical to the formation of a good seal. The actual sealing, as well as the pretreating of components, is done in controlled, high-temperature environments. The temperature, atmosphere, and speed at which the seals pass through these environments are all very accurately controlled.

Matched seals are advantageous in environments experiencing extreme variations in temperature. By using glass and metal with similar coefficients of expansion, a completely unstressed seal is provided. Seals using nickel-iron-cobalt alloys are typically matched in design because of the thermal expansion characteristics of the material.

These seals permit relatively thin-walled outer shells, which can be stamped rather than machined in order to reduce cost.

4-3.5.3.2 Compression Seals

A compression seal is often used for a device that must withstand high differential pressure. Because glass is very strong under compression and weak in tension, the thickness of metal surrounding the glass is very critical. In a compression seal, hermeticity is accomplished by keeping the glass in heavy compression by a strong outer metal shell. The glass, in turn, transmits a compressive force to the inner electrode. As the components are heated in the sealing furnace, the outer shell expands to a larger inside diameter; the glass then becomes soft and flows to fill the cavity. As the seal cools, the glass sets, and the outer metal shell contracts more than the glass. As the seal continues to cool, the glass comes under compression and a very strong mechanical seal results. The outer member must be strong enough to keep the seal under compression because if the glass is allowed to come under tension, the seal could crack and fail.

4-3.5.4 Epoxy Sealing

Epoxies are used in many ways to create seals in ordnance devices. Although epoxy is not normally used in applications for which hermeticity is required, it is often used to seal devices for which leak rates in the range of 1×10^{-5} std cc/s are acceptable. Therefore, epoxy is usually not used when good hermeticity is required.

Epoxies or sealing compounds for ordnance applications can be divided into two general categories, potting compounds and adhesives. Potting compounds are typically used to fill a void or totally encapsulate a device. They may be used to support lead wires and provide a moisture barrier. Potting is not used to structurally hold the lead wires or electrodes in place but only restrain excessive movement. In ordnance, adhesives are used to bond parts together physically and often to create waterproof seals. Epoxy adhesives have been shown to give excellent moisture protection without the cost of making a hermetic seal.

Epoxies able to withstand various environments and conditions are currently available. Epoxy preforms are also available, which allow cleaner and faster batch processing. The wide variety of epoxies and epoxy systems on the market allows the user to tailor physical and chemical properties to specific applications. Epoxy systems provide an inexpensive sealing or bonding alternative, especially when true hermetic sealing is not required.

4-4 OTHER EXPLOSIVE COMPONENTS

4-4.1 DELAY ELEMENTS

Delay elements are incorporated into an explosive train to enhance target damage by allowing the munition to penetrate before exploding or to control the timing of sequential operations. When the explosive train provides a time lag, the component creating this lag is called a delay element. The delay must of course be incorporated in the fuze so that it will not be damaged during impact with the target. This feature is most easily achieved by placing the fuze in the base of the munition. If this placement is not possible, the delay must be buried deep in the fuze cavity for protection if the forward portion of the fuze is stripped from the munition on target impact.

Generally, delay columns burn like cigarettes, i.e., they are ignited at one end and burn linearly. Delays may be ignited by a suitable primer. Ignition should occur with as little disruption of the delay material as possible because a violent ignition can disrupt or even bypass the delay column. For this reason, baffles, special primer assemblies, and expansion chambers are sometimes included in a delay element. A typical arrangement is that of Delay Element, M9, shown in Fig. 4-12. Representative delays covering various time ranges have been compiled in MIL-HDBK-777 (Ref. 15).

The harmful effects of moisture and other atmospheric gases make sealed delay elements desirable in all cases and mandatory for fuze designs that are not adequately sealed against the ingress of moisture.

Delay powders are divided into two categories: those whose reaction products are largely gaseous and those known as gasless. All current design effort has been applied to gasless delays. Gasless delay compositions are superior to other types, particularly if long delay times are needed or if space is limited and the escape of hot gases cannot be tolerated. In general, gasless delays are pyrotechnic mixtures of an oxidant and a metallic fuel carefully selected to yield a minimum volume of gaseous reaction products.

Delays that are sealed or protected from the atmosphere produce more consistent times and have better storage characteristics. Hence there is a trend toward totally sealed delay systems.

4-4.1.1 Gas-Producing Delay Mixtures

The largest class of gas-producing delays is black powder elements (Ref. 1). Since the burning of gas-producing mixtures depends on the transfer of heat between the gaseous reaction products and the solid, the rate is a direct function of pressure. The burning surface is all of the surface exposed to the gas and includes pores and cracks in the pellet or column. To prevent infiltration of the gases, which could cause erratic delay time, including instantaneous blowby, the delays are often loaded at pressures of 414 to 483 MPa (60,000 to 70,000 psi) in increments having a length-to-diameter ratio (*L/D*) of 1.

Black powder is hygroscopic and must be kept dry; thus a sealed element is required. In delays up to approximately 0.4 s, an obturated system is used. For longer delays a vented system is required to avert bursting of the container (fuze) or excessively fast burning rates. Consequently, seals that vent under pressure are used. Two such arrangements are shown in Fig. 4-13.

Delay times extend from a few milliseconds to 60 s. The longer times are used for powder train fuzes that are still used on smoke and illuminating projectiles. The rate of burning of the vented delays is nominally 0.22 s/mm (5.5 s/in.) and varies with atmospheric pressures, such as changes experienced when fired from sea level to altitude. Time under 10 ms is difficult to attain with pyrotechnic mixtures because of pressure blowby from structural weakness of the thin column required. A solution exists, however, in the use of a pressure-type delay that consists of a thick column (*L/D* = 1) of low-density, coarse granule black powder pressed at 48 MPa (7000 psi) and involves a rapid buildup in pressure, which terminates in the rupture of a metal disk. See Fig. 4-14.

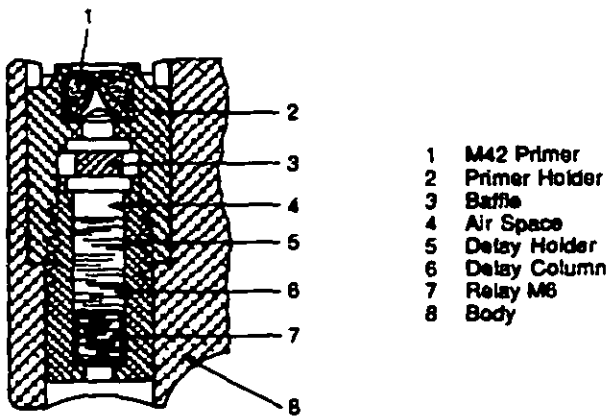


Figure 4-12. Delay Element, M9

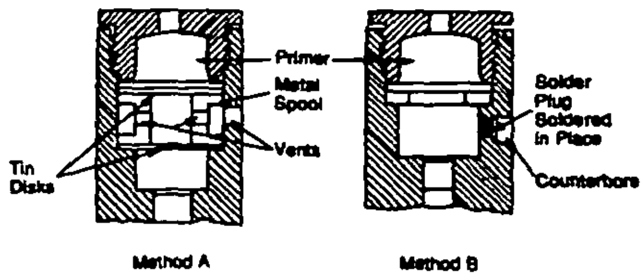


Figure 4-13. Sealing Methods for Vented Delays (Ref. 17)

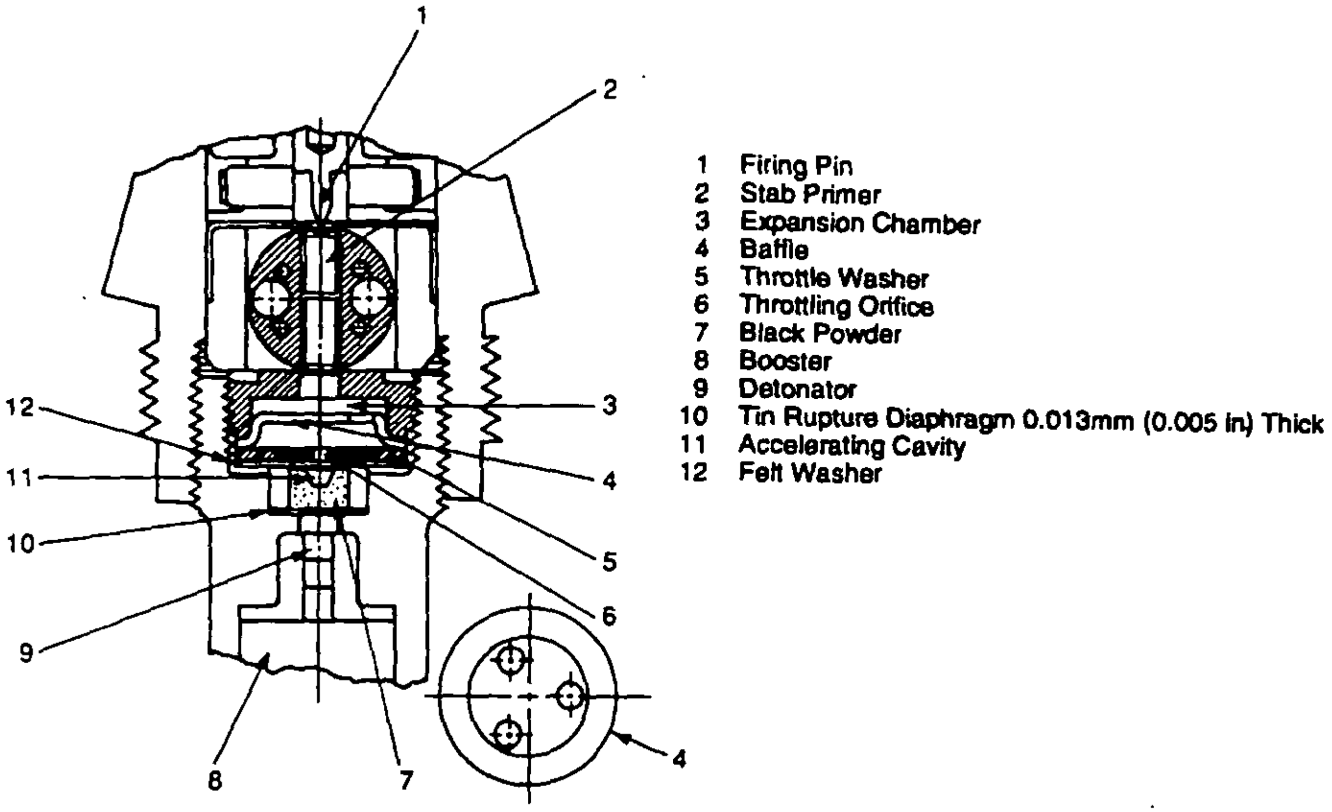


Figure 4-14. Pressure-Type Delay (Ref. 17)

Another method used to obtain delays under 10 ms is to press a column of lead styphnate at a pressure of 414 to 552 MPa (60,000 to 80,000 psi). Secondary explosives can be used to obtain very short delays by the burning to detonation phenomenon. This necessitates a long lead of the secondary explosive in the order of several inches in length and a confined system of igniting the explosive by means of a primer. Heavy confinement is required to enable the high-pressure buildup necessary to attain a detonating output.

4-4.1.2 Gasless Delay Mixtures

The limitations of gas-producing delay compositions and the inherent problems associated with their design have led to the development of numerous gasless delay mixes. Table 4-6 and Ref. 20 give the burning rates of current gasless delay compositions.

Since the burning of a pyrotechnic delay composition is essentially a heat transfer process and since the peak temperatures are lower than those of most explosive reactions, it is to be expected that temperatures of –54° to 52°C (–65° to 125°F), the usually specified operating range of fuzes, should have a significant effect on burning rates. In general, the effect can be up to a 25% variation.

4-4.2 RELAYS

A relay is a small explosive component used to pick up a weak explosive stimulus, augment it, and transmit the amplified impulse to the next component in the explosive train. Nearly all relays are loaded with lead azide, a primary explosive. The diameter of a relay is generally the same as that of the preceding and the following components.

Relays are commonly used to "pick up" the explosion from a delay element or a black powder delay train. They are sometimes used to receive the explosion transferred across a large air gap. Subsequently, they initiate a detonator.

A typical relay, the M11, is shown in Fig. 4-15. It has a closing disk of onionskin paper on the input end to contain the explosive but not to interfere with picking up a small explosive stimulus. Fig. 1-43 shows a relay in a fuze application.

4-4.3 LEADS

The purpose of a lead (rhymes with feed) is to transmit the detonation wave from detonator to booster. Leads, being secondary explosives, are less sensitive to initiation than either detonators or relays and are arranged accordingly in the explosive train.

TABLE 4-6. BURNING RATES OF GASLESS DELAY COMPOSITIONS (Ref. 20)

COMPOSITION, %	APPROXIMATE INVERSE BURNING RATE, s/cm	s/in.
$BaCrO_2/Cr_2O_3/B$	1.77-3.35	4.5-8.5
44/41/15	1.77	4.5
44/42/14	2.56	6.5
41/44/13	3.35	8.5
$BaCrO_4/B$		
amorphous	0.2-1.38	0.5-3.5
crystalline	3.54-4.92	9-12.5
95/5	0.59	1.5
90/10	0.24	0.6
$BaCrO_4/KClO_4/W$		
40/10/50	4.92	12.5
70/10/20	16.14	41
$BaCrO_4/KClO_4$(Zr-Ni) alloys	1.2-4.33	3-11
60/14/9(60-30)/17(30-70)	2.4	6
60/14/3(70-30)/23(30-70)	4.33	11
$BaCrO_4/PbCrO_4/Mn$	1-4.92	2.5-12.5
0/45/55	0.85	2.17
30/33/37	3.72	9.45
30/33/37	6.53	16.58
BaO_2/Se/Talc		
84/16/0.5 added	0.9	2.3
Red Lead/Si/Celite		
80/20/3 to 7 added	1.57-4.33	4-11
PbO_2/Zr		
28/72	< 0.2	< 0.5
$Zr/Ni/BaCrO_4/KClO_4$		
5/31/42/22	2.56	6.5
5/17/70/8	7.0	17.8

Leads may be of the flanged type or of the closed type. Flanged cups are open on the flanged end, whereas closed cups have a closing disk similar to that of the detonators shown in Figs. 4-4(A) and 4-4(D). Flanged cups are pressed, glued, or staked into place, but closed leads are usually held by staking. The choice of type is based on fuze geometry and production considerations.

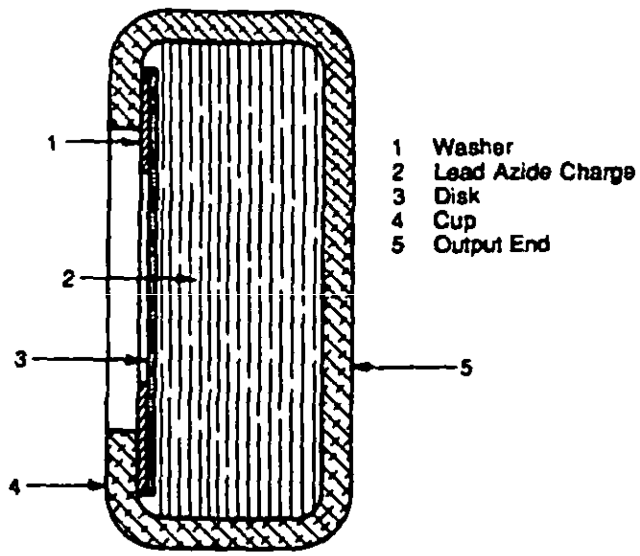


Figure 4-15. Relay, M11 (Ref. 15)

Loading pressures for leads range from 69 to 138 MPa *(10,000 to 20,000 psi).* For convenience in manufacturing, pellets are often preformed at lesser pressures and then reconsolidated in the cup. CH6, PBXN-5, and Comp A5 are the most common explosives for leads. Tetryl leads exist in some stockpiled ammunition.

Because leads are used to transmit detonation waves, their size and shape might conveniently be set by the configuration of the fuze. That is, the diameter is nearly equal to the preceding component, and the length depends on the distance between the preceding and succeeding components. Some leads have relatively small *L/D* ratios and other ratios are quite large. *L/D* ratios greater than unity are generally more reliable and effective. Some transmit detonation around corners or angles. The efficiency of the lead depends upon explosive density, confinement, length, and diameter. The effectiveness of the lead depends upon its initiating the next component (booster charge) over a sufficient area so that it too will form a stable detonation. Some configurations demand duplicate leads to assure reliable initiation of the booster charge.

4-4.4 BOOSTER CHARGES

The booster charge completes the fuze explosive train. It contains more explosive material than any other element in the train. The booster charge is initiated by one or several leads or by a detonator. It amplifies the detonation wave to a sufficient magnitude or maintains detonating conditions for a long enough time to initiate the main charge of the munition.

Although a booster may be made with one particular main charge in mind, boosters should be made as large and effective as practical to allow maximum interchangeability and future changes in main charge design, loading procedures, and explosive materials, which may require more effective booster output.

In general, however, the mechanical design of a fuze leaves a certain amount of vacant space in the fuze cavity. If the designer fills this with as large a cylindrical booster pellet as possible, he will be doing as well as is possible. Booster geometry is usually not critical in fuze designs, although in a few cases, such as narrow ogive bombs, it does become important.

4-4.4.1 Booster-Loading Techniques and Explosives

The density to which the explosive is packed into a booster charge affects both sensitivity and output. Thus loading techniques are important. At present, there are three methods used to load booster cups: (1) loading one or more preformed, fully consolidated pellets, (2) inserting a preformed pellet of low density and applying consolidating pressure with the pellet in place, and (3) pouring a loose charge into the cup and consolidating it in place.

The first method is the simplest, most economical, and the most widely used in fuze practice. Pellets can be produced to close size tolerances and uniformity. This method, however, is not acceptable with more complicated shapes or in some high-performance weapons. Conical shapes, for example, are always pressed in place. Clearances resulting from the accumulation of tolerances of the cup, containers, and pellets in the first method require the use of inert padding, such as cardboard and felt disks, to fill them. Each of the last two methods assures a firmer mounting of the explosive by completely preventing voids between pellet and cup. Hence one method or the other must be used when the round is subjected to acceleration sufficiently large to shift, fracture, or further consolidate the pellet because these conditions may lead to premature or improper detonations. The third method is the most convenient when only a few samples are needed.

CH6, PBXN-5, and Comp A5 are the most widely used explosives for boosters. Tetryl, PETN, TNT, and RDX have been used; however, they are no longer approved for boosters or leads for various reasons (Ref. 14).

4-4.4.2 Description of Booster Charges and Housings

It is important that loading density of boosters be uniform. If the density is allowed to vary unduly, this variability will be reflected in the profile of the wave front generated in the main charge. For this reason, usual practice is to limit pellet lengths to about one diameter, although *L/D* ratios of up to three have been used successfully.

In shaped charge munitions for which initiation of the main charge from the rear is essential, spit-back booster systems are sometimes employed. In these systems, such as shown in Fig. 4-16, the booster is pressed into a cup, which has a concave hemispherical shape at its base. This permits the booster to initiate a second booster located in the base of the munition over a large air gap. The system requires close control of all dimensions of the auxiliary booster, of the fuze body that contains it, and in the loading procedures. With the development of point-initiating systems using crush switches or piezoelectric devices with base fuzes, spit-back systems are not employed as often as they once were. However, spit-back initiation is being used on a 30-mm shaped charge warhead.

4-4.5 SPECIAL EXPLOSIVE ELEMENTS

A number of special explosive components may be found in explosive trains or as independent elements. These spe-

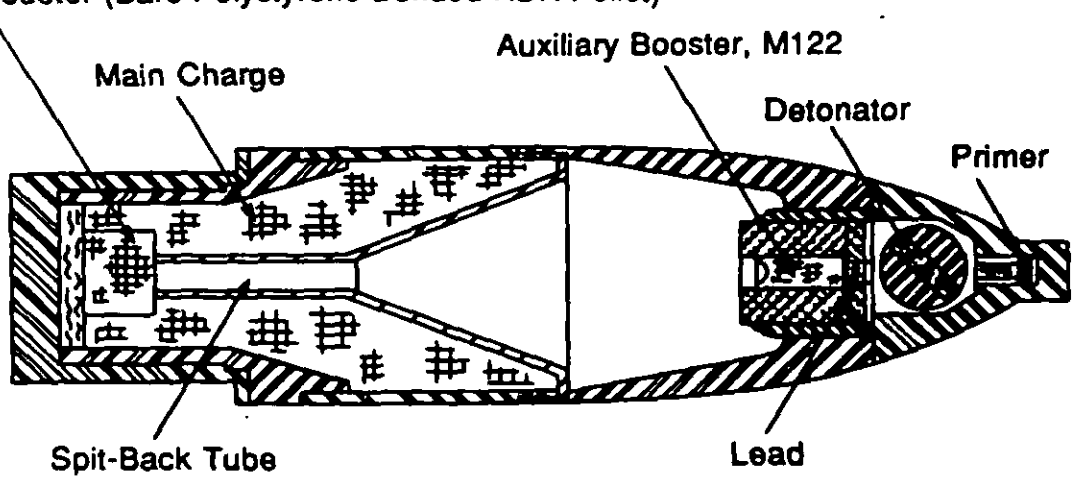


Figure 4-16. 70-mm (2.75-in.) HEAT Rocket With Spit-Back Explosive System (Ref. 21)

cial explosive components are discussed in the paragraphs that follow.

4-4.5.1 Actuators

An actuator is an explosive-actuated mechanical device that does not have an explosive output. In an explosive train it is used to do mechanical work such as close a switch, align a rotor, or remove a lock on a rotor. Most present actuators are electrically initiated. They are discussed more fully in par. 7-2.2.

4-4.5.2 Igniters (Squibs)

Igniters or squibs are used to ignite propellants, pyrotechnics, and flame-sensitive explosives. They have a small explosive output that consists of a flash or a flame. A typical squib is shown in Fig. 4-6. Igniters are electrically initiated and are similar in construction to electric primers. Igniters consist of a cylindrical cup (usually aluminum, copper, or plastic), lead wires, a plug and a wire or carbon bridge assembly, and a small explosive charge. The cup may be vented or completely open on the output end.

4-4.5.3 Fuses

Fuses are tubes of fabric or metal that contain a column of black powder or other pyrotechnic material. (*Note the spelling of "fuses" as distinguished from "fuzes".*) They are used to transmit fire to a detonator but only after a specified time delay; delay times are adjusted by varying the length of the fuse. Delay fuses were employed in early designs of hand grenades and pyrotechnic explosive trains and were used in demolition work and mining. Fuses have also been used in a self-destruct system with delay time exceeding 90 s.

4-4.5.4 Detonating Cord

Detonating cord, or prima cord, consists of a small fabric or plastic tube similar to that used for fuses; however, the core load is a detonating explosive instead of a pyrotechnic. The cord has the ability to carry a detonating wave along its entire length. Explosives used are PETN or RDX, both of which require a high-intensity shock wave for initiation. Core loads are from 4.3 g to 85 g per meter (20 to 400 gr per foot). This cord is widely used in the blasting and demolition industries to initiate isolated charges where simultaneity is desirable. This cord does not supply a safety delay as does fuse cord.

4-4.5.5 Mild Detonating Fuse

Mild detonating fuse (MDF) is basically a detonating cord of lower, and thus more controllable, energy (Ref. 22). Fig. 4-17(A) shows the tube form of MDF, and Fig. 4-17(B) shows the ribbon form. A thin-walled metal sheath (tube) replaces the nonmetallic sheath of the larger cord. The sheath is usually of lead for ease of manufacture and flexibility, although soft aluminum is used is as steel or even silver. The latter is applied to exotic uses such as spacecraft. Core loads are from 0.021 to 10.6 g per meter (0.1 to 50 gr per foot); however, reliability becomes a problem when the load drops much below 0.52 g per meter (2.5 gr per foot). Explosives used are usually PETN, RDX, and HNS.

An overlay of fibrous material and plastic is often used to minimize further the damage to the surroundings along the detonating path. MDF has many uses in munitions and fuzes. Fuze, MT, M577, par. 1-5.2, Fig. 1-33, and Fuze, XM750, par. 1-14, Fig. 1-52, are examples.

4-4.5.6 Flexible, Linear-Shaped Charge

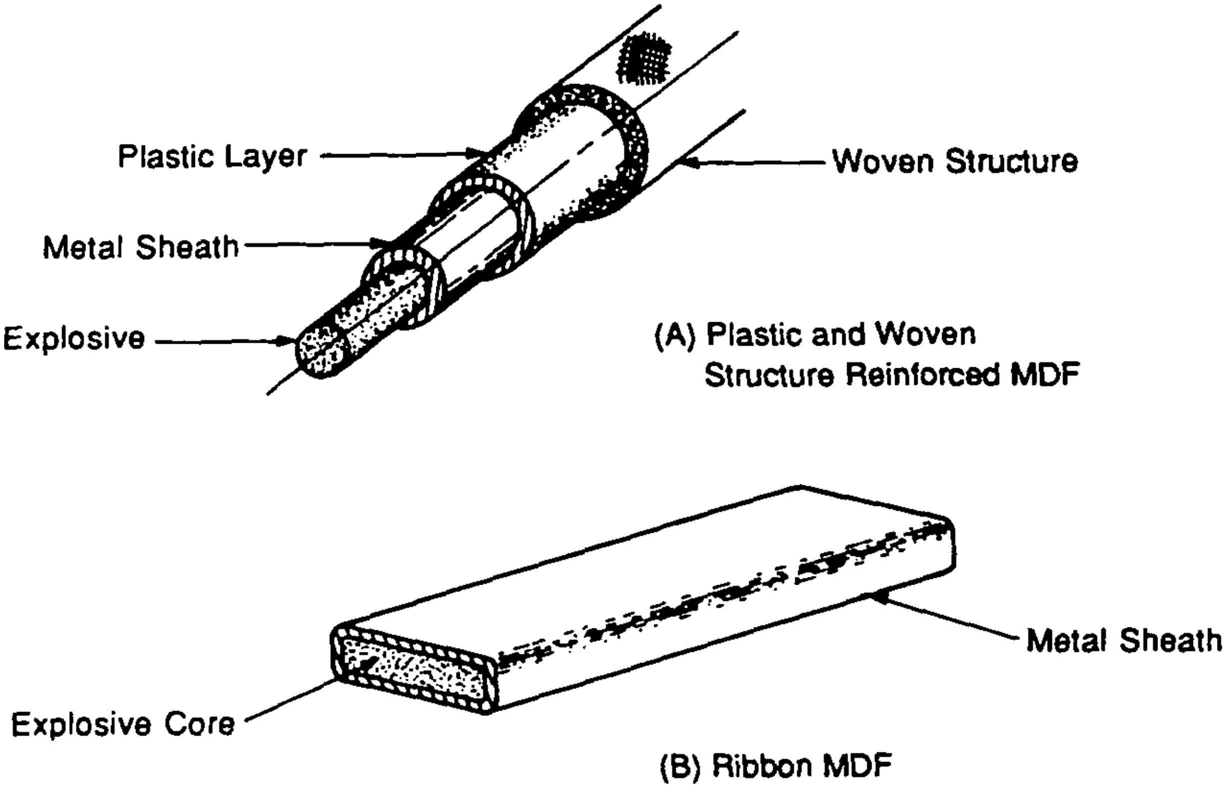
An outgrowth of the detonating cord and mild detonating fuse is the flexible, linear-shaped charge shown in Fig. 4-18. It is a metal-sheathed detonating cord geometrically configured in a chevron shape to obtain a shaped charge output along its length. Its availability is in core loads of 1.05 to 85 g per meter (5 to 400 gr per foot). Sheath metals are lead or soft aluminum. Its uses unclude stage separation, vehicle destruct, emergency escape systems, and other applications for which remote, fast, and reliable cutting of metal, wood (trees), wires, and tubes is required. This cord is used to open the outer case of cluster bombs to allow dispersion of submunitions, such as the MK 118 Mod 0 bomblet shown in Fig. 1-28.

4-4.5.7 Explosive Trails and Logic

Requirements exist for simultaneous initiation of widely separated points of a warhead, e.g., the implosion system of nuclear weapons and the selective detonation of nonnuclear warheads at various points to obtain a directional effect. Detonators at each point would require a safety and arming device (SAD) at each point unless high electrical energy EBW or EFI systems were used.

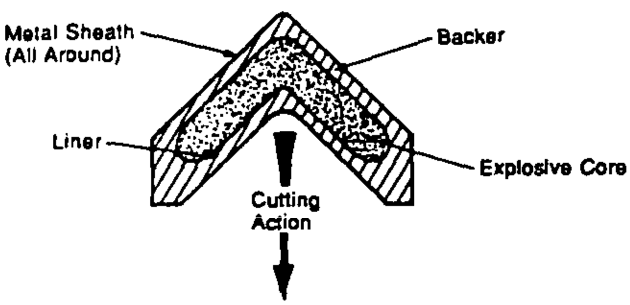
A channeled high-explosive (HE) charge called an explosive trail is a viable solution to multiple initiation points and requires only a single safety and arming (S&A) mechanism. Physically the trail consists of a plastic-bonded secondary explosive loaded in small rectangular channels that are milled or molded in an inert base of clear plastic or aluminum. It can be characterized as a very long explosive lead of small cross-sectional area.

Explosive trails can also be formed into an explosive logic SAD (Ref. 23). Fig. 4-19 represents a simple explosive logic SAD that is composed of inputs from three detonators labeled A, B, and C. To achieve a detonation output, the firing sequence must be in the exact order of A, then B, then C. The arrowheads represent null gates, which consist of a signal and a control channel. The intersections, where logic switching occurs, are labeled 1 through 6. If a detonation in a control channel reaches the intersection before a detonation in the signal channel, the latter will be cut off and the signal channel cannot proceed. Thus if B or C is fired before A, the null gates at Point 3 or 2 are cut (because of the shorter legs to the signal channel), and no explosive path is available to reach the output.



From the catalog of the Ensign-Bickford Company, Aerospace Division, Simsbury, CT, circa 1986.

Figure 4-17. Types of Detonating Fuses



From the catalog of the Ensign-Bickford Company, Aerospace Division, Simsbury, CT, circa 1986.

Figure 4-18. Flexible, Linear-Shaped Charge

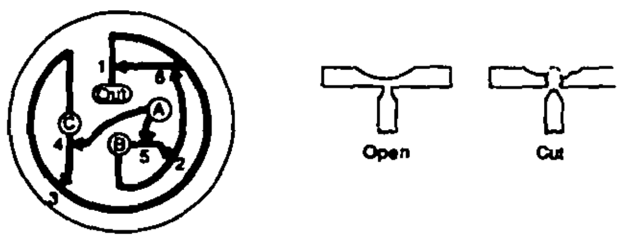


Figure 4-19. Simple Explosive Logic Device

Proper operation of this SAD is described in the paragraphs that follow.

If detonation from A reaches Intersections 4 and 5 before their respective signal detonations, 4 and 5 will be cut.

If detonation from Input B then occurs, it will not be able to pass Intersection 5. Instead it will travel along the signal channel and cut the gate at 6. The signal detonation from C will pass through Intersection 3. (It has not been cut.) The detonation then advances to Intersection 6. Input B has previously cut the gate at 6, so C cannot detonate the control channel at Intersection 1. The detonation from C can thus proceed along the longer signal channel, through Intersection 1, and into the output lead.

4-5 CONSIDERATIONS IN EXPLOSIVE TRAIN DESIGN

4-5.1 GENERAL

The explosive reactions employed in fuzes are usually started by relatively weak impulses. The function of the explosive train is to accomplish the controlled augmentation of a small impulse into one of suitable energy in order to cause a high order detonation of the main charge of the munition.

When the fuze designer designs an explosive train, he must first make a number of important decisions. Before he can select the explosive components or charges, he must have a clear idea of the input stimulus that starts the explosive reaction and of the final output the system is to have to produce the desired effect on the target. Between these extremes he must assemble a variety of explosive components to establish a detonation wave, introduce the desired delay, guide the detonation through the required path, and augment the detonation.

Good design practice must be applied to the selection of all explosive components. All components must be of the proper geometry and sensitivity and must have the correct density and confinement. They must be compatible with other explosives, adhesives, metals, and other fuze materials, and they must be assembled in a manner that will enable them to withstand the extremes of the factory-to-function environments. A valuable aid to the designer is the compendium of explosive train components used in modern fuzes given in MIL-HDBK-777 (Ref. 15). A standard component should always be used, if applicable, before designing and developing a special item.

The phenomena of initiation, propagation, and output for all of the components necessary to design an explosive train have been discussed in the preceeding paragraphs. From these data the designer should be able to build an explosive train that will meet the requirements of the fuzing system under consideration. Since the design of explosive trains has not been reduced to formula, only test and evaluation will determine the adequacy of the design.

4-5.2 PROBLEMS IN EXPLOSIVE TRAIN DESIGN

In the course of designing the train, many problems arise, such as determining the sizes of the various components, packaging each one, spacing or positioning them, and most important, making use of the new characteristics created by this train effect.

In fuzes employing delay elements, primers that produce essentially a flame output are used to initiate the deflagration. It is sometimes necessary to initiate delay mixes across a sizable air gap. Such an arrangement is practical, but care must be taken to avoid destroying the reproducibility of the delay time. If initiation from the primer is marginal, delay times may become long. On the other hand, the delay time may be considerably reduced if particles from the primer imbed themselves in the mix (and thus effectively shorten the delay column) or if the delay column is disrupted by the primer blast. Frequently, a web or baffle is used between a delay and its primer to reduce blast effects and particle impingement.

Flash detonators and relays are sometimes initiated from a distance by a primer, a delay, or even another detonator. The alignment of the two components is probably most important to successful initiation. If the air gap is confined, it should be at least as large as the detonator diameter and perhaps slightly larger.

A convenient method used to decide the adequacy of a given system is to vary the charge weight of the initiating component in order to find the marginal condition for initiation. Generally, the designer chooses a component with double the marginal weight.

After the amplification of the explosive impulse has carried through several components in the train (donor to acceptor, donor to acceptor, etc.) and a detonation has been produced, even more care must be exercised to complete the process. Initiation of a CH6 or Comp A5 lead from a detonator is indicative of the types of problems encountered. Once again, confinement is most important. A heavily confined charge can reliably initiate another explosive component, whereas a charge of twice that amount would be required if it were unconfined. Empirical data obtained under various conditions indicate that the effects of confinement are optimum when the wall thickness of the confining sleeve is nearly equal to the diameter of the column. On the other hand, the nature of the confining material is almost as important. Data have been obtained which show that a detonation can be transferred across an air gap nearly twice as far if the donor is confined in brass or steel rather than in aluminum. Relative data on gap distance for various acceptor-charge-confining materials are steel, 13; copper, 7; and aluminum, 4.

Fuze designers seldom work with unconfined charges. The explosive components are nearly always loaded into metal cylinders or cups. Even this relatively thin-walled confinement gives considerable improvement over air confinement in transmitting or accepting detonation. As indicated, further improvement can be made by increasing the confinement.

When a detonation is being transmitted from one explosive charge to another, the air gap should be kept small for greatest efficiency. Such a condition exists in initiating a booster from a lead. A different condition exists, however, when firing from a detonator to a lead. In this instance the output face of the detonator (donor charge) is confined in a metal cup; hence a thin metal barrier is interposed in the path of the detonation wave. The initiation mechanism of the acceptor charge may now be somewhat different because fragments of this barrier will be hurled at the surface of this next charge. A small gap between the components greatly aids initiation in this situation. Generally, when a detonation must be transferred across a metal barrier, the air gap between the donor charge and barrier should be negligible, but a small gap (approximately 1.6 mm (0.0625 in.)) between barrier and acceptor charge may be desirable. Beyond the interrupter, explosives must be used that are no more sensitive than those approved in MIL-STD-1316 (Ref. 14).

If confinement of the detonator is marginal, the output can be enhanced directionally by encasing it in a steel sleeve and/or by forming a hemispherical indentation in the output end to give directionality by means of a shaped charge effect.

Long or dogleg-shaped channels to transmit a primer or detonator blast to a flame-initiated detonator are troublesome in spin munitions. Centrifugal force pulls the hot slag particles to one side of a straight bore where side wall friction absorbs much of the energy intended for initiation. The dogleg, designed to bypass a delay element selectively, as shown in Fig. 1-43, exhibits a high failure rate under spin because the slag must change direction. The solution is either to increase the size of the initiating primer or detonator or to interpose a relay charge at the outermost point of the dogleg channel. The interposing of a relay charge is the method chosen most often. Static firing tests while the fuze is in a spin mode are useful in assessing the adequacy of this ignition train.

A problem seldom encountered in nonunderwater weapons is the significant impediment introduced by water infiltration between the detonator and lead. Obviously, the preferred solution is to seal out any water; otherwise a detonator-lead relationship, which has been shown to be totally adequate in a normal environment, can be a total failure under submerged conditions.

Designs occasionally appear in which a booster pellet is relied upon to act as a dimensional stop for a screwed-in-place retainer cup. This is not a recommended procedure because fracture of the pellet can occur and remain undetected.

Some geometries require a side initiation (right angle) of a lead charge. This initiation, however, is undesirable if a stable detonating wave is to be developed. In such cases side initiation can be made to work with specialized conditions of enhanced detonator confinement, directional orientation, and a lead of sufficient length to develop an adequate detonating wave.

Since the sensitivity of explosive varies inversely to its pressed density, it has been a practice to present the less dense end of a booster pellet toward the initiating lead. A "V" ridge in the pressing tool marks the denser end. Double-acting rams that press the pellet simultaneously from both ends can make this precaution unnecessary because the density gradient is de-emphasized.

Obturated delay elements that depend upon a crimp over the periphery of the primer to secure and seal are sensitive to crimping irregularities that cause leakage, and thereby induce long times, or cause duds. A screw cap is a more reliable closure and seal. If a screw cap is not used, a considerable amount of quality control is needed.

Sometimes in older designs the detonator is adequately out of line relative to the lead. If initiated in the out-of-line position, however, the detonator can crack or otherwise breech the side wall of the fuze and present a possible hazard to filler explosive or adjacent components. This situation is simply a structural problem, but it must not go undetected.

Aerodynamic heating with the faster munitions and the longer exposure times has necessitated development and use of explosives more resistant to heat, e.g., HNS.

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PART TWO
BASIC ARMING ACTIONS

Part Two explains principles involved and methods used in the arming process. The arming process provides a transition between two conditions: (1) the safe condition which is required for handling, transportation, and storage and (2) the armed condition which is required for proper detonation of the ammunition on or near the target. Chapter 5 presents the environmental energy sources available for aming the fuze. Chapters 6, 7, and 8 discuss mechanical mechanisms, electronic logic and power sources, and other unique devices and circuitry that are used in the arming process of fuzes.

CHAPTER 5
ELEMENTARY PRINCIPLES OF ARMING

This chapter covers the elementary principles of fuze arming. It begins with a description of the fuze arming process from the safe to the armed condition. The basic mechanical concepts involved are discussed. The environmental forces useful in the arming process as well as those that could be detrimental are enumerated and expanded. The ballistic environments covering gun-launched munitions with high acceleration, mortar and rocket munitions with low acceleration, and bombs with gravity acceleration are included. Pertinent equations to calculate the magnitudes of the forces useful for arming are given.

The sources of potential arming energy from the launch environment are listed as setback, creep, centrifugal acceleration, tangential acceleration, Coriolis acceleration, torque, ram air, aerodynamic heating, and propellant pressure. A description of the relative usefulness of each is given.

Three methods of sensing the environment within the gun tube at launch are explained. These methods are the sensing of the exit from the gun barrel by magnetic induction, the sensing of frontal air pressure, and the use of the bore rider system.

The use and application of nonenergy-producing environments for arming are explained as evaporation and light and darkness.

The nonenvironmental energy sources in use are explained as springs, electrical power, and metastable compounds. Restrictions on their use for safety purposes are given.

5-0 LIST OF SYMBOLS

A = cross-sectional area of projectile, m^2 (ft^2)
a = acceleration of the projectile, m/s^2 (ft/s^2)
C = moment of gyroscopic couple, N·m (lb·ft)
C_d = drag coefficient, dimensionless
c_p = heat capacity at constant pressure, J/(kg·K) (Btu/(lbm·°F))
c_v = heat capacity at constant volume, J/(kg·K) (Btu/(lbm·°F))
D = sensor diameter, m (ft)
d = diameter of projectile, m (ft)
E = open-circuit voltage, V
F = setback force, N (lb)
F_c = centrifugal force, N (lb)
F_{co} = Coriolis force, N (lb)
F_{cr} = creep force, N (lb)
F_d = linear aerodynamic drag force, N (lb)
F_t = tangential force, N (lb)
g = acceleration due to gravity, m/s^2 (ft/s^2)
H_p = output power, W (ft·lb/s)
h = depth of water, m (ft)
I = moment of inertia with respect to axis of spin, $kg\cdot m^2$ ($slug\cdot ft^2$)
K = ratio of heat capacity at constant pressure to heat capacity at constant volume = c_p/c_v, dimensionless
M = Mach number, dimensionless
m = mass of projectile, kg (slug)
m_p = mass of part, kg (slug)
N = number of turns in the coil, dimensionless
n = number of calibers of length in which rifling makes one complete turn, dimensionless
P = gas pressure on projectile base, Pa (lb/ft^2)
P_f = frontal pressure, Pa (lb/ft^2)
P_m = measurement of pressure at orifice, Pa (lb/ft^2)
P_s = stagnation pressure, Pa (lb/ft^2)
P_w = hydrostatic pressure, Pa (lb/ft^2)
Q = rate of flow impinging on the vane, m^3/s (ft^3/s)
r = radius of center of gravity (CG) of the part from projectile axis, m (ft)
r_f = correction factor for recovery temperature T_r, dimensionless
r_1 = outer radius of blade area, m (ft)
r_2 = inner radius of blade area, m (ft)
T_a = ambient temperature, K
T_o = temperature of air at stagnation point, K
T_r = recovery temperature, K
Δt = time for sensor to leave gun barrel, s
v = velocity of projectile, m/s (ft/s)
v_m = muzzle velocity, m/s (ft/s)
v_r = radial velocity, m/s (ft/s)

v_1 = speed of air reaching the vane, m/s (ft/s)
v_2 = speed of air leaving the vane, m/s (ft/s)
α = angular acceleration, rad/s^2
α_1 = angle of air reaching the vane, rad
α_2 = angle of air leaving the vane, rad
$\Delta\phi$ = change in flux, Wb
ρ = mass density of air, kg/m^3 (slug/ft^3)
ρ_w = weight density of water, N/m^3 (lb/ft^3)
Ω = precessional angular velocity, rad/s
ω = rotational velocity, rad/s

5-1 INTRODUCTION

The primary purpose of the fuze is to function the bursting charge in a munition at a specified time and place. The arming function of the fuze ensures that the munition can be activated only within specified limits of the time and place requirements. The need for many types of fuzes results from the numerous types of munitions in use and the various environments in which they must operate.

To ensure safety, all fuzes must be designed to withstand the effects of stringent environmental conditions encountered from factory to functioning at the target. Although some environments—such as pressure, spin, acceleration, and ram air—are used in the arming cycle, others—such as vibration, shock, and humidity—must be tolerated so that fuze performance during use will not be compromised.

In designing a fuze safety and arming device (SAD), it is very important to use the environmental forces that are the most predictable and consistent. It is good practice, and usually mandatory, to use at least two separate and independent environmental forces. These various forces, including those resulting from ballistic environments, are discussed.

5-2 MECHANICAL ARMING CONCEPTS

The safety and arming (S&A) mechanism of the fuze is positioned in the explosive train where it precedes only those high-explosive (HE) materials that have been approved for in-line use by the Services Safety Review Board. Table 5-1 contains a list of approved lead and booster explosives. The term "detonator safe" designates a particular status of the arming device. An unarmed fuze is said to be detonator safe when an explosion of the detonator cannot initiate or cause burning, melting, or charring of subsequent components in the explosive train (lead and booster charges). Fig. 5-1(A) shows a simple arming device that illustrates detonator safety.

TABLE 5-1. APPROVED EXPLOSIVES FOR ALL SERVICES

Composition A3	PBXN-6
Composition A4	DIPAM
Composition A5	HNS Type I or Type 2 GRA
Composition CH6	Tetryl*
PBXN-5	Tetryl Pellets*

*No longer manufactured. Not for use in new developments.

Fig. 5-1(A) shows how the out-of-line detonator is not subject to initiation by the firing pin. It also shows how accidental initiation of the nonaligned detonator would not initiate the lead charge or the booster. Conversely, Fig. 5-1(B) shows the in-line condition, after arming, in which the firing pin can reliably initiate the detonator and the detonator can initiate the explosive lead.

The arming process consists mainly of the actions involved in aligning the explosive train elements or in removing barriers along the train. The time for this process to take place is controlled so that the fuze cannot function until it has traveled a safe distance from the launching site, a distance beyond which the hazards to the launch crew asso-

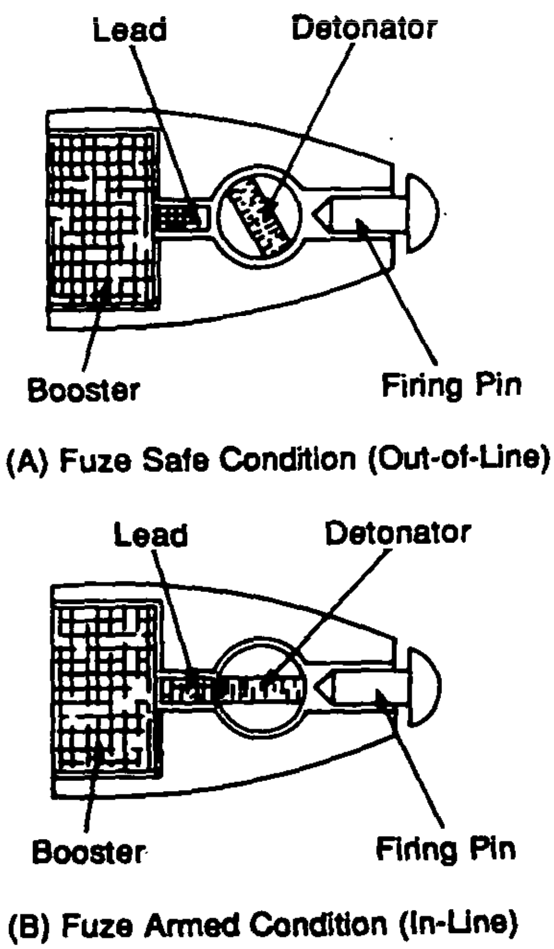


Figure 5-1. Simple Arming Device

ciated with early functioning of that munition are acceptable. For design purposes, it is often more realistic to convert distance into time and therefore consider the arming action in terms of elapsed time from launch. Hence an arming mechanism often consists of a device to measure an elapsed time interval. The designer must ensure that there is sufficient energy to align the train and to control the arming time in accordance with the safety requirements of the particular munition. Occasionally, in high-performance weapons an elapsed time inherent in the arming process provides sufficient delay to meet fuze safety requirements, but more often, the fuze designer must develop a suitably accurate arming delay time-measuring device.

Arming mechanisms operate with an input of energy that results from the launching and ballistic environments. The following environments or energy sources are frequently useful:

1. Setback acceleration
2. Ram air pressure
3. Angular acceleration
4. Deceleration (creep or drag)
5. Gravity
6. Aerodynamic heating
7. Hydrostatic pressure
8. Rotational velocity (centrifugal force)
9. Arming wires (pull pins)
10. Evaporation
11. Manual motion
12. Muzzle exiting.

Current safety criteria require that the fuze SAD be locked in the safe position by at least two independent safety mechanisms. The forces enabling these safety features must be derived from different environments. Sometimes it is not possible to use two independent ballistic environments to perform the enabling and arming processes. In these cases the designer is permitted to use an action taken to initiate launch, e.g., an electrical input from the launcher, as an environment. In order to use this action, however, the signal generated must irreversibly commit the munition to complete the launch cycle.

5-3 SEQUENCE OF FUZE BALLISTIC ENVIRONMENTS

The ballistic environments for which a fuze may be designed are depicted in Fig. 5-2. Munitions that are launched from guns experience high initial acceleration, which is ideal for use as an arming environment. This acceleration occurs within the gun tube; hence this phase of flight is termed interior ballistics. The free-flight phase is termed exterior ballistics, and the target engagement phase is defined as terminal ballistics. The solid line curve in Fig. 5-2 shows the phases of flight for a typical projectile. There is a narrow range between the interior and exterior ballistic regions called the intermediate ballistic phase. In this phase the munition has cleared the launch tube but is still exposed to the propelling gases.

Self-propelled munitions, commonly called missiles or rockets, may experience low-to-medium acceleration (5 to 5000 g). A typical missile acceleration curve is represented by the dashed line in Fig. 5-2. The other environment, shown by the constant acceleration line of Fig. 5-2, is limited to gravity and lack of gravity. Bombs, grenades, and

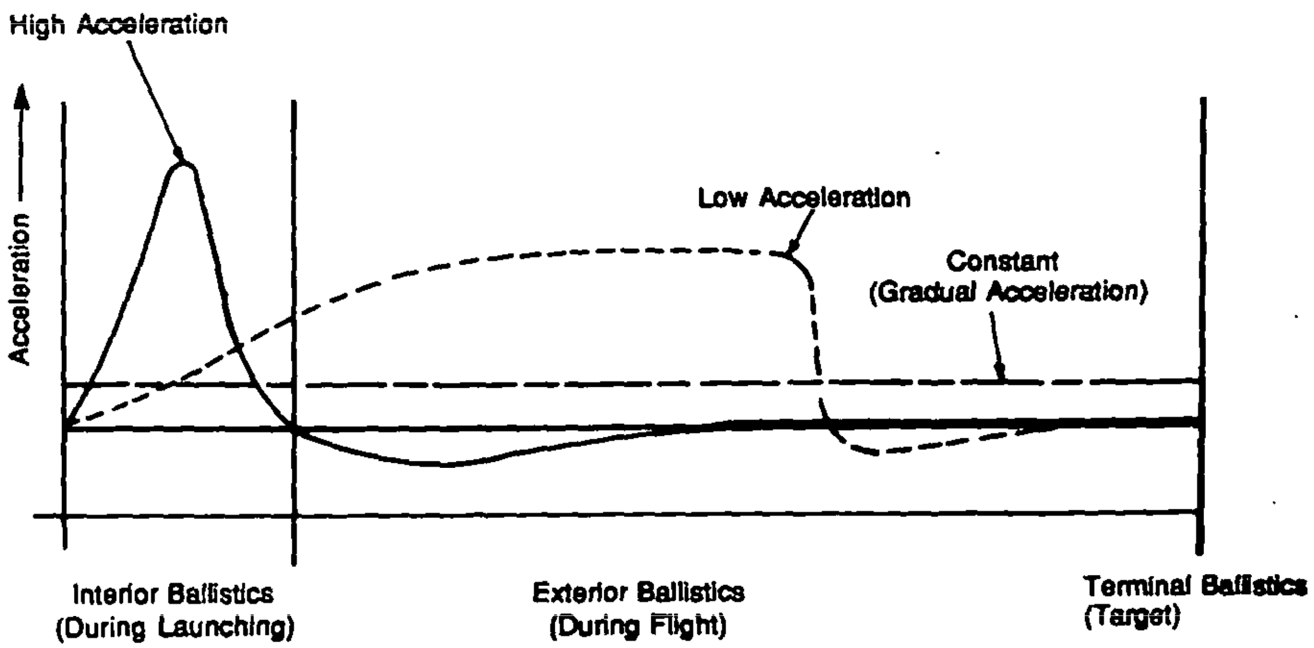


Figure 5-2. Ballistic Environments of a Fuze

stationary ammunition operate in this environment. Low-velocity (subsonic) bombs and mortar projectiles in free flight experience air drag forces that are below 1 *g* for a significant period of time.

5-3.1 BALLISTIC EQUATIONS

The forces that result from acceleration (setback) during launch, deceleration due to air drag, and in the case of normal artillery, rotational velocity for stabilization can be determined from the equations in the paragraphs that follow. They can then be used for designing the arming components.

5-3.1.1 Acceleration

Acceleration a of the projectile due to the rapid expansion of propellant gases within the gun tube is

$$a = \frac{PA}{m}, \text{ m/s}^2 \text{ (ft/s}^2\text{)*} \quad (5\text{-}1)$$

where

P = gas pressure acting on projectile base, Pa (lb/ft^2)
m = mass of the projectile, kg (slug)
A = cross-sectional area of projectile, m^2 (ft^2).

Since A and m are constant, the acceleration a is proportional to the propellant gas pressure P. A typical pressure-travel curve for a projectile in a gun tube is shown in Fig. 5-3.

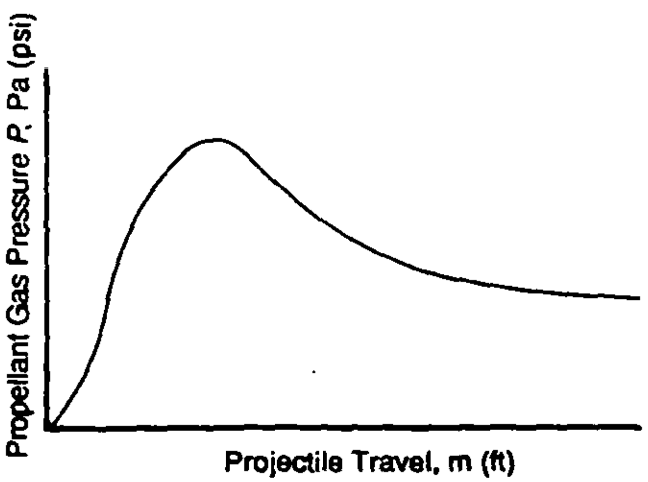


Figure 5-3. Typical Pressure-Travel Curve

*Although inch is a more convenient unit to use with fuzes, foot is used to simplify the equations.

5-3.1.2 Drag

A projectile decelerates linearly and rotationally during flight due to air resistance. The aerodynamic drag force F_d is computed by

$$F_d = \frac{\rho A v^2 C_d}{2}, \text{ N (lb)} \quad (5\text{-}2)$$

where

F_d = linear aerodynamic drag force, N (lb)
C_d = drag coefficient, dimensionless
v = velocity of projectile, m/s (ft/s)
ρ = mass density of air, kg/m^3 (slug/ft^3).

Drag depends on projectile shape and is least for slender bodies, i.e., it decreases with an increase in the ratio of length to diameter. Fig. 5-4 shows C_d relative to projectile velocity in Mach number for a specific projectile. Mach number M is the speed of the projectile divided by the local speed of sound.

There is no general technique for calculating the rotational aerodynamic drag force of a spinning projectile. Both the linear and rotational drag forces result in a decay of the linear and rotational free-flight velocities. This decay can be computed by using complex aeroballistic models of the projectile. The results of such calculations made on several typical projectiles indicate that the spin speed decays at roughly one-third the rate of linear velocity decay for many projectiles.

5-3.1.3 Rotational Velocity

Many small arms and artillery projectiles are stabilized by the spin imparted by the rifling in the tube. The rotational velocity ω due to this spin offers a potential energy source for the arming process. It may be calculated from

$$\omega = \frac{2\pi v}{dn}, \text{ rad/s} \quad (5\text{-}3)$$

where

n = number of calibers of length in which rifling makes one complete turn, dimensionless
d = diameter of projectile, m (ft).

5-3.2 BALLISTIC ENVIRONMENTS

Three types of ballistic conditions are considered: high acceleration, low acceleration, and acceleration due to gravity. Each condition is described in the paragraphs that follow.

5-3.2.1 High Acceleration

Projectiles fired from small arms, guns, howitzers, mortars, recoilless rifles, and most shoulder-fired rockets are

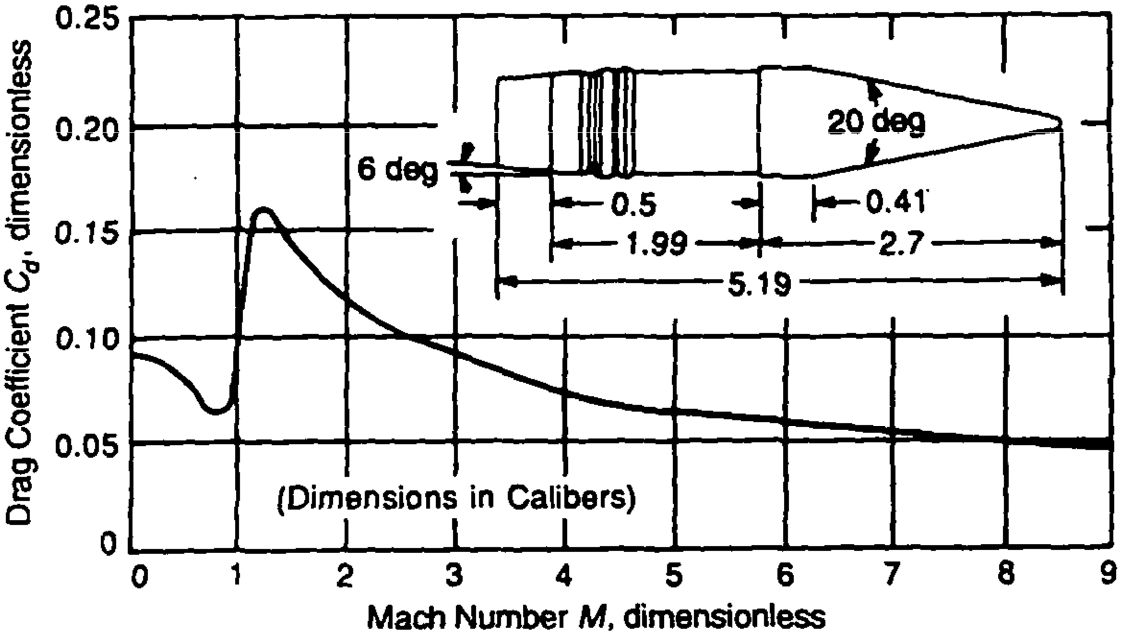


Figure 5-4. Drag Coefficient Versus Projectile Velocity

subjected to the ballistic environment called high-acceleration launching. During the interior ballistic period, the acceleration of the projectile can reach from 800 to 124,000 g, depending on the weapon, and then drop to zero a few calibers beyond the muzzle of the gun tube. Useful inertial forces created are setback and, for projectiles that spin, centrifugal and tangential.

In the exterior ballistic environment, i.e., free flight, the projectile is decelerated by the air resistance. The drag forces on the projectile produce creep of its internal parts. Finally, at the target the projectile encounters impact forces that often are of extreme magnitudes.

Both spin-stabilized and fin-stabilized missiles and projectiles are associated with high acceleration. In general, fins are used to stabilize projectiles having either low or very high velocities, and spin is used to stabilize those having intermediate velocities. Spin stabilization is usually limited to bodies having a length-to-diameter ratio of seven or lower.

The spin-stabilized projectile is subjected to all of the forces discussed in par. 5-3.1. Throughout free flight, the spin of the projectile decays, but the rate of decay is usually so small that for arming the designer may consider the spin constant for the first second or so of flight. Sensing of spin decay is often used to trigger self-destruction of the projectile if a target is not hit in aerial target applications.

Fin-stabilized projectiles launched with high initial acceleration are subjected to all of the forces discussed in par. 5-3.1 except those resulting from spin. These projectiles do not spin, or if they do, the spin rate is so small that the forces usually cannot be used for arming functions.

5-3.2.2 Low Acceleration

The second type of ballistic environment for which fuzes are designed is one in which a missile carries its own propellant. Since the propellant is consumed during the first portion of flight, it may be many seconds rather than milliseconds before the missile attains maximum velocity. Therefore, the acceleration is much less than that of a gun-launched projectile. Fig. 5-2 illustrates this condition.

Low acceleration is generally in the range of 3 to 100 g. Such accelerations can be as small as those produced by vibration or rough handling. To use this environmental condition for arming, a time-integrating-type arming device is essential in order to prevent handling forces from arming the fuze.

5-3.2.3 Acceleration Due to Gravity

Acceleration due to gravity is the major force acting on free-fall weapons such as bombs and canister-contained submunitions. Since this is not a unique environment, the designer must resort to manual, external mechanical operations or canister-induced environments to achieve a safe system. Bomb fuzes use arming wires, electrically induced signals from the aircraft, and ram-air-operated turbines or vanes to meet current safety standards. Canister-released munitions—mines, submunitions, grenades—use the interlocking constraints within the canister, electrically induced signals, and spin (in projectile-launched mines) as arming environments.

A number of designs have been proposed for a device that is capable of sensing accelerations less than one g. Such a device could be used as a second unique environment for those munitions that experience a significant portion of their ballistic flight at low velocity or at high altitudes where the *g* level is less than 0.9 *g*. Examples of such munitions are subsonic mortar projectiles, ballistic missiles, and free-fall weapons such as bombs and mines.

One such device is discussed in Ref. 1 and illustrated in Fig. 5-5. In this design the ball exerts a force on the sloping surface of the arms. This force results in a torque about the pivots that rotates the arms outward—represented by the dashed line in Fig. 5-5—and locks the timing disk to prevent the timer from running. When the ball experiences an essentially zero *g* condition, the spring force overcomes the torque generated by the ball, and the ball is cammed to the position shown by the solid line in Fig. 5-5 and then releases the timer. In this particular design the timer must run continuously for 25 s during which the *g* level must remain below 0.15. This design also works independently of the orientation of the device because there will always be a force from the ball on the arm by either a wedging action or as a direct component of its weight. Although a number of zero *g* devices have been proposed, none of these mechanisms have been incorporated into SADs other than in tests.

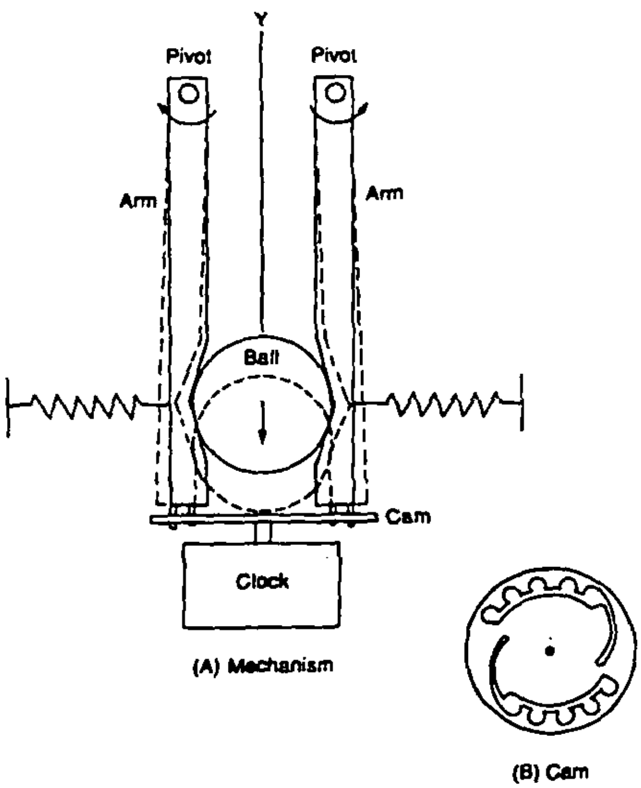


Figure 5-5. Zero *g* Mechanism (Ref. 1)

5-4 ENVIRONMENTAL ENERGY SOURCES

In addition to acceleration, munitions experience numerous types of shocks, vibration, and other environmental stresses from manufacture to target. Since these forces can vary widely in magnitude and duration, fuzes must be designed to sense and respond to the selected arming environments and to survive and remain safe from all others. This process can become exceedingly difficult at times since in some cases the ballistic environments selected for arming can be reproduced by shock, vibration, and mishandling. This is the principal reason for the requirement to use a minimum of two independent arming mechanisms in modern US fuze safety devices.

The paragraphs that follow discuss a number of environmental energy sources that can be used for arming in order to achieve a safe and reliable fuzing system.

5-4.1 SETBACK

Setback is the relative rearward movement of component parts in a munition undergoing forward acceleration during launch. The force necessary to accelerate the parts, together with the munition, is balanced by a reaction, or setback force. Setback force *F* is calculated by determining the acceleration *a* of the projectile and multiplying it by the mass m_p of the part affected.

$$F = m_p a = m_p \frac{PA}{m}, \text{ N (lb)} \qquad (5\text{-}4)$$

where

m_p = mass of part, kg (slug).

Fig. 5-6 shows the propellant force *PA* and the setback force *F* on the fuze.

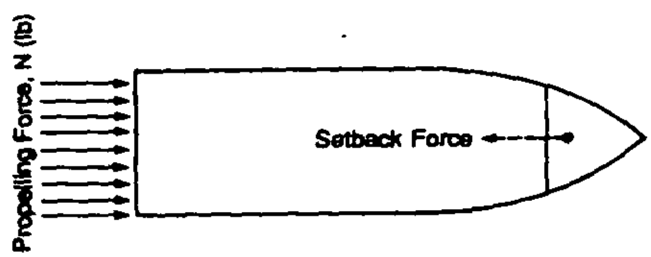


Figure 5-6. Setback Force on a Fuze Part

5-4.2 CREEP

Creep is the tendency for internal component parts of a munition to move forward as the munition decelerates from drag force as shown in Fig. 5-7. This reaction is similar to setback but is much smaller and acts in the opposite direction. The inertial force is calculated by multiplying the mass of the part m_p by the deceleration of the munition. By using Eq. 5-2, the creep force F_{cr} on a fuze part is determined by

$$F_{cr} = \frac{\rho A v^2 C_d m_p}{2m}, \text{N (lb)}. \qquad (5\text{-}5)$$

Figure 5-7. Creep Force on a Fuze Part

5-4.3 CENTRIFUGAL FORCE

A force commonly used as one of the arming environments of spin-stabilized projectile fuzes is centrifugal force. The designer should be aware, however, that whenever frictional forces are increased during setback, centrifugal arming forces may not prevail until the rotational velocity increases sufficiently or setback diminishes or ceases to exist. Centrifugal forces F_c are calculated from

$$F_c = m_p r \omega^2, \text{N (lb)} \qquad (5\text{-}6)$$

where

r = radius of the center of gravity (CG) of the part from the projectile axis, m (ft).

Fig. 5-8 illustrates this force.

5-4.4 TANGENTIAL FORCE

Tangential forces may be used for arming in some fuzes. For example, spring-biased weights move tangentially under the application of angular acceleration. The tangential force F_t is given by

$$F_t = m_p r \alpha, \text{N (lb)}. \qquad (5\text{-}7)$$

where

α = angular acceleration, rad/s^2.

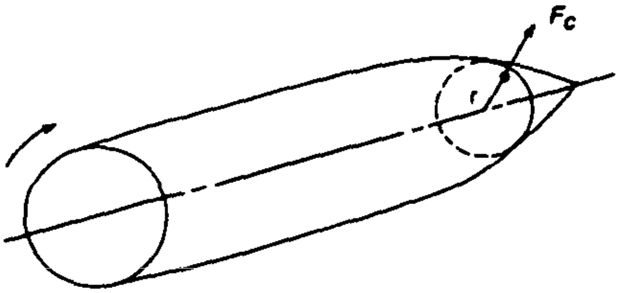


Figure 5-8. Centrifugal Force on a Fuze Part

5-4.5 CORIOLIS FORCE

The Coriolis force is seldom used to operate an arming device, but in certain fuze designs its effect may be taken into account to improve fuze operation. It is illustrated in Fig. 5-9 as a force on a ball in a radial slot that rotates at the angular velocity ω. If the ball is not moving relative to the slot, there is no Coriolis force. When the ball moves in the slot, there must be a Coriolis force. A simple explanation is afforded by citing the Coriolis force as that necessary to change the tangential velocity of the ball as its distance from the center of rotation changes. The Coriolis force F_{co} is calculated by

$$F_{co} = 2 v_r m_p \omega, \text{N (lb)} \qquad (5\text{-}8)$$

where

v_r = radial velocity, m/s (ft/s).

The Coriolis force, as shown in Fig. 5-9, is perpendicular to the radial motion of the part and is in the plane swept out by the radius.

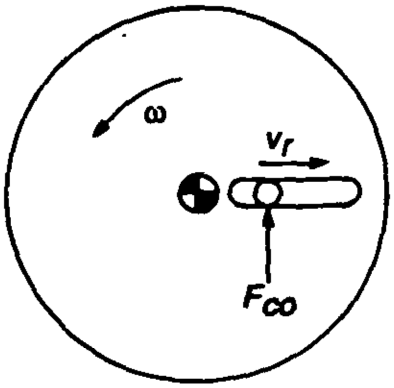


Figure 5-9. Coriolis Force on a Fuze Part

5-4.6 TORQUE

Torque is the product of a force and its lever arm. Usually a torque causes an angular acceleration of a part, and the acceleration is proportional to the torque in excess of that necessary to overcome friction. For fuze parts torque is associated with three main types of angular acceleration: (1) that experienced by all parts as the munition increases or decreases its spin, (2) that caused by centrifugal effects, and (3) gyroscopic precessional accelerations resulting from out-of-plane torques.

In the first type the torque is equal to the product of the moment of inertia and the angular acceleration. The effects of inertia are useful for creating short delays in arming devices.

Driving torque can be derived from centrifugal force acting at the center of mass of a moving part where the mass center is not coincident with the pivot point. The pivot axis may be perpendicular to the spin axis as in the Semple Centrifugal Firing Pin shown in Fig. 5-10(A) or parallel to it as in the rotating barrier of Fig. 5-10(B).

Gyroscopic torques result when a part experiences a torque about any axis other than its spin axis. It will precess, i.e., it will turn about still another axis. The rate and direction of turning can be calculated from the equations concerning the dynamics of rotating bodies. It is readily shown that the part will turn about an axis that is perpendicular to both the spin axis and the input torque axis. The moment of the gyroscopic couple C is

$$C = I\omega\Omega, \text{ N·m (lb·ft)} \tag{5-9}$$

where

I = moment of inertia with respect to axis of spin, $kg \cdot m^2$ ($slug \cdot ft^2$)
Ω = precessional angular velocity, rad/s.

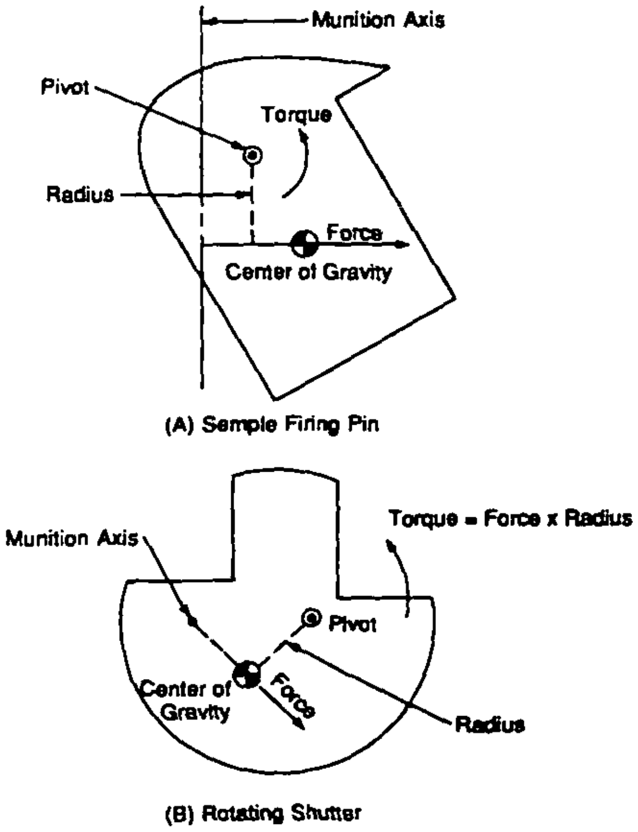


Figure 5-10. Torque on a Fuze Part

5-4.7 AIR RESISTANCE

The movement of the munition through air produces two potentially useful stimuli for arming. One is from the pressure, or ram air, and the other is from aerodynamic heating.

5-4.7.1 Ram Air

Aerodynamic forces are used to rotate or oscillate vanes in bombs, mortars, rockets, and submunitions. The torque created depends upon the airflow past the blades or the vanes. The power developed is a function of area, angle of attack, and mean radius of the blades, as well as of density and velocity of the airstream. Usually an empirical solution is developed from tests in a wind tunnel.

If it is assumed that a turbine-type vane is used to produce electrical power and/or mechanical power to effect fuze arming, the power output may be expressed by using Euler's equation of rate of change of angular momentum as (Ref. 2)

$$H_p = Q\rho\omega(v_1 r_1 \cos\alpha_1 - v_2 r_2 \cos\alpha_2), \text{ W (ft·lb/s)} \tag{5-10}$$

where

H_p = output power, W (ft·lb/s)
Q = rate of flow impinging on the vane, m^3/s (ft^3/s)
ω = angular velocity of the turbine, rad/s
v_1 = speed of the air reaching the vane, m/s (ft/s)
v_2 = speed of the air leaving the vane, m/s (ft/s)
r_1 = outer radius of blade area, m (ft)
r_2 = inner radius of blade area, m (ft)
α_1 = angle of air reaching the vane, rad
α_2 = angle of air leaving the vane, rad.

The turning of a propeller shaft controlled by an appropriate constant speed governor may be used to drive a mechanical gear train, which aligns an explosive train in a programmed period of time. Vanes may also be used to power a generator in electronic fuzing. As an alternate to rotating a vane, ram air can cause a vane to oscillate at a nearly constant frequency regardless of air velocity and thus eliminate the need for a speed regulator. (See par. 6-7.2 for further discussion.)

Ram air also can be used to operate fluidic generators, as shown in Fig. 1-46, or bellows and thereby eliminate some of the moving parts in an arming system. In addition to providing an independent arming stimulus, ram air devices have the additional advantages of simplistic design, low cost, and reliability and can perform mechanical arming delay functions or be used as a power source for proximity and electronic time fuzes.

5-4.7.2 Aerodynamic Heating

As munition speeds approach supersonic and beyond, the fuze, if it is located on the nose, can absorb significant heat from the compression of air during flow around the body. The temperature will vary from point to point being the greatest at the stagnation point at the tip. At the stagnation point the temperature of the air T_o is related to the Mach number M of flow and ambient temperature T_a by the expression (Ref. 3)

$$\frac{T_o}{T_a} = 1 + 0.2M^2, \text{ dimensionless} \tag{5-11}$$

where

T_o = temperature of air at stagnation point, K
T_a = ambient temperature, K.

The temperature at the surface of the fuze is less than this value due to conduction of heat into the regions of cooler air or fuze material. The temperature at the surface of the fuze, which is called the recovery temperature T_r, requires a correction factor r_f to Eq. 5-11. Thus the recovery temperature T_r is given by

$$T_r = T_a(1+0.2r_fM^2), \text{ K} \tag{5-12}$$

where

r_f = correction factor for recoverty temperature T_r, dimensionless
T_r = recovery temperature, K.

The value of r_f is approximately 0.9 for a wide range of conditions.

Although aerodynamic heating provides a unique environment potential for arming a fuze, it has not been used in any US or known foreign fuze designs. It has had some use as a self-destruct (SD) feature in small-caliber rounds, and in this capacity some reliability problems have existed.

The fuze and weapon designers are usually more concerned about the deleterious effects of aerodynamic heating. Aerodynamic heating can cause the plastic ogives of proximity fuzes to melt in approximately 0.1 s after muzzle exit at speeds of 1100 m/s (3609 ft/s) (Ref. 4). The resultant melting can cause surface roughness with attendant drag increases. In addition, aerodynamically induced thermal shock stress has led to cracking of plastic ogives, which has resulted in early bursting of the round. Thermal expansion coefficient, ultimate strain capability, and melting temperature are all important parameters in the selection of plastic materials for the noses of proximity fuzes. The weapons designer is also concerned with the effects on internal components, in particular the explosives in the warhead and the threat to the structural integrity of the weapon.

5-4.8 AMBIENT PRESSURES

Hydrostatic pressure is often used in underwater mines, torpedoes, and depth charges to perform arming and in some instances firing functions. Hydrostatic pressure P_w is determined by

$$P_w = \rho_w h, \text{ Pa (lb/ft}^2) \tag{5-13}$$

where

ρ_w = weight density of water, N/m^3 (lb/ft^3)
h = depth of water, m (ft).

Barometric pressure changes are used in some high-trajectory missiles for switching logic in electronic, barometric, or fluidic arming devices.

5-4.9 MUZZLE EXIT AND IN-BORE ENVIRONMENTS

5-4.9.1 Magnetic-Induction Sensor

Some projectiles are launched from smooth bores and therefore experience little or no spin. For this type of munition a magnetic sensor could be used to detect the time when the projectile exits the gun muzzle and thus provide a second signature independent of setback for arming a SAD (Ref. 5).

One such magnetic sensor design, which has been used on guided missiles, is illustrated in Fig. 5-11. The sensor contains a simple coil that fits around a permalloy keeper and center post. The ring-shaped permanent magnet, magnetized axially, surrounds the coil and contacts the keeper. The assembled sensor fits within a cylindrical recess in the projectile, flush with its surface.

When the projectile is inside the gun, the barrel completes the magnetic circuit as shown in Fig. 5-12(A). For illustrative purposes six flux lines are shown to pass through the magnet and the center post and to surround the coil, while two flux paths do not pass through the center post nor surround the coil. These latter lines are known as "leakage" paths. When the projectile is just outside the gun barrel, (Fig. 5-12(B)), two flux paths that originally surrounded the coil become leakage paths. Thus the number of flux lines surrounding the coil has been reduced from six to four. If the flux lines are plotted with a known scale by solution of Maxwell's equations, the actual flux change in webers can

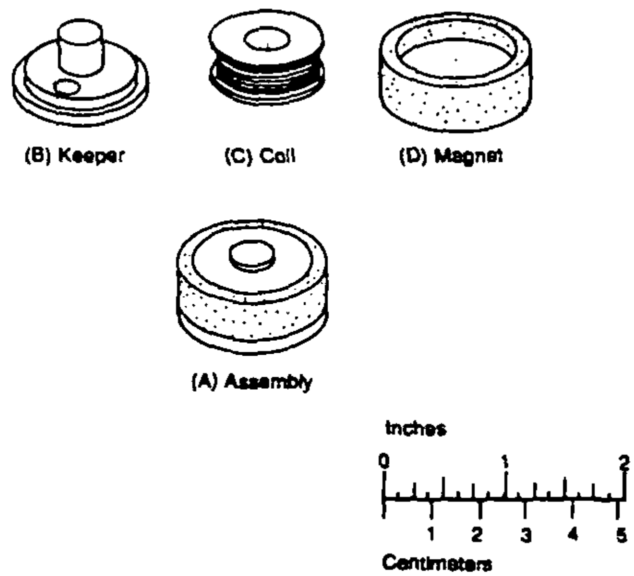


Figure 5-11. Assembled Induction Sensor and Its Components (Ref. 5)

be calculated by multiplying the number of lines by the scale factor.

The open-circuit voltage E at the coil terminals is given by Faraday's law of induction

$$E = \frac{-N\Delta\phi}{\Delta t}, \text{V} \qquad (5\text{-}14)$$

where

N = number of turns in the coil, dimensionless
$\Delta\phi$ = change in flux, Wb
Δt = time for the sensor to leave the gun barrel, s.

Since Δt is the sensor diameter divided by the muzzle velocity, Eq. 5-14 becomes

$$E = -N\Delta\phi\frac{v_m}{D}, \text{V} \qquad (5\text{-}15)$$

where

v_m = muzzle velocity, m/s (ft/s)
D = sensor diameter, m (ft).

Eq. 5-15 shows that the open-circuit voltage is proportional to the muzzle velocity.

This voltage could be used to fire an electroexplosive device to unlock the out-of-line mechanism in a fuze. Since this voltage is generated at muzzle exit, an appropriate arming delay would be required to achieve safe separation.

5-4.9.2 Frontal Pressure Sensor

When a projectile is fired, a transient pressure pulse is generated around the projectile by the compression of the air column in the gun tube. This induced frontal pressure is physically defined by the Rankine Hugoniot relations for a propagating shock wave generated by a piston moving down an open-end tube (Ref. 6). A fuze could use this pressure for an arming signature by locating an orifice anywhere on the nose of the projectile and using the force generated to unlock the rotor. The true pressure at the orifice, termed frontal pressure P_f, would be

$$P_f = P_m\left(\frac{2K}{K+1}M^2 - \frac{K-1}{K+1}\right)^{\frac{1}{K-1}} + \left(\frac{(K+1)M^2}{2}\right)^{\frac{K}{K-1}}, \text{Pa (lb/ft}^2) \qquad (5\text{-}16)$$

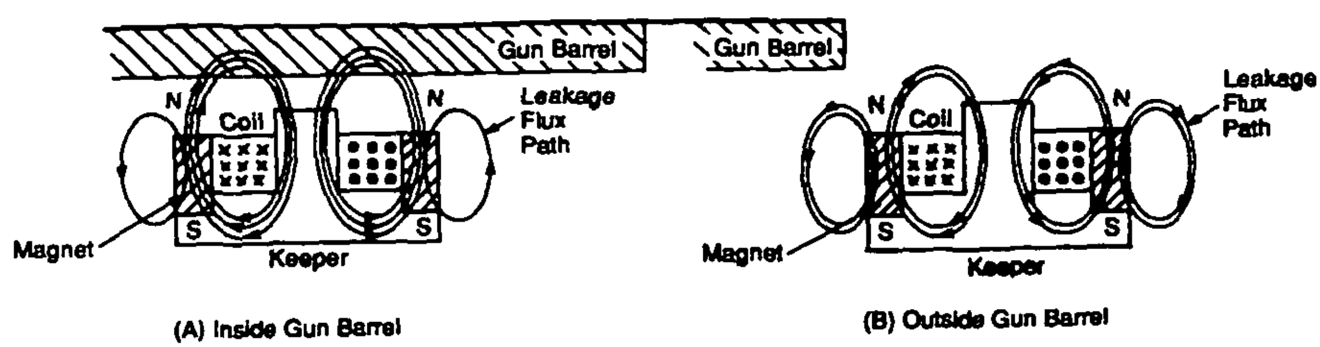


Figure 5-12. Sensor Inside and Outside Gun Barrel

$$P_f = P_m\left(\frac{2K}{K+1}M^2 - \frac{K-1}{K+1}\right)^{\frac{1}{K-1}} + \left(\frac{(K+1)M^2}{2}\right)^{\frac{K}{K-1}}, \text{Pa (lb/ft}^2\text{)} \quad (5\text{-}16)$$

where

K = ratio of heat capacity at constant pressure to heat capacity at constant volume = c_p/c_v, dimensionless

c_p = heat capacity at constant pressure, J/(kg·K) (Btu/(lbm·°F))

c_v = heat capacity at constant volume, J/(kg·K) (Btu/(lbm·°F))

P_m = measurement of pressure at orifice, Pa (lbm/ft^2).

Fig. 5-13 is a graph of the log of stagnation pressure P_s and the log of frontal pressure P_f versus the log of projectile velocity v. The results of experimental tests on a 20-mm, frontal pressure fuze agree well with Eq. 5-16.

5-4.9.3 Bore-Rider Sensor

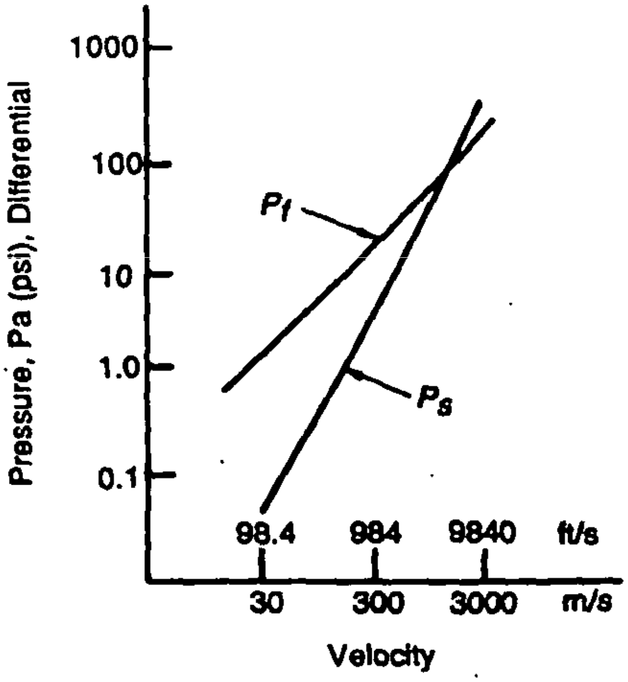


Figure 5-13. The Log of Stagnation Pressure P_s and the Log of Frontal Pressure P_f vs the Log of Projectile Velocity (Ref. 6)

Another method used to sense the exit of a projectile from the gun muzzle is a lock on the SAD that makes physical contact with the interior surface of the barrel. This method is commonly called a bore rider and has been used in nonspin munitions, such as mortars. The S&A element that makes barrel contact is usually a spring-loaded pin which was formerly ejected from the fuze at muzzle exit but is now captivated to avert the danger of the pin hitting friendly troops. The bore rider should be designed and interlocked in the SAD so that it is not released until after a valid acceleration is sensed. It should fail safely if it moves out and is not stopped by contact with a gun bore. Storage and handling safety is enhanced by a safety pin that is removed just prior to firing. Also fuzes using this concept must provide a delay to achieve a safe separation distance before arming.

5-4.10 PROPELLANT PRESSURE

The generation of pressure by propellant gas is an environment useful as an arming signature for base-mounted fuzes used in mortars and rockets and for shoulder-launched grenades. Figs. 5-14(A) and (B) illustrate two methods used to implement this type of system.

In the device shown in Fig. 5-14(A), the inlet valve permits the propellant gas to enter the reservoir via a ball-check valve, which closes when sufficient back pressure exists. Gas bled through the metering orifice provides delayed arming before the pressure diaphragm is pushed against the S&A release and shears the shear wire.

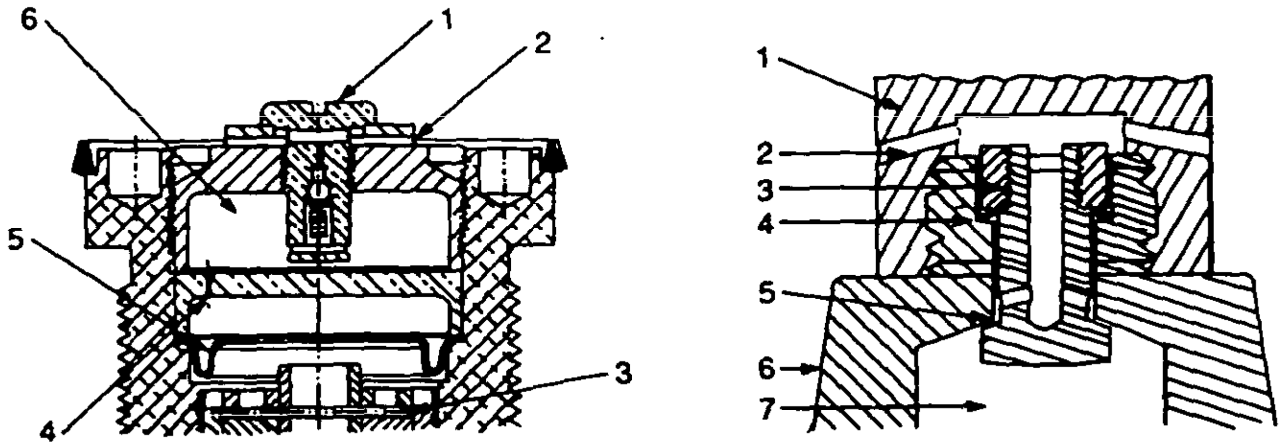
The valve for a mortar-base fuze, Fig. 5-14(B), operates in a similar fashion by admitting propellant gas pressure to a reservoir until back pressure is sufficient to close the poppet valve and trap the pressure, which can then be used to actuate the S&A mechanism.

Since the pressure generated by propellants can be in the MPa range (thousands of psi), the variety of mechanisms that can be used for a SAD is numerous. Their inherent advantages are ruggedness, simplicity, and a fail-safe feature. Their disadvantage is that propellant particles can clog or score valves if proper traps and filters are not used. Also extreme caution must be used in developing the design to prevent propellant gases from coming into contact with explosives in the fuze and the munition.

Ref. 7 provides a theoretical study of the various components of a pressure-operated system—inlet valve, restrictor, and chamber volume—as well as numerous patents and bibliographies of reports relating to pressure-arming techniques for fuzes.

5-5 NONENERGY-PRODUCING ENVIRONMENTS

A change in ambient environments can alter the characteristics of certain materials sufficiently to cause fuze arming either directly or indirectly without inducing energy into



(A) Delayed Arming System for Rocket Base Fuze

(B) Valve for Mortar Base Fuze

1 Ball-Check Valve Assembly
2 Filter Screen
3 Shear Wire
4 Metering Orifice
5 Pressure Diaphragm
6 Reservoir

1 Mortar Tail Boom
2 Tail Boom Inlet Port
3 Valve Poppet
4 Snap-Action Spring
5 Valve Seat
6 Mortar Shell
7 Reservoir

Figure 5-14. Pressure-Driven Portions of S&A Mechanisms (Ref. 7)

5-5.2 DIURNAL AND NOCTURNAL TEMPERATURE CHANGES

In most regions of the world, certain conditions change significantly every 24 h, e.g., temperature, humidity, and light. Any one or a combination of these changes can be detected and used to provide single or multiple arming cycles for mines and booby traps.

5-6 NONENVIRONMENTAL ENERGY SOURCES

Munitions—such as hand-emplaced mines, booby traps, demolition devices, and hand grenades—that experience little or no motion or unique environment when emplaced or launched are forced to use manual operations to achieve arming. These munitions generally require the removal of wires, pins, clips, or screws sometimes in combination with hand rotation of the explosive train to the in-line position and/or other manual operations. (See Chapter 12 for further discussion.) Because of the lack of environmental energy for arming these munitions, the designer must strive to achieve the maximum safety possible consistent with their intended use and deployment. This would include provisions for delayed arming; safety redundancy for such delays; consideration of human errors during loading, shipping, storage, and handling; and minimizing or avoiding the use of stored energy devices whenever possible.

5-6.1 SPRINGS

Springs are commonly used in fuzes to restrain pins and detents on out-of-line mechanisms. They also are used to power clocks and other escapements that provide delay to achieve safe distance. An external force, environmental or manual, should be used to operate the spring only during the arming period. This is especially true when springs are used to align the explosive train. The various types of springs used in fuzes are discussed in par. 6-2.

5-6.2 ELECTRICAL POWER

Batteries, turbine alternators, fluidic and propellant generators, and external power sources from the launch platforms are commonly used to perform arming functions. They may be located in the fuze, on the launcher, or in other parts of the munition. Such fuze power sources can be used to align or partially unlock S&A mechanisms through actuation of electroexplosive pistons, bellows motors, and actuators or solenoids and to provide electrical energy for delayed arming, timing, switching, electronic logic functions, and firing of electric primers and detonators. The various types of self-contained fuze power sources either in use or commercially available are discussed in par. 3-5.

5-6.3 METASTABLE COMPOUNDS

Active chemicals can be used to generate heat or gases to perform arming functions. They may be ignited electrically or mechanically. Bellows motors, piston actuators, and rotacs are typical explosive, gas-operated devices. Squibs or igniters are examples of heat-producing devices; however, they are used more often to ignite other flame-sensitive explosives that are not associated with fuze arming functions. Heat generators can be used to achieve delays by melting obstructions or locks. Gas generators can be combined with restrictor elements to obtain delays, and the gas can then be used to perform other arming functions including detonator initiation.

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CHAPTER 6
MECHANICAL ARMING DEVICES

The various types of mechanisms useful as arming devices of fuzes are presented. Numerous mechanisms used for fuze safety and arming devices are presented in some detail with the design rationale, capabilities, and limitations of each. Design equations are included.

Springs are described as cheap and reliable sources of stored energy, and appropriate design equations are given. Basic spring forms, including variants suited to the special requirements of specific munitions, are illustrated. Spring motion equations pertaining to reactions in environments, such as setback and spin of various munitions, are listed and explained.

Clockwork used in fuzes is described, and details of the escapement mechanisms and special springs used are presented. Tooth form and the design of escape wheels and pallets are discussed, and the appropriate design equations are included.

The zigzag setback safety pin—the leading setback safety device for nonspin munitions—is shown, and its design analysis and equations are presented.

A very low-friction device, called a rolamite, is included as a potential low-friction inertia device, and the design parameters and equations are given.

Ball lock and release mechanisms that are widely used in fuzes are discussed and illustrated. Precautionary measures concerning the weaknesses of some of the designs are emphasized.

A novel means of averting a potential safety failure in a rocket fuze that experiences accidental release from an aircraft on takeoff or landing is included.

A simple and inexpensive spiral spring mechanism used to achieve delayed arming in high-spin, small caliber ammunition is illustrated, and design equations are provided to determine the centrifugal force acting on the spring during projectile spin.

Rotary mechanisms for safety and arming purposes are shown with special emphasis on two newer arrangements: (1) the gearless runaway escapement system and (2) a true fail-safe system that can meet a need not previously satisfied.

New approaches to environment sensing, ram air in this instance, are described: (1) a vibrating spring-tempered metal diaphragm and (2) an oscillating flat plate with restoring spring. The diaphragm also functions as a power source (generator).

6-0 LIST OF SYMBOLS

A = linear acceleration, m/s^2 (ft/s^2)
A_A = pin cross-sectional area, m^2 (ft^2)
A_{dp} = acceleration of driving pulse, g-units
A_g = linear projectile acceleration (rectangular pulse), g-units
A_t = acceleration at a specific time, m/s^2 (ft/s^2)
a = acceleration in x-direction, m/s^2 (ft/s^2)
a_d = deceleration, g-units
a_g = acceleration, g-units
a_i = imposed acceleration, g-units
a_r = rocket acceleration, m/s^2 (ft/s^2)
$a'(t)$ = applied acceleration, g-units
a'' = design minimum acceleration assumed constant, g-units
B = spring rate of bias spring, N/m (lb/ft)
b = spring width, m (ft)
C = constant = $\dfrac{1-\mu/\tan\phi_s}{1+2\mu\tan\phi_s-\mu^2}$, dimensionless
C_1, C_2 = arbitrary constants of integration, m (ft)
D = mean diameter of coil, m (ft)
D_G = diameter of gun barrel, m (ft)
d = diameter of wire, m (ft)
d_i = inside diameter of case, m (ft)
d_o = outside diameter of arbor, m (ft)
E = modulus of elasticity, Pa (lb/ft^2)
F = load force, N (lb)
F_c = centrifugal force, N (lb)
F_{co} = Coriolis force on ball, N (lb)
F_n = normal force, N (lb)
F_R = resultant force, N (lb)
F_{RR} = resisting force, N (lb)
F_r = restraining force that disappears when mass moves, N (lb)
F_s = driving force due to setback, N (lb)
F_t = force tangent to ribbon bundle, N (lb)
F_0 = initial force on mass in assembled position, N (lb)
F_α = force due to angular acceleration, N (lb)
f = friction force of side walls, N (lb)
f_n = escapement frequency, Hz
G = torque on escape wheel, N·m (lb·ft)
G_f = frictional torque, N·m (lb·ft)
G_1 = spring bias level in g-units at beginning of first stage of track where G is a multiple of the gravitational constant g and represents a nondimensional force of G times the weight of moving part
G_{II} = spring bias level in g-units at the end of last stage of zigzag track
G_m = shear modulus, Pa (lb/ft^2)
G_0 = torque due to prewinding of spring, N·m (lb·ft)
G_t = torque, N·m (lb·ft)

g = gravitational constant, m/s^2 (ft/s^2)
I = total moment of inertia, kg·m^2 (slug/ft^2)
I_A = area moment of inertia, m^4 (ft^4)
I_i = moment of inertia of part with respect to pivot, kg·m^2 (slug·ft^2)
I_L = moment of inertia of leaf about axis of rotation, kg·m^2 (slug·ft^2)
I_m = moment of inertia of oscillating mass, kg·m^2 (slug·ft^2)
I_r = moment of inertia of rotor, kg·m^2 (slug·ft^2)
I_s = moment of inertia of shutter, kg·m^2 (slug·ft^2)
I_z, I_P, I_D = moments of inertia about the three respective axes, kg·m^2 (slug·ft^2)
K_i = mechanism constant for the ith stage of track = $1 + \left(\frac{k_g}{r_i}\right)^2 \left[\frac{1 + \mu \tan\alpha'_i}{\tan\alpha'_i(\tan\alpha'_i - \mu)}\right]$, dimensionless
K_θ = $\sin\theta_0$, dimensionless
k = spring constant, N/m (lb/ft) (for torsion bar units are N·m/rad (lb·ft/rad))
k_g = radius of gyration for mass, m (ft)
k' = constant depending on the cross section of spring, m^4 (ft^4)
k_1 = proportionality constant, dimensionless
k_2 = gear ratio (constant) between escape wheel pinion and gear driven by translating mass, dimensionless
L_i = lead of the ith stage of helix, m/turn (ft/turn)
ℓ = length of spring, m (ft)
m = mass, kg (slug)
m_b = mass of ball, kg (slug)
m_{br} = mass of ribbon bridge, kg (slug)
m_p = mass of part, kg (slug)
m_s = mass of shutter, kg (slug)
m' = mass of driving force, on Fig. 6-31, kg (slug)
N = rotation, rev/s
N_c = number of active coils, dimensionless
N_w = number of teeth on the escape wheel, dimensionless
n = number of stages, dimensionless
p = damping coefficient, kg/s (slug/s)
$p\dot{x}$ = damping force of surrounding medium proportional to velocity, N (lb)
Q = impressed force, N (lb)
R = ratio of setback drive force to friction resisting force, dimensionless
R_1 = value of R at peak acceleration in the gun tube, dimensionless
r = radial location of mass with respect to spin center, m (ft)
r_c = radius of cavity into which unwinder opens, m (ft)
r_{cg} = radial distance from pivot to center of gravity of leaf, m (ft)
r_d = radius of disk, m (ft)
r_g = radius of gear driven by translating mass, m (ft)
r_{ip} = radius to point of interaction between mass and guide pin, m (ft)
r_n = minimum natural (free position unmounted) radius of curvature of coil, m (ft)
r_p = radius of pallet, m (ft)
= distance from the center of the pivot pin hole to the center of mass of the shutter, m (ft)
r_t = distance from the projectile axis to the center of the pivot, m (ft)
r_w = radius of escape wheel, m (ft)
r_m' = radius of the mass from center of spin, m (ft)
r_0' = inital radius, m (ft)
$\ddot{r}$ = radial acceleration of the ball, m/s^2 (ft/s^2)
r_0 = distance of center of mass of body from spin axis before projectile is fired, m (ft)
r_1 = outer radius of coil, m (ft)
r_2 = inner radius of coil, m (ft)
S = distance, m (ft)
S_f = stress factor, dimensionless
s_s = spiral constant, m/rad (ft/rad)
T = twist of rifling, turns/caliber
T_t = arming time, s
t = time from release of body, s
t_d = functioning delay, s
t_s = spring thickness, m (ft)
t_{1arm} = arming time for a single leaf, s
v_i = velocity to traverse ith stage of zigzag, m/s (ft/s)
v_{min} = velocity change of a rectangular pulse of acceleration Level A with duration just long enough to cause a zigzag track of n stages to disengage from drive pin, m/s (ft/s)
v_t = projectile velocity at a specific time, m/s (ft/s)
W = weight of moving part, N (lb)
W_L = weight of leaf, N(lb)
W_p = part weight, N (lb)
x_T = total gear ratio of gear train, dimensionless
x_{ip} = displacement of mass from an initial position, m (ft)
x_0 = initial position of mass and represents the amount of precompression in bias spring, m (ft)
x_1 = displacement from equilibrium or an initial position, m (ft)
$\dot{x}$ = velocity, m/s (ft/s)
$\ddot{x}$ = acceleration of mass with respect to its mounting structure or to fuze body, m/s^2 (ft/s^2)
$\ddot{y}$ = acceleration of mounting structure or fuze with respect to a fixed frame of reference such as a gun or ground, m/s^2 (ft/s^2)
α = angular acceleration, rad/s^2
α_a = angle between perpendicular to direction of accelerleration and line through the center of gravity of leaf and axis of rotation of leaf, rad
α'_i = helix angle of the ith stage of cam track, rad

$\beta = \sqrt{\frac{k}{m} - \frac{p^2}{4m^2}}$, s^{-1}

Δx_i = length of ith stage of zigzag track, m (ft)

Δx_n = length of last stage of zigzag track, m (ft)

θ = position of disk with respect to spin axis, rad

θ_A = angle, rad

θ_{arm} = angle through which leaf must rotate to arm, rad

θ_b = angle between ribbon bridge and centrifugal force vector, deg

θ_c = angular orientation of center of gravity of leaf, rad

θ_{dg} = degrees of the required angle for driving gear, deg

θ_l = angular displacement of leaf, rad

θ_p = angle between extreme positions of pallet, rad

θ_0 = initial angular displacement, deg

θ_1 = number of revolutions necessary to wind the spring from its unwound position to the tightly wound position around the arbor, rev

θ' = angular position of disk at which the fuze may become armed, rad

$\ddot{\theta}$ = angular acceleration, rad/s^2

μ = coefficient of friction, dimensionless

τ = shear stress, Pa (psi)

ϕ = angular displacement of shutter, rad

ϕ_s = slot spiral angle, rad

$\phi_1 = (\text{Sin}^{-1}) \frac{\sin\theta'}{\sin\theta_0}$, rad

$\phi_2 = \frac{\pi}{2}$, rad

ω = spin rate of projectile, rad/s

6-1 INTRODUCTION

Usually the first approach to designing a fuze is to improve or modify an existing design because it is generally faster and economically advantageous. From the standpoints of safety and reliability, it may be practical to use designs that have stood the test of time if acceptable performance can be achieved. Fuzes operated by mechanical devices use mechanisms such as springs, gears, sliders, rotors, and plungers. Typical mechanisms used in standard fuzes are described and illustrated in this chapter.

6-2 SPRINGS

Springs provide a simple source of stored energy that remains constant over the 20-yr shelf life required for fuzes. They also act as biasing means for various fuze components, i.e., detents (locks), pins, balls, sliders, and rotors.

6-2.1 TYPES OF SPRINGS

The three spring configurations used in fuze arming mechanisms are (1) the flat leaf spring, a thin beam, (2) the flat spiral spring, a leaf spring wound into a spiral sometimes called a clock spring, and (3) the helical coil spring. Variants of these are the conical spring, a helical coil spring with a decreasing coil diameter; the torsion spring, a helical coil spring that operates by rotary motion; the straight bar torsion spring, a length of wire twisting about its axis; and the constant torque spring, a spiral spring used in the buckling mode. Illustrations of and equations for various springs are given in Table 6-1.

The general equation for a spring such as the one shown in Fig. 6-1 is an expression of Hooke's law, which states that deflection is proportional to the load force F

$$F = -kx_1, \text{ N (lb)} \qquad (6\text{-}1)$$

where

k = spring constant, N/m (lb/ft*)

x_1 = displacement from equilibrium, m (ft).

The minus sign indicates that the force exerted by the spring is in the opposite direction from displacement.

The spring constant k depends on the physical properties of the spring material and the geometry of the spring, e.g., for a helical compression spring, Eq. 6-1 becomes

$$F = -\frac{G_m d^4 x_1}{8N_c D^3}, \text{ N (lb)} \qquad (6\text{-}2)$$

where

G_m = shear modulus, Pa (lb/ft^2)

D = mean diameter of coil, m (ft)

N_c = number of active coils, dimensionless

d = diameter of wire, m (ft).

6-2.2 ELEMENTARY EQUATIONS OF MOTION FOR A SPRING MASS SYSTEM

For a basic mass, e.g., a detent or a slider, and spring system with the spring under an initial compression x_0, from Newton's First Law the load force F is

$$F = ma = m\ddot{x} = -kx, \text{ N (lb)} \qquad (6\text{-}3)$$

where

a = acceleration in the x-direction, m/s^2 (ft/s^2)

m = mass kg (slug)

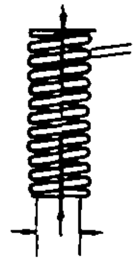
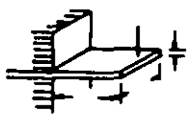
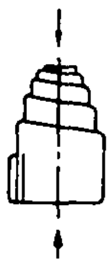
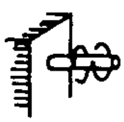
$\ddot{x}$ = acceleration in the x-direction, m/s^2 (ft/s^2).

The minus sign indicates that the force is in the opposite direction from the displacement. The general solution to differential Eq. 6-3 is obtained by integration and is

$$x = C_1 \sin(t\sqrt{k/m}) + C_2 \cos(t\sqrt{k/m}), \text{ m (ft)} \qquad (6\text{-}4)$$

*Although "inch" is a more convenient unit to use with fuzes, "foot" is used to simplify the equations.

TABLE 6-1. SPRING EQUATIONS (Ref. 1)

HELICAL COMPRESSION		LOAD, N (lb)	STRESS, Pa (lb/ft^2)
Constant Pitch		$P = \frac{fGd^4}{8D^3N}$	$S = \frac{8PD}{\pi d^3}K_w$
Conical		Calculate as helical compression spring of uniform diameter using average mean diameter of active coils. This applies only until first active coil "bottoms" or touches next coil. The spring is recalculated as each coil deflects until it becomes inactive.	
Flat Leaf			
Simple Beam		$P = \frac{4fEbt^3}{L^3}$	$S = \frac{1.5PL}{bt^2}$
Cantilever		$P = \frac{fEbt^3}{4L^3}$	$S = \frac{6PL}{bt^2}$
Volute		$P = \frac{fGbt^3K_2}{D^3N}$	$S = \frac{PD_iK_F}{K_1bt^2}$
		Note: K_1, K_2, and K_F are Wahl stress correction factors whose values may be found in Ref. 1	
Torsion Bar			
Round		$M = \frac{\pi^2 d^4 G\theta}{16L}$	$S = \frac{16M}{\pi d^3}$

b = spring width, m (ft)
D = mean coil diameter, m (ft)
D_i = mean coil diameter of inner coil, m (ft)
d = wire diameter, m (ft)
E = modulus of elasticity, Pa (lb/ft^2)
f = deflection, m (ft)
G = shear modulus, Pa (lb/ft^2)
K_w = Wahl stress correction factor, dimensionless
L = spring length, m (ft)
M = torque, N·m (lb·ft)
N = number of coils, dimensionless
P = force, N (lb)
S = stress, Pa (lb/ft^2)
t = spring thickness, m (ft)
θ = angular deflection, rad

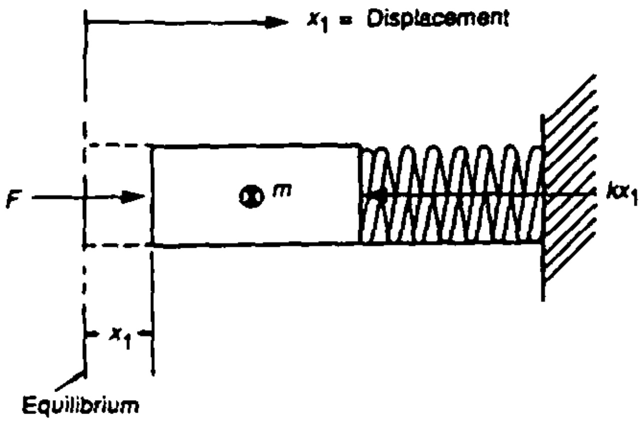


Figure 6-1. Basic Mass and Spring System

where

C_1, C_2 = arbitrary constants of integration which must be evaluated to fit boundary conditions, m (ft)

t = time from release of body, s.

At the start $t = 0$, $x = x_0$, and the velocity $\dot{x} = 0$; these conditions require that $C_1 = 0$ and $C_2 = x_0$. Eq. 6-4 becomes

$$x = x_0 \cos(t\sqrt{k/m}), \text{ m (ft)}. \quad (6\text{-}5)$$

At assembly most fuze springs have an initial displacement x_0 in order to require a threshold force to activate the mass.

When a constant force Q is impressed on the mass, independent of displacement and time, the equation of motion is

$$Q = m\ddot{x} + kx, \text{ N (lb)} \quad (6\text{-}6)$$

where

Q = impressed force, N (lb).

At $t = 0$, $x = x_0$, and $\dot{x} = 0$. This results in an undamped oscillation around a rest point Q/k and

$$x = x_0 \cos(t\sqrt{k/m}) + \frac{Q}{k}[1 - \cos(t\sqrt{k/m})], \text{ m (ft)}. \quad (6\text{-}7)$$

Sometimes the mass m moves through a fluid, in which case a term representing the viscous resistance $p\dot{x}$ should be added to Eq. 6-3, i.e.,

$$m\ddot{x} = -kx - p\dot{x}, \text{ N (lb)} \quad (6\text{-}8)$$

where

$\dot{x}$ = velocity, m/s (ft/s)

p = damping coefficient, kg/s (slug/s).

The minus sign indicates that the force is in the opposite direction from the velocity. If $p < \sqrt{km}$, the solution of Eq. 6-8 is

$$x = \left(\frac{px_0}{2m\beta}\sin\beta t + x_0\cos\beta t\right)\exp\left(-\frac{pt}{2m}\right), \text{ m (ft)} \quad (6\text{-}9)$$

where

$$\beta = \sqrt{\frac{k}{m} - \frac{p^2}{4m^2}}, \text{ s}^{-1}.$$

This is a damped oscillation.

6-2.2.1 Inclusion of Friction

Fig. 6-2 shows a mass undergoing an accelerating force such as setback. W_p is the weight of the moving part, and a_i is the imposed constant linear acceleration expressed in g-units. The force of friction is given by $\mu W_p a_i + f$ where μ is the coefficient of friction and f is the friction force of the side walls.

For a nonrotating fuze the equation is

$$m\ddot{x} + kx = F_r - (f + \mu W_p a_i), \text{ N (lb)} \quad (6\text{-}10)$$

where

F_r = restraining force that disappears when mass moves, N (lb)

f = friction force of side walls, N (lb)

μ = coefficient of friction, dimensionless

W_p = weight of moving part, N (lb)

a_i = imposed acceleration, g-units.

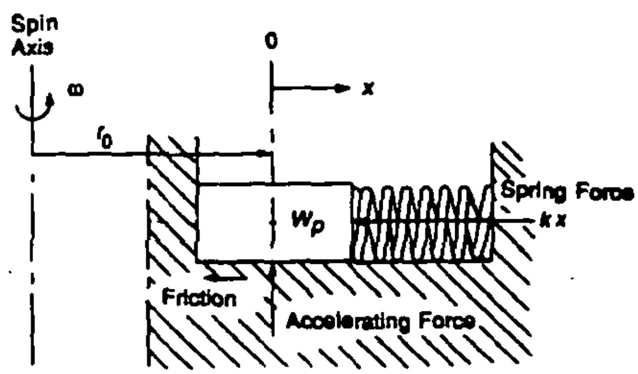


Figure 6-2. Mass and Spring Under Acceleration

For fired projectiles, a_i is a function of the time after firing. The deceleration caused by air drag, however, is nearly constant; therefore, the deceleration forces on the body are assumed to be constant and equal to $W_p a_i$. Eq. 6-10 can be solved for x as

$$x = x_0 \cos\left(t\sqrt{\frac{k}{m}}\right) - \frac{f + \mu W_p a_i}{k}\left[1 - \cos\left(t\sqrt{\frac{k}{m}}\right)\right], \quad \text{m(ft)} \qquad (6\text{-}11)$$

and the time t to move a distance S is obtained by solving Eq. 6-11:

$$t = \sqrt{\frac{m}{k}}\,\mathrm{Cos}^{-1}\left(\frac{kS + kx_0 + f + \mu W_p a_i}{kx_0 + f + \mu W_p a_i}\right), \text{ s.} \qquad (6\text{-}12)$$

Thus the arm time t required to release a lock or arm a fuze can be determined.

If the second term in Eq. 6-11 is greater than the first term, friction will prevent motion of the mass.

6-2.2.2 Effect of Centrifugal Force

Centrifugal forces caused by projectile rotation can effectively move sliding masses in a direction perpendicular to the spin axis of the projectile. The force is computed as the product of the mass of the body, the distance from the axis of rotation to the center of gravity of the body, and the square of the angular velocity in rad/s.

Suppose, as in Fig. 6-2, the centrifugal force is opposed by a spring. The equation of motion is

$$m\ddot{x} = (mr_0\omega^2 - F_0 - f) - (k - m\omega^2)x, \text{ N (lb)} \qquad (6\text{-}13)$$

where

F_0 = initial force on mass in assembled position, N (lb)

ω = spin rate of projectile, rad/s

r_0 = distance of center of mass of body from spin axis before projectile is fired, m (ft).

With an initial force F_0, the equation for displacement at any later time is

$$x_1 = \left(\frac{-F_0 - f + mr_0\omega^2}{-m\omega^2 + k}\right)\left(1 - \cos\sqrt{\frac{k}{m} - \omega^2}\,t\right), \quad \text{m (ft)} \qquad (6\text{-}14)$$

and the time t to move a given distance S is

$$t = \frac{1}{\sqrt{\frac{k}{m} - \omega^2}}\,\mathrm{Cos}^{-1}\left(1 - \frac{(m\omega^2 - k)S}{F_0 + f - mr_0\omega^2}\right), \text{ s.} \qquad (6\text{-}15)$$

6-2.3 SPRINGS USED IN FUZES

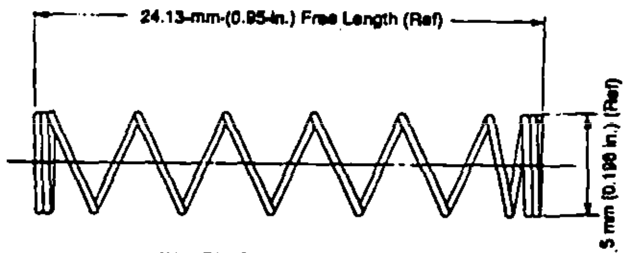
Fig. 6-3 illustrates a typical method used to specify coil springs used in compression. Diameters, length, type of ends, wind, material, finish, and heat treatment must be specified, as well as force and deflection characteristics (Refs. 2 and 3).

The Belleville spring is a special spring in the shape of a conical washer that snaps from one stable position to another when the proper force is applied. In par. 12-2.2 the Belleville spring equations are given and its application is illustrated for use in a mine.

6-2.3.1 Power Springs

Power springs, also called mainsprings, are flat spiral springs most often used to drive clockwork. The spring is usually contained inside a hollow case to which one end of the spring is attached; the other end is attached to an arbor, as shown in Fig. 6-4. Experiments have determined that a maximum number of turns are delivered when the wound spring occupies about half the volume available between arbor and case. Under this condition the length ℓ of the spring is

$$\ell = \frac{d_i^2 - d_o^2}{2.55ts}, \text{ m (ft)} \qquad (6\text{-}16)$$



Wire Dia. 0.33 mm (0.013 in.) (Ref)
No. of Active Coils 6 1/4 (Ref)
Total No. of Coils 9 (Ref)

Notes:
1 MIL-A-2550 Applies
2 Material: Chromium Nickel Stainless and Heat-Resisting Steel Spring Wire, Type 302, per ASTM A313
3 One to Two Close-Wound Coils on Each End Squared Within ±5 deg
4 Direction of Helix, LH
5 Min ID 4.19 mm (0.165 in.)
6 Max OD 5.08 mm (0.200 in.)
7 Spring Shall be Set by Compressing to Solid Height After Forming
8 Solid Height 3.05 mm (0.120 in.) Under a 3.6-N (0.82-lb) Force Max
9 Force at Height of 13.5 mm (0.530 in.) 1.6 N (0.35 lb) Min
10 Force at Height of 4.32 mm (0.170 in.) 3.4 N (0.77 lb) Max
11 Dimensions Denoted by (Ref) are for Reference Only to Meet Specifications 1 through 10

Figure 6-3. Compression Spring Data

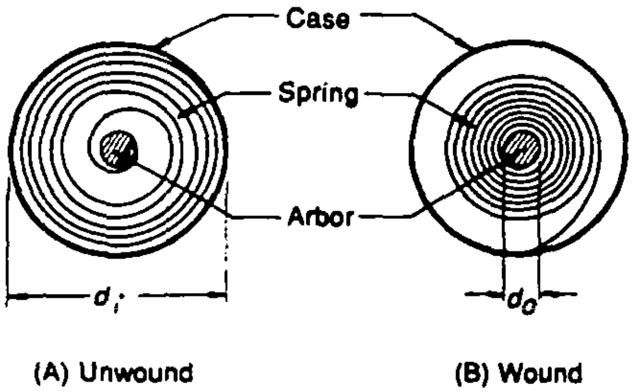


Figure 6-4. Typical Cased Power Spring

where

d_i = inside diameter of case, m (ft)
d_o = outside diamter of arbor, m (ft)
t_s = spring thickness, m (ft).

The number of revolutions θ_1 necessary to wind the spring from its unwound position to the tightly wound position around the arbor is

$$\theta_1 = \frac{\sqrt{2(d_o^2 + d_i^2)} - (d_o + d_i)}{2.55 t_s}, \text{ rev.} \quad (6\text{-}17)$$

Fig. 6-5 can be used to determine the maximum torque for a given power spring design. This figure is based on clock-spring steel corresponding to American Iron and Steel Institute (AISI) 1095 with a Rockwell hardness of C49-51. For example, a strip 25.4 mm (1.0 in.) wide and 0.635 mm (0.025 in.) thick will carry a maximum torque of 3.02 m·N (26.75 in.·lb). Since torque is proportional to width, a strip 0.635 mm (0.025 in.) thick and 12.7 mm (0.50 in.) wide will carry a maximum torque of 1.51 m·N (13.37 in.·lb).

6-2.3.2 Leaf and Torque Springs

The mass system of escapements can be regulated by cantilever springs, torque springs, and hairsprings. However, hairsprings, special spiral springs of relatively fragile construction, are essentially no longer used in projectile fuze timing mechanisms because of their nonrugged nature.

Leaf and torque springs are straight springs deflected by bending or torsion. Figs. 6-36 and 6-39 depict the applica-

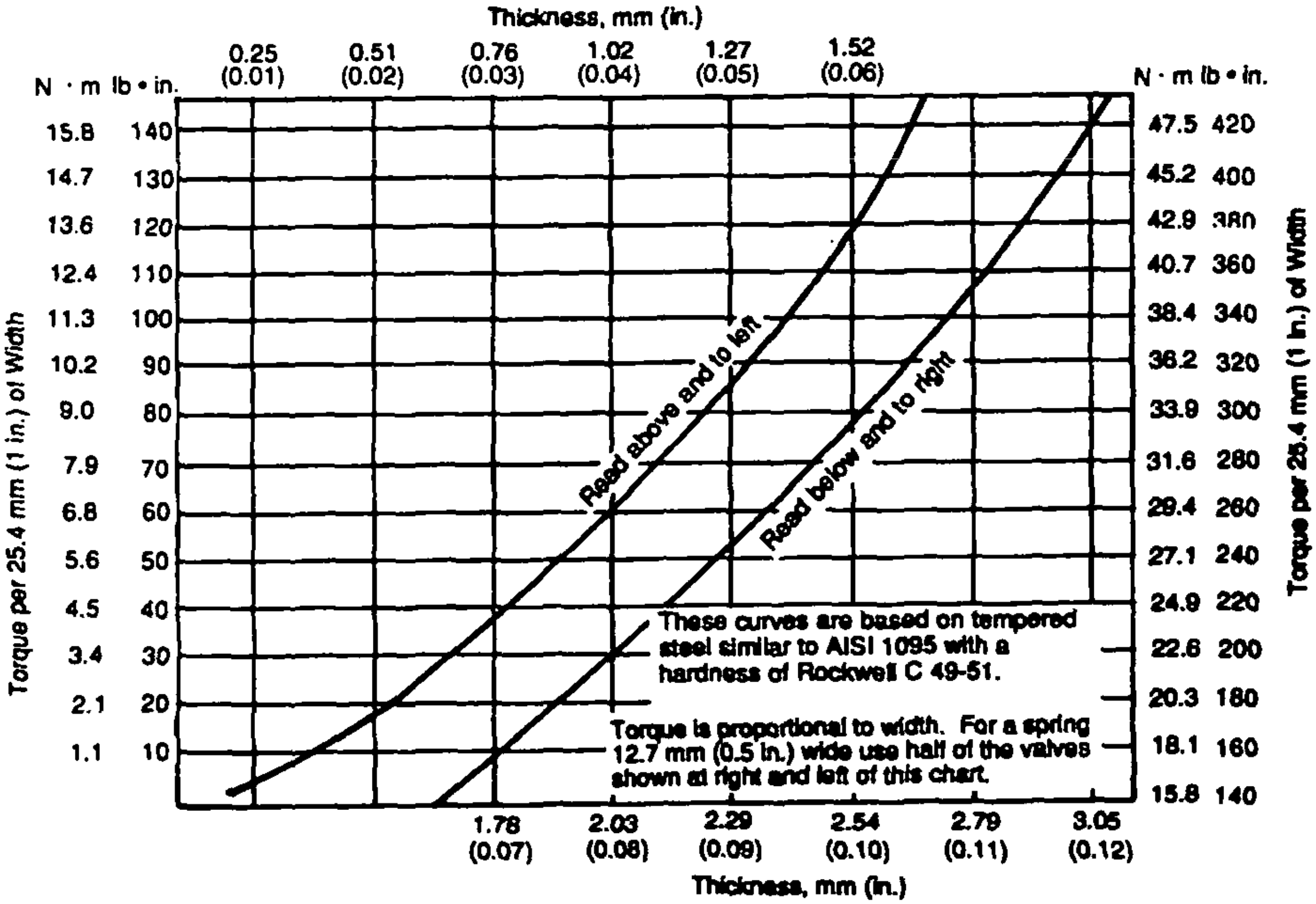


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Figure 6-5. Maximum Torque per 25.4 mm (1 in.) of Spring Width for Motor Springs

tion of a leaf spring and torque spring, respectively. Table 6-1 gives design equations for these springs.

6-2.3.3 Constant-Force Springs

One type of constant-force spring is called a negator spring, as shown in Fig. 6-6, which is wound so that a constant force causes continuous unwinding of the coils. It is made by forming a spring of flat stock to a tight radius, i.e., the coils touch one another. The spring is placed over an arbor that has a diameter slightly greater than the free inside diameter of the unstressed spring.

When a force F is applied in a radial direction from the axis, the spiral uncurls; the force is practically independent of deflection. The magnitude of the force F is

$$F = \frac{Et_s^3 b}{26.4}\left[\frac{1}{r_n^2} - \left(\frac{1}{r_n} - \frac{1}{r_1}\right)^2\right], \text{N (lb)} \quad (6\text{-}18)$$

where

b = spring width, m (ft)
r_n = minimum natural (free position unmounted) radius of curvature of coil, m (ft)
r_1 = outer radius of coil, m (ft)
E = modulus of elasticity, Pa (lb/ft^2).

Design equations for constant-force springs are presented in Table 6-2. The stress factor S_f used in the equations depends upon the material used and the anticipated spring life. For high-carbon steel at less than 5000 cycles, a value of 0.02 is suggested.

6-2.3.4 Helical Volute Spring

Volute springs (See Table 6-1.) function in a similar manner to conical compression springs. They are made from tapered metal strips wound on the flat so that each turn telescopes into the preceding one. The coils can be wound tightly to obtain damping friction or loosely with space between the coils to eliminate friction.

Nonlinearity of the load deflection curve, in which the larger coils bottom sooner than the smaller ones, is useful in shock-absorbing applications. A linear curve can be obtained by winding the larger coils with a greater helix angle; this procedure enables all coils to bottom simultaneously.

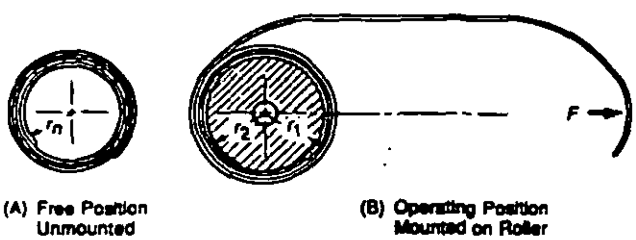


Figure 6-6. Negator Spring

The outstanding feature of the volute spring is its ability to resist higher lateral stresses than the helical spring. This characteristic makes it ideal as a stowable and/or extendable standoff probe for some munitions. See par. 1-14 for an application to a fuel-air-explosive munition. For this application the metal strip is a constant width and is wound with a constant lead (helix). (See Fig. 6-7 for an example of a helical volute spring.) Design parameters for these stowable probes are presented in Ref. 5.

6-3 A SLIDING ELEMENT IN AN ARTILLERY FUZE

This analysis shows the effect of angular acceleration and centrifugal force on the operation of a spring/mass system driven by setback, as shown in Fig. 6-8. The force F_α due to angular acceleration is

$$F_\alpha = mr\alpha, \text{N (lb)} \quad (6\text{-}19)$$

where

r = radial location of mass with respect to spin center, m (ft)
α = angular acceleration, rad/s^2.

The centrifugal force F_c is

$$F_c = mr\omega^2, \text{N (lb)}. \quad (6\text{-}20)$$

The vector sum of the two forces F_α and F_c is the resultant side force F_R:

$$F_R = (F_\alpha^2 + F_c^2)^{1/2}, \text{N (lb)}. \quad (6\text{-}21)$$

For a rifled barrel having a constant twist, the angular acceleration α is

$$\alpha = \frac{2\pi TA}{D_G}, \text{rad/s}^2 \quad (6\text{-}22)$$

where

A = linear acceleration, m/s^2 (ft/s^2)
T = twist of rifling, turns/caliber
D_G = diameter of gun barrel, m (ft)

and the projectile spin rate ω is

$$\omega = \int \alpha dt, \text{rad/s}. \quad (6\text{-}23)$$

Substitution of the expression for α from Eq. 6-22 into Eq. 6-19 gives

$$F_\alpha = \frac{mr2\pi TA}{D_G}, \text{N (lb)} \quad (6\text{-}24)$$

TABLE 6-2. DESIGN EQUATIONS FOR CONSTANT-FORCE NEGATOR SPRINGS (Refs. 1 and 4)

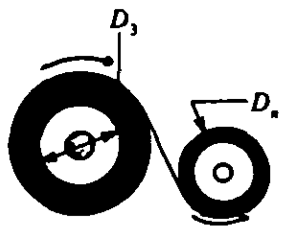
VARIABLE, m (in.)	SPRINGS WITH 10 COILS OR LESS	SPRINGS WITH OVER 10 COILS
Spring Width b	$b = \frac{26.4F}{Et_sS_f^2}$	$b = \frac{26.4F}{Et_sS_f^2}$
Minimum Natural Radius of Curvature r_n	$r_n = \sqrt{\frac{Ebt_s^3}{26.4F}}$	$r_n = \frac{r_m}{1.2}$
Maximum Natural Radius of Curvature r_m	———	$r_m = \sqrt{\frac{Ebt_s^3}{26.4F}}$
Spring Thickness t_s	$t_s \geq \frac{26.4F}{Ebs_f^2}$	$t_s \geq \frac{26.4F}{Ebs_f^2}$
Arbor Radius r_2	$r_2 = 1.2r_n$	$r_2 = 1.2r_m$
Spring Length ℓ	$\ell = \delta + 10r_2$ or $= 1.57N(D_1 + D_2) + 3\pi D_3$	$\ell = \delta + 10r_2$ or $= 1.57N(D_1 + D_2) + 3\pi D_3$

D_1 = diameter of outside coils, m (in.)
D_2 = diameter of storage drum, m (in.)
D_3 = diameter of output drum, m (in.)
E = modulus of elasticity, Pa (lb/in.^{2})
F = force, N (lb)
N = number of active coils, dimensionless
S_f = stress factor, dimensionless
δ = deflection, m (in.)

CONSTANT-FORCE MOTOR SPRING

$$M = \frac{Ebt^3D_3}{13}\left(\frac{1}{D_n} + \frac{1}{D_3}\right)^2$$

$$S = Et\left(\frac{1}{D_n} + \frac{1}{D_3}\right)$$



b = width of coil, m (in.)
D_n = natural diameter of coil, m (in.)
D_3 = diameter of output drum, m (in.)
M = torque, N·m (lb·in.)
t = thickness of coil, m (in.)

and substitution of the expression for ω from Eq. 6-23 into Eq. 6-20 gives

$$F_c = mr\left(\frac{2\pi T}{D_G}\int A dt\right)^2, \text{N (lb)}. \quad (6\text{-}25)$$

At a specific time t after firing, the acceleration A has a specific value A_t, and the integral yields a specific value of projectile velocity v_t. By substituting for F_a and F_c in Eq. 6-21, the side load force F_R becomes

$$F_R = \frac{2\pi mrT}{D_G}\left[A_t^2 + \left(\frac{2\pi T}{D_G}\right)^2 v_t^4\right]^{1/2}, \text{N (lb)}. \quad (6\text{-}26)$$

The driving force F_s on the weight due to setback is

$$F_s = mA, \text{N (lb)} \quad (6\text{-}27)$$

and the resisting force F_{RR} is

$$F_{RR} = \mu F_R, \text{N (lb)}. \quad (6\text{-}28)$$

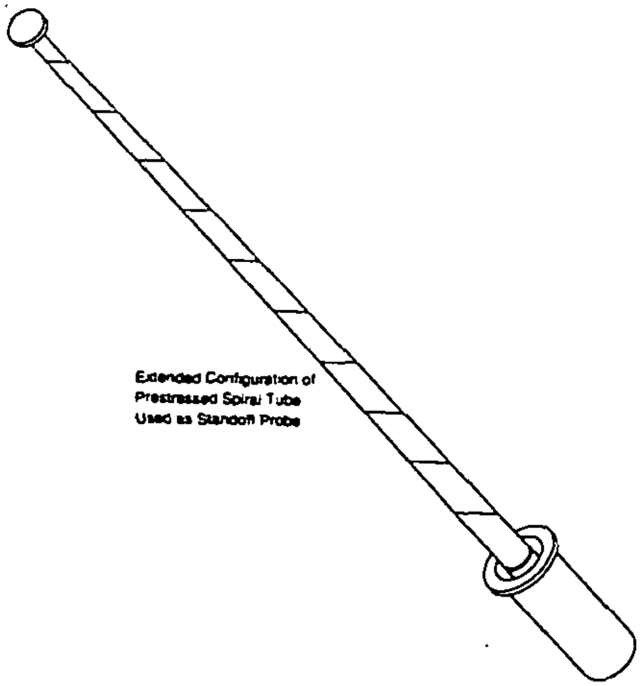


Figure 6-7. Helical Volute Spring (Ref. 5)

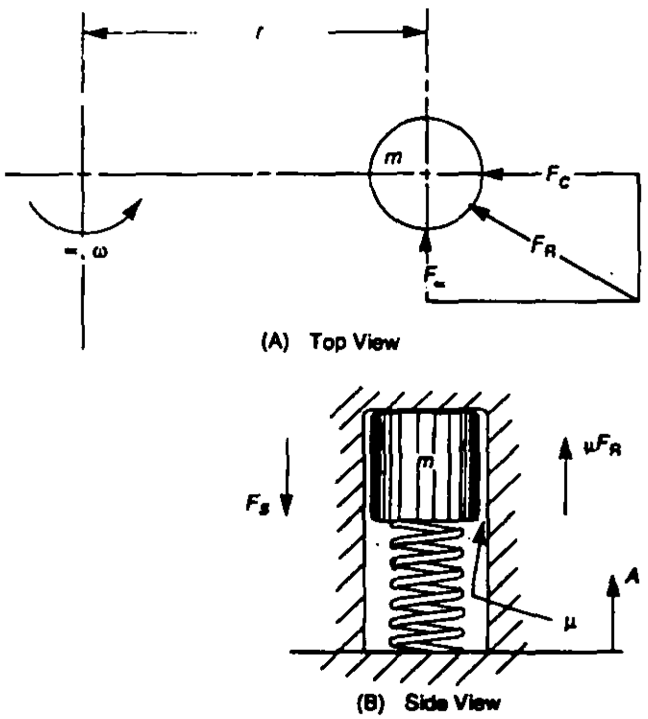


Figure 6-8. Sliding Element in an Artillery Fuze

The ratio R of the driving force F_s to resisting force F_{RR} at time t then becomes

$$R = F_s/F_{RR}, \text{ dimensionless}$$

$$R = \frac{D_G A_t}{2\pi\mu r T\left[A_t^2 + \left(\frac{2\pi T}{D_G}\right)^2 v_t^4\right]^{1/2}}, \text{ dimensionless}. \tag{6-29}$$

An important value of R occurs at the peak acceleration in the gun tube. (Actually, the weight is probably fully retracted before this time, but this gives the maximum values of A_t and v_t consistent with the problem.) The pertinent data for the 155-mm, M185 gun firing the XM549 HE, rocket-assisted projectile (RAP) at charge 8 occurs at a time 5 ms after firing. When the projectile has traveled 0.46 m (1.5 ft) down the gun barrel, it is moving at about 304.8 m/s (1000 ft/s), and its acceleration is 13,140 g. The gun tube rifling has a twist of one turn in 20 calibers (0.05).

Thus the value R_t for R by Eq. 6-29 becomes

$$R_t = \frac{(0.155)}{2\pi\mu r\, 0.05} \times \frac{(13{,}140 \times 9.8)}{\left[(13{,}140 \times 9.8)^2 + \left(\frac{2\pi 0.05}{0.155}\right)^2 (304.8)^4\right]^{1/2}}$$

$$R_t = \frac{0.34}{\mu r}$$

where

R_t = value of R at peak acceleration in the gun tube, dimensionless.

When $r = 2.54 \times 10^{-2}$ m (1.0 in.),

$$R_t = \frac{13.39}{\mu}, \text{ dimensionless}.$$

For typical values of the coefficient of friction, such as $\mu = 0.2$, R_t would have a value of 66.93 at a radial location of 2.54×10^{-2} m (1.0 in.) off the spin center. This value indicates that the setback force driving the weight is at least 66.9 times larger than the resisting force caused by side load friction.

6-4 MISCELLANEOUS MECHANICAL COMPONENTS

6-4.1 HALF-SHAFT RELEASE DEVICE

The half-shaft release device shown in Fig. 6-9 is often used where small forces or torques must be applied to con-

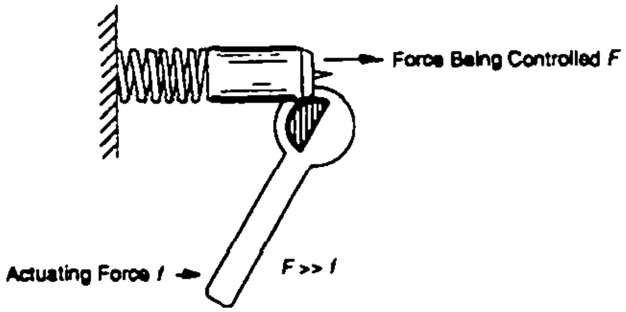


Figure 6-9. Half-Shaft Release Device

trol or release large forces or torques. The device is a very compact and effective force multiplying linkage.

6-4.2 SHEAR PINS

A shear pin can be designed to restrain an element against impacts that result from normal handling shocks. The pin will shear when a force $W_p a_d$ produces a shear stress τ

$$\tau = \frac{W_p a_d}{2A_A}, \text{Pa (lb/ft}^2\text{)} \quad (6\text{-}30)$$

where

A_A = pin cross-sectional area, m^2 (ft^2)

a_d = deceleration, g-units.

The factor 2 in the denominator of Eq. 6-30 assumes the pin to be in double shear, i.e., supported on two sides. It is also assumed that the load is concentrated at the middle of the pin. The area of the pin can be found for any deceleration a_d by using the ultimate shear strength, i.e., 517 MPa (75,000 lb/in.^{2}) for steel.

6-4.3 DETENTS

The purpose of detents is to restrict motion by exerting their shear strength. The shear stress τ is computed by

$$\tau = \frac{F}{A_A}, \text{Pa (lb/ft}^2\text{)} \quad (6\text{-}31)$$

where

F = total load, N (lb).

The motion of the detents is complicated if they are allowed to become skewed; they twist and jam if the clearance is too large or if the length in the guide is too short. With a short rod, large clearance, and sharp corners, friction increases because the load is concentrated at the bearing areas and creates a tendency to gall or gouge. Fig. 6-10 illustrates this problem.

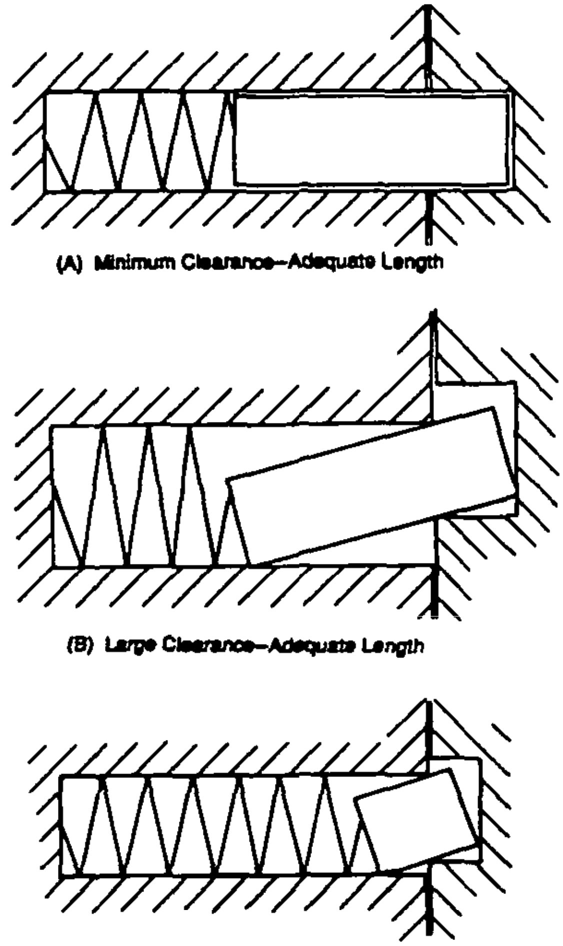


Figure 6-10. Detent Actions

Although many detent configurations fit Fig. 6-10, there are others especially configured to suit specific conditions. One such design is for the detents holding the firing pin of the superquick PD fuze MK 27-1 (Fig. 10-11). The detent geometry requires a very loose fit in the detent bore to enable the diminishing setback force in-bore near the muzzle to hold the detents in the locked position even though the centrifugal force is increasing rapidly. This enhances bore safety (par. 10-3.4).

6-4.4 ACTUATING LINKAGE

An example of fuze linkage is the inertial all-way switch for graze action. Fig. 6-11 illustrates how an inertia ring will move a trigger plate regardless of the direction of the force on the inertia ring. The fingers then raise the lever along its guide.

6-4.5 SPIRAL UNWINDER

The spiral unwinder system (Ref. 6) provides an arming delay in fuzes because of the effect of projectile spin. The unwinder consists of a tightly wound spiral coil of soft

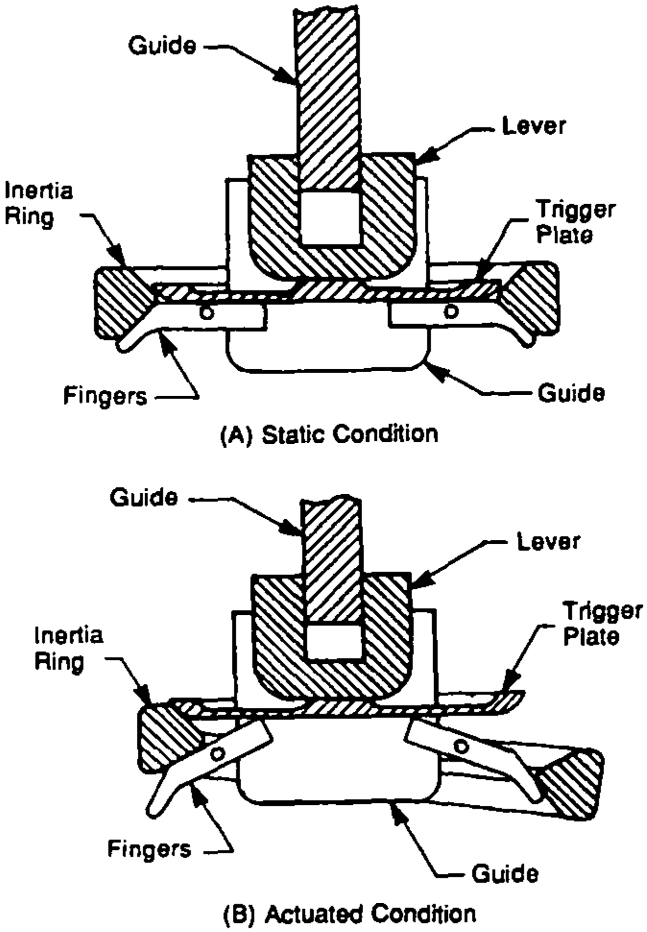
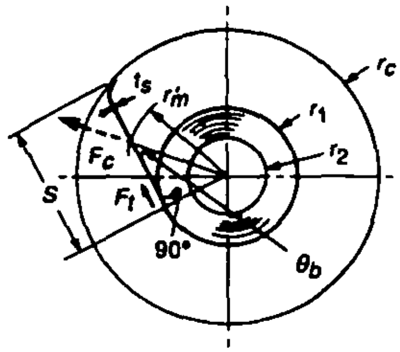


Figure 6-11. Firing Ring for All-Way Switch



r_c = radius of cavity into which the unwinder opens
r_1 = radius of outer coil
r_2 = radius of inner coil
r'_m = radius of midpoint of ribbon bridge
S = length of ribbon bridging between bundle and cavity wall
t_s = ribbon thickness
F_t = tangential force
F_c = centrifugal force

Note: For simplification ribbon is assumed to be straight and tangent to the bundle.

Figure 6-12. Nomenclature for Spiral Unwinder

metal ribbon that is concentric with the spin axis around a hub and is surrounded by a circular cavity, as shown in Fig. 6-12. After firing setback has ceased, projectile spin causes the free end of the ribbon to move outward across the gap and to press against the cavity wall. Continuing spin transfers successive portions of the coiled ribbon progressively outward until all of the ribbon has unwound from the central hub. The time taken by the unwinder to unwrap provides the arming delay. As the last coil of the unwinder ribbon opens, successive members in the arming sequence are released or unblocked. The unwinder has been used to block a striker in the safe position, to restrain an explosive train barrier, and to provide electrical switching.

The tightly wound bundle must be free to rotate around the central hub by means of either a loose fit or preferably by a bearing sleeve on which the ribbon is wrapped. Correct direction of coil winding relative to projectile spin is mandatory. A light retainer spring around the outside of the coil bundle keeps the coil intact during transport or rough handling.

Delay time can be varied from a few milliseconds to a half-second depending on projectile spin rate, ribbon length (0.254 to 0.914 m (10 to 36 in.)), and cavity diameter. The unwinder requires high spin rates; 200 rps is about the lowest application to date. Unwinders have been made of soft aluminum, copper, or brass ribbon. The ribbon is about 0.076 mm (0.003 in.) thick and is made by rolling round wire flat to avoid ragged edges that would cause a stoppage of motion.

The unwinder begins to operate and continues to operate when the force causing bundle rotation exceeds the rotational friction drag forces. (See Fig. 6-12 for definitions of symbols and units.) The centrifugal force F_c acting on the unbalanced ribbon bridge is

$$F_c = 4m_{br}\pi^2N^2r'_m, \text{ N (lb)} \quad (6\text{-}32)$$

where

m_{br} = mass of ribbon bridge, kg (slug)
N = rotation, rev/s
r'_m = radius of mass from center of spin, m (ft).

The force F_t tangent to the bundle at its outside diameter is

$$F_t = F_c\cos\theta_b, \text{ N (lb)} \quad (6\text{-}33)$$

where

θ_b = angle between ribbon bridge and centrifugal force vector, deg

and torque G_1 on the ribbon bundle is

$$G_1 = F_t r_1, \text{ m·N (ft·lb)}. \quad (6\text{-}34)$$

6-4.6 ZIGZAG SETBACK PIN

Zigzag setback pins have been developed for use in a variety of ordnance fuzing applications. The device shown in Fig. 6-13 consists of a spring-biased weight constrained to oscillate and move linearly, both concurrently, by means of a zigzag cam track and a guide pin, either of which is fixed relative to the other. Linear movement of the weight is used to perform a safety, arming, or fuzing function such as unlocking the fuze explosive train interrupter, actuating a switch, or initiating an explosive element in the fuze. These functions must never occur during handling; they must always occur during use of the munition. Therefore, the unique response of the zigzag mechanism is used to distinguish the forces of munition launch, flight, and target impact from those forces produced during munition transport and handling.

Among the many acceleration-sensing mechanisms available, the zigzag mechanism is one of the best. Its combination of simplicity, compactness, and the high degree of safety provided by its ability to discriminate between shock pulses that have large and small changes in velocity is not matched by any other device.

Three factors govern the safety (or stimulus needed for arming) of the zigzag mechanism. The first is the product of axial stroke and average bias level produced by the spring. Without zigzag action this product is equal to the minimum drop height needed for arming, assuming an inelastic impact in the drop. (See the lowest drive curve of Fig. 6-14. Note that the lowest velocity change is required to operate the setback pin over the range of acceleration shown.) If available space and usage conditions are such that a long stroke and high bias level are valid design parameters, adequate safety can be obtained without using a zigzag track.

The second factor relates to the helical track that forces the weight to rotate. Part of the axial (linear) drive force is exerted on the track so that the weight is driven by only a fraction of the force developed by the drive pulse. Furthermore, rotation of the weight creates a "flywheel" effect whereby a small torque is applied to a member having a large inertia; thus it takes a relatively long time to build up speed. Such a device can be called a "nut and helix" mechanism, and it provides improved safety over the axial spring-mass system, as shown by the second curve from the bottom in Fig. 6-14.

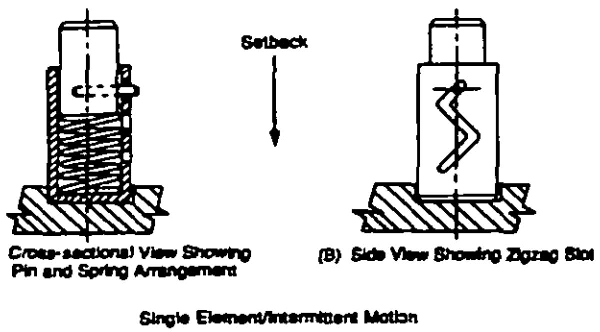


Figure 6-13. Zigzag Setback Pin (Ref. 7)

The third factor involved in safety of the zigzag mechanism is its start-and-stop action. Each time the guide pin reaches an intersection in the zigzag cam track, the weight must stop its axial travel, stop rotating in one direction, and start rotating in the opposite direction. For the weight to move past the first leg of the track, the drive force must still be present to start motion for the second leg. Thus a sustained drive pulse is needed for arming, and an impulse cannot cause the weight to coast through its arming stroke. The effect of having this start-and-stop action can be seen by comparing the response shown in the top curves with the bottom two curves in Fig. 6-14.

The velocity change and acceleration plane shown in Fig. 6-14 represents all rectangular pulses. Each curve separates the plane into two regions—a function region, i.e., all points above the curve, and a no-function region in which pulses will not cause the guide pin to reach the bottom of the track, i.e., all points below the curve. These curves also define the minimum acceleration a pulse must have to function the zig-zag, no matter how great the velocity change, and the minimum velocity change a pulse must have to function the zigzag, no matter what the acceleration amplitude. The equation of motion for the zigzag mechanism is

$$mK_i\ddot{x} + B(x_{ip} + x_0) = m\ddot{y}, \text{ N (lb)} \qquad (6\text{-}35)$$

where

x_{ip} = displacement of mass from an initial position, m (ft)

$\ddot{y}$ = acceleration of mounting structure or fuze with respect to a fixed frame of reference such as gun or ground, m/s^2 (ft/s^2)

B = spring rate of bias spring (change in force per change in length), N/m (lb/ft)

K_i = mechanism constant for ith stage of track defined as

$$K_i = 1 + \left(\frac{k_g}{r_i}\right)^2 \left[\frac{1 + \mu \tan\alpha'_i}{\tan\alpha'_i(\tan\alpha'_i - \mu_i)}\right], \text{ dimensionless} \qquad (6\text{-}36)$$

where

k_g = radius of gyration for mass, m (ft)

r_{ip} = radius to the point interaction between mass and guide pin, m (ft)

μ = coefficient of friction between guide pin and cam track, dimensionless

α'_i = helix angle of the ith stage of cam track, rad.

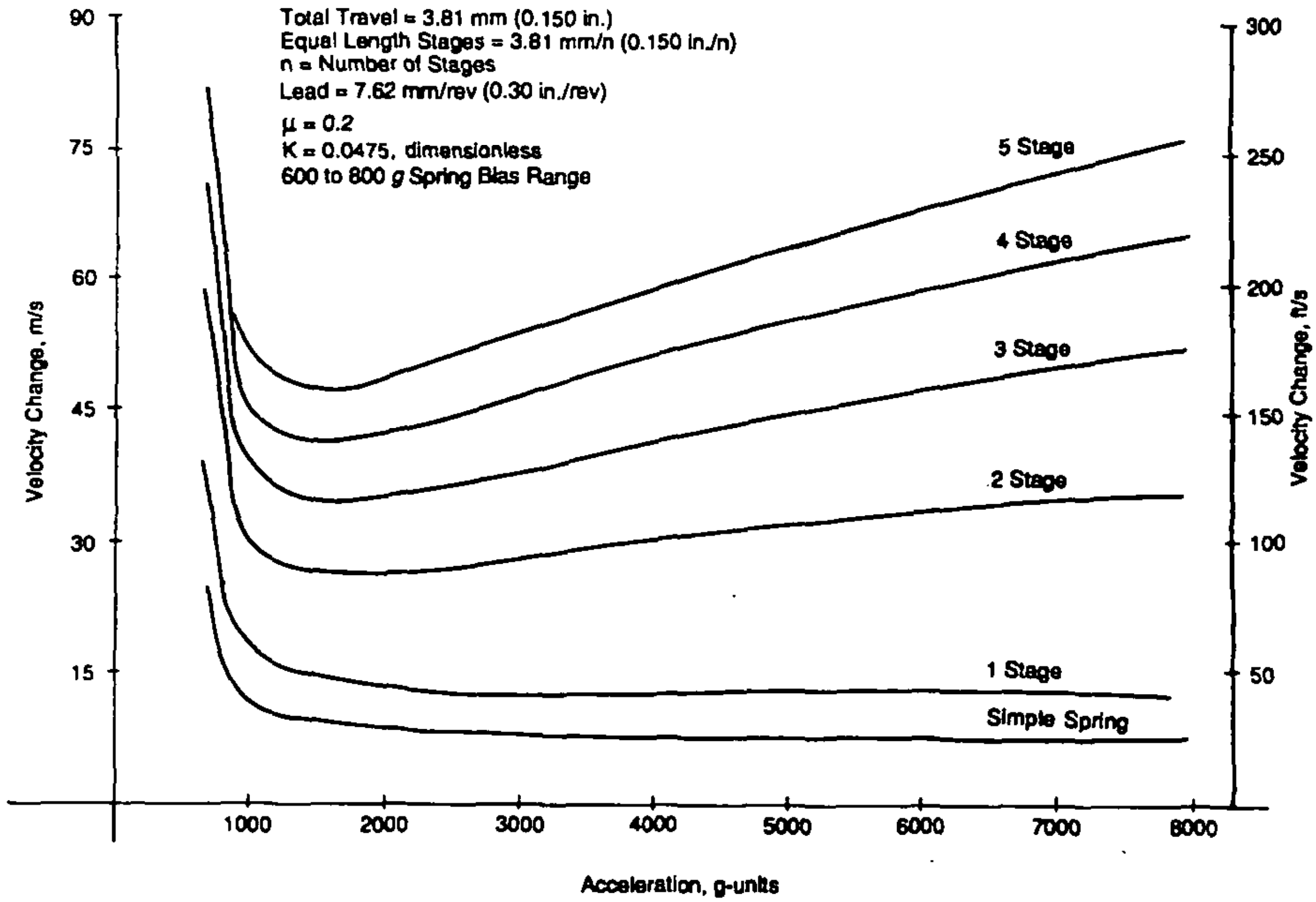


Figure 6-14. Analysis Showing the Effect of the Number of Stages on Performance (Ref. 7)

If L is the lead of the helix angle,

$$\alpha'_i = \mathrm{Tan}^{-1}\left(\frac{L_i}{2\pi r_{ip}}\right), \text{deg} \qquad (6\text{-}37)$$

where

L_i = lead of the ith stage of helix, m/turn (ft/turn).

When the safety, or nonfunction, characteristics of a zigzag mechanism are analyzed as in Fig. 6-14, the rectangular pulse provides a realistic worst-case driving function. The equation of motion for generating the curves of Fig. 6-14 is a special solution of Eq. 6-35 for the case of specific rectangular drive pulses

$$v_{min} = \sum_1^n v_i, \ \frac{\text{m}}{\text{s}}\left(\frac{\text{ft}}{\text{s}}\right) \qquad (6\text{-}38)$$

where

assuming a linear spring constant, the velocity to traverse the ith stage of zigzag is

$$v_i = A_g\sqrt{\frac{WgK_i}{B}}\,\mathrm{Cos}^{-1}\left[1 - \frac{F\Delta x_i}{\dfrac{W(A_g - G_1)}{B} - \sum_1^{i-1}\Delta x_i}\right],$$

$$\text{m/s (ft/s)} \qquad (6\text{-}39)$$

v_{min} = velocity change of a rectangular pulse of acceleration level A, m/s (ft/s)

A_g = linear projectile acceleration (rectangular pulse), g-units.

v_{min}, under the influence of A_g, has a duration just long enough to cause a zigzag track of n stages to disengage from the guide pin. The pulse drives the weight through all stages of the track except the last, for which it drives only a part of the length of the last stage. This pulse provides sufficient energy and momentum to the mass to allow it to coast to a stop at the end of the final stage of the cam track. The mechanism is assumed to be armed at this point, even though the mass may be permitted to move farther because of the clearance designed into a specific device. This assumption is based on the fact that the zigzag track and guide pin are not likely to reengage and return to the full-safe position once they have disengaged. Other terms in Eq. 6-39 are

W = weight of the moving part, N (lb)
K_i = mechanism constant per Eq. 6-36 that applies for the ith stage of the zigzag track, dimensionless. (The mechanism constant depends on the helix angle of the track, and this angle can be different for each stage.)
g = gravitational constant m/s^2 (ft/s^2)
Δx_i = length of the ith stage of the zigzag track, m (ft)
G_1 = spring bias level in g-units at the beginning of the first stage of the track, where G is a multiple of the gravitational constant g and represents a nondimensional force of G times the weight of the moving part
n = number of stages, dimensionless

$$F = \frac{WG_{11} - 0.5B\Delta x_n}{WA_{dp}}, \text{ when } i = n, \text{ dimensionless} \quad (6\text{-}40)$$

or

$$F = 1, \text{ when } i < n, \text{ dimensionless} \quad (6\text{-}41)$$

G_{11} = spring bias level in g-units at the end of the last stage of the zigzag track
A_{dp} = acceleration of driving pulse, g-units
Δx_n = length of the last stage of the zigzag track, m (ft).

The arming time T_t, or time required for the mass to move through the engaged portion of its stroke, under such a rectangular driving pulse is simply

$$T_t = v_{min}/A_{dp}g, \text{ s.} \quad (6\text{-}42)$$

By incrementing the amplitude of the rectangular drive pulse A_{dp} through all possible values and solving Eq. 6-35 for each value, a sensitivity plot for the zigzag mechanism is obtained, as shown in Fig. 6-14.

6-4.7 ROLAMITE

The rolamite mechanism, discussed in Refs. 8 and 9, is composed of two rolling elements (typically cylinders) constrained by parallel guide surfaces and an entwined, flexible metallic band under spring tension. The motion of the rollers is rolling, not sliding. One roller always counterrotates to the other. The coefficients of friction for rolamites are from 1 to 10% of those for ball or roller bearings with equal diameter rolling elements under the same load. This low-friction aspect is one of the primary advantages of the rolamite.

Another useful characteristic of the rolamite geometry is the capability of the band to generate varying forces along the length of travel. These forces can be used to establish breakaway levels, for force biases, for detents, for latching forces, etc. This capability can be explained by investigating the energy stored in the band, as shown in Fig. 6-15. If motion is assumed to the right, the band is forced to assume the curvature of the rolling element at point B, to go through a complete inflection at point C, and is allowed to return to its flat condition at point A. Hence strain energy is added to the band at point B, is quickly regained and reintroduced in the form of opposite curvature at point C, and is gained back from the band at point A.

A wide variety of applications have been devised and are illustrated in Refs. 8 and 9. Some arrangements potentially suitable to fuze design are shown in Fig. 6-16. Fig. 6-16(A) represents a switch with liquid damping, (B) an explosive train interrupter, and (C) a low-friction inertial plunger.

6-4.8 BALL LOCK AND RELEASE MECHANISMS

These mechanisms have long been used in fuze design and still serve useful purposes. A ball bearing is very uniform dimensionally and is a low-cost, reliable item. Although the designs are far too numerous to be covered in this handbook, some examples are shown in Figs. 1-36, 3-6, and 6-17, and a search of compendiums on fuzes will produce many more.

The designer should be aware of the consequences of a ball(s) being omitted during production and the consequences of brinelling, which could produce reliability or safety defects.

6-4.9 FORCE DISCRIMINATING MECHANISM (FDM)

The FDM, as shown in Fig. 6-18, evolved as a way to avoid the safety failure of the nonspin rocket base Fuze MK 191, Mod 1 when the rocket head is subjected to a tumbling mode. This condition occurs under jettison or inadvertent separation from the aircraft when the head and motor separate on ground impact.

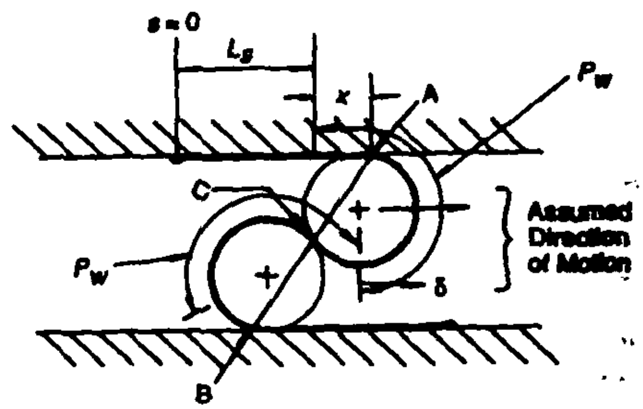
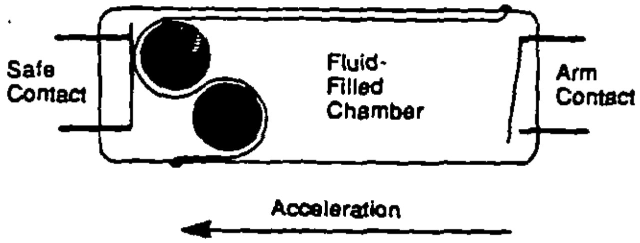
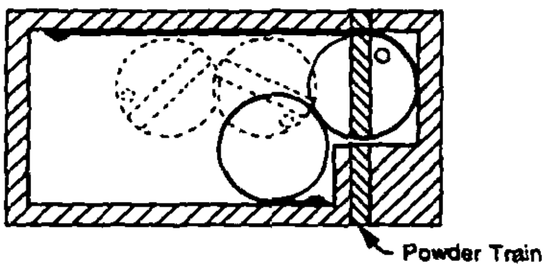


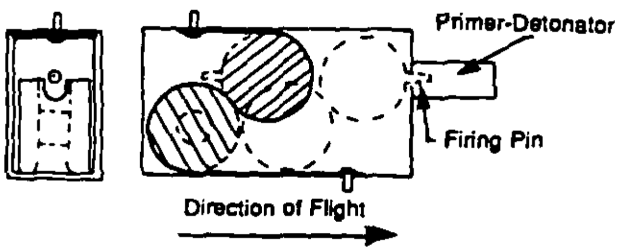
Figure 6-15. Energy Storage in a Rolamite Geometry (Ref. 8)



(A) Rolamite S&A Switch (Ref. 10)



(B) Rolamite S&A Mechanism (Ref. 8)



(C) Rolamite Firing Pin Mechanism

Figure 6-16. Rolamite Applications for Fuzing

The FDM consists of a link work controlled by two weights (balls) located at different distances from the center of gravity (CG) of the rocket head. One ball and its link are heavier and move the linkages rearward under linear acceleration and thus remove a lock on the rotor.

In the tumble mode, centrifugal force on the other ball and link, which are located at a greater distance from the center of gravity, overcomes the heavier ball and link and retains the lock on the rotor. Thus the FDM discriminates between linear force and centrifugal force.

6-5 ROTARY DEVICES

Some components of the arming mechanisms are pivoted so that they can turn through a specified angle. The rotation may be caused by centrifugal forces, linear forces, or unwinding springs. The axes of the rotating members may be parallel to, perpendicular to, or at an angle to the munition axis. These features are discussed in regard to whether the devices are in stable or unstable equilibrium, i.e., whether the munition spin causes or merely affects their motion. These devices follow the general principle that the rotors turn until the potential energy of the rotor in the force field is at a minimum.

6-5.1 DISK ROTOR

If the disk rotor is used in a spinning munition, torques are created to cause the disk to rotate in its own plane about an axis perpendicular to the spin axis. The rotor shown in Fig. 6-19 is in an initial position with its symmetrical diametral axis at the angle θ to the spin axis of the munition.

When the angle θ is zero, there is no more drive torque, i.e., the disk has reached the position of dynamic equilibrium. As shown in Fig. 6-20, the device may actually become armed before $\theta = 0$ deg. This is because the output from the detonator may be propagated across the gap at the overlap of detonator and lead charges. At this point the explosive train is no longer safe. Hence, for minimum arming distance, the designer must calculate the time for the angle θ to reduce to θ', rather than to 0.

The equation of motion for a disk is the equation for torque about the pivot axis. For the disk shown in Fig. 6-19, the torque equation is

$$I_z\ddot{\theta} = W_p a_g \mu r_d - (I_p - I_D)\,\omega^2 \sin\theta\cos\theta, \quad \text{N·m (lb·ft)} \tag{6-43}$$

where

r_d = radius of disk, m (ft)
θ = any intermediate position of disk, rad
a_g = acceleration, g-units
$\ddot{\theta}$ = angular acceleration of disk, rad/s^2
ω = spin rate of projectile, rad/s
I_z, I_p, I_D = moments of inertia about the three respective axes, kg·m^2 (slug·ft^2).

If a_g is zero, the frictional torque is zero. The solution of Eq. 6-43 then becomes an elliptic integral of the first kind

$$t = \frac{1}{\omega}\sqrt{\frac{I_z}{I_p - I_D}}\int_{\phi_1}^{\phi_2}\frac{d\phi}{\sqrt{1 - K_\theta^2 \sin^2\phi}}, \text{ s} \tag{6-44}$$

where

$\phi_1 = \text{Sin}^{-1}\dfrac{\sin\theta'}{\sin\theta_0}$, rad

$\phi_2 = \dfrac{\pi}{2}$, rad

$K_\theta = \sin\theta_0$, dimensionless
θ' = angular position of disk at which the fuze may become armed, rad
θ_0 = initial angular displacement, rad.

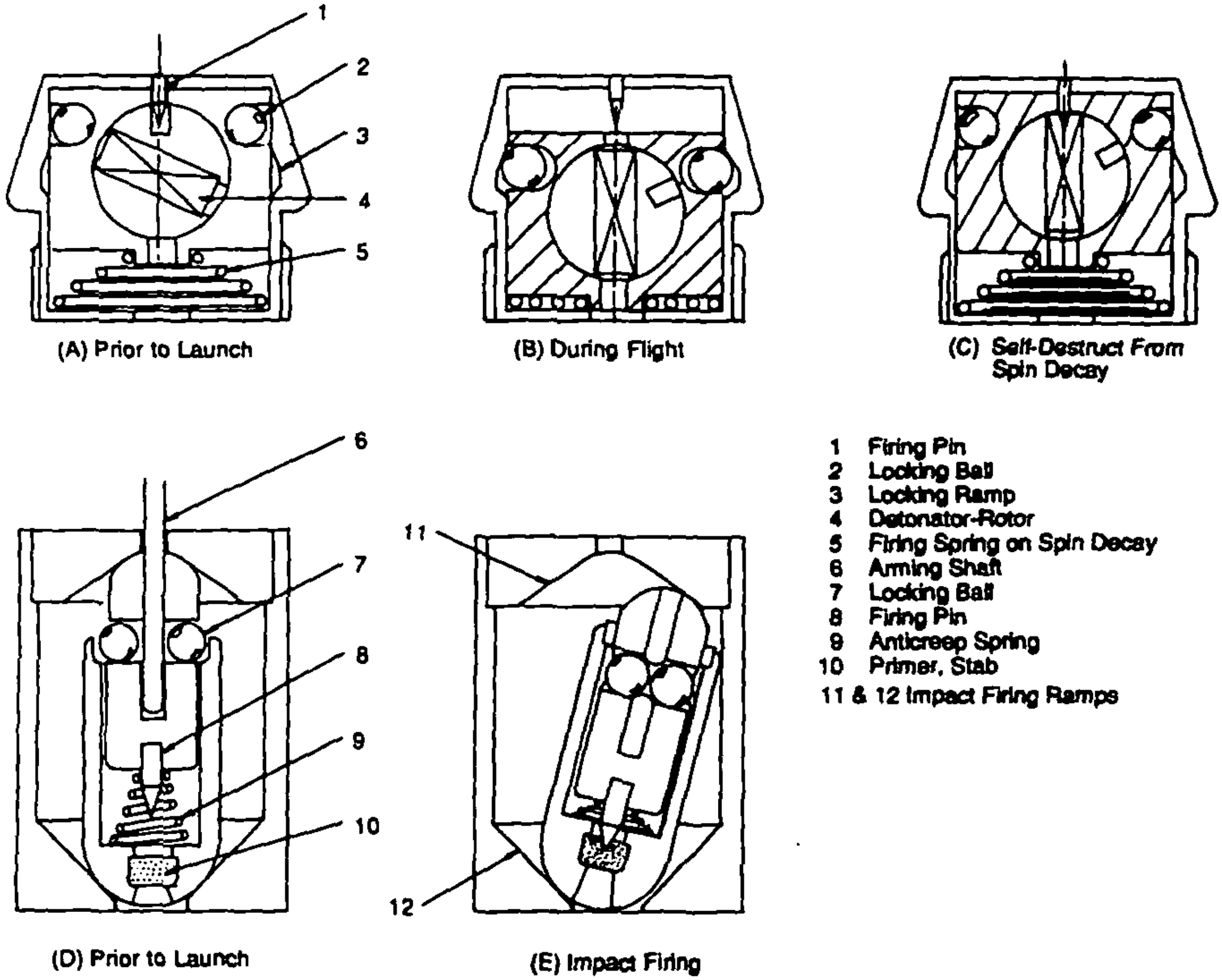


Figure 6-17. Ball-Lock Mechanisms (Refs. 11 and 12)

Tables of integrals can be used to solve Eq. 6-44 for time t.

If a_t is not zero, Eq. 6-43 is best solved by using a computer.

The centrifugal pendulum shown in Fig. 6-21 is a simple variation of the disk rotor; thus the same equation of motion with minor adjustments to the friction radius applies.

6-5.2 THE SEMPLE FIRING PIN

This device, shown in Figs. 6-22 and 6-23, operates by centrifugal effects, which cause it to pivot into a preferred orientation when released. The equation of motion of the leaf leads to the torque equation

$$I_i\ddot{\theta} = G_f - m_p r(r_{cg}\sin\theta_c)\,\omega^2 + W_p a_i r_{cg}\cos\theta_c,\quad \text{N·m (lb·ft)} \tag{6-45}$$

where

G_f = frictional torque, N·m (lb·ft)

r_{cg} = radial distance from pivot to center of gravity of leaf, m (ft)

m_p = mass of part (leaf), kg (slugs)

I_i = moment of inertia of part with respect to pivot, kg·m² (slug·ft²)

θ_c = angular orientation of center of gravity of leaf, rad.

The frictional torque G_f may be very small compared to the centrifugal force F_c.

6-5.3 SEQUENTIAL ELEMENT ACCELERATION SENSOR

These devices respond to a continued linear acceleration in the direction of the projectile axis, as shown in Fig. 6-24.

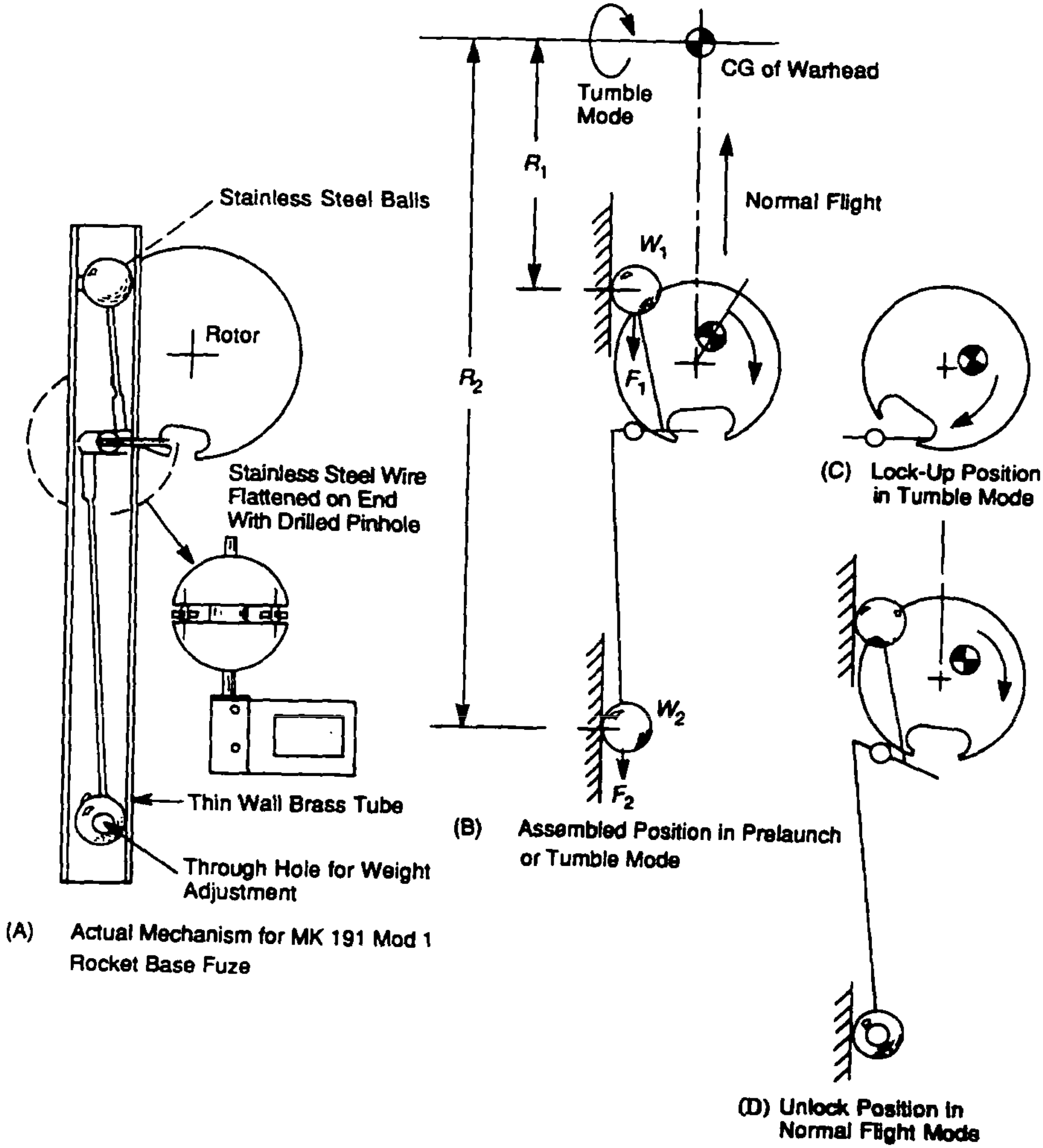


Figure 6-18. Force Discriminating Mechanism (FDM)

The mechanism consists of a series of interlocked, pivoted segments or leaves, each held in position by a spring. When a sustained acceleration occurs, such as when the projectile is launched, the first segment rotates through an angle sufficient to release the second segment, which, after rotating, releases the third segment. When this last segment completes its rotation, it releases another element in the fuze, e.g., a timer or rotor.

The mechanisms are designed to operate under sustained setback. Any short-period acceleration such as may occur in a fall or a jolt will not cause all of the leaves to rotate.

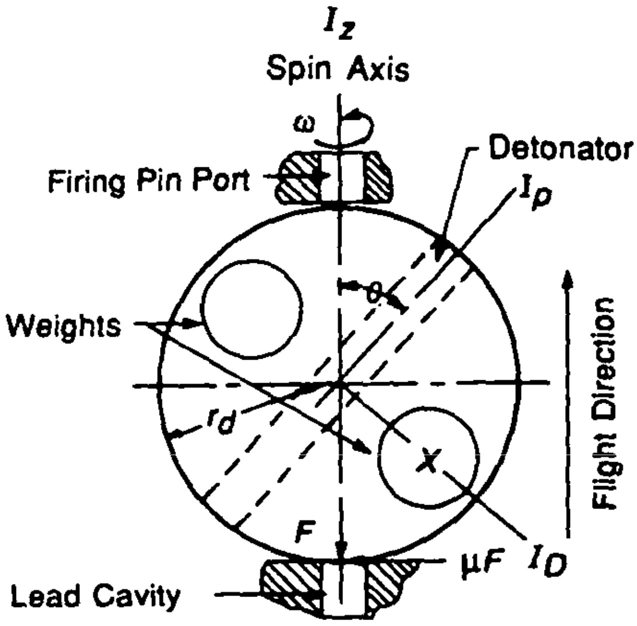


Figure 6-19. Disk Rotor

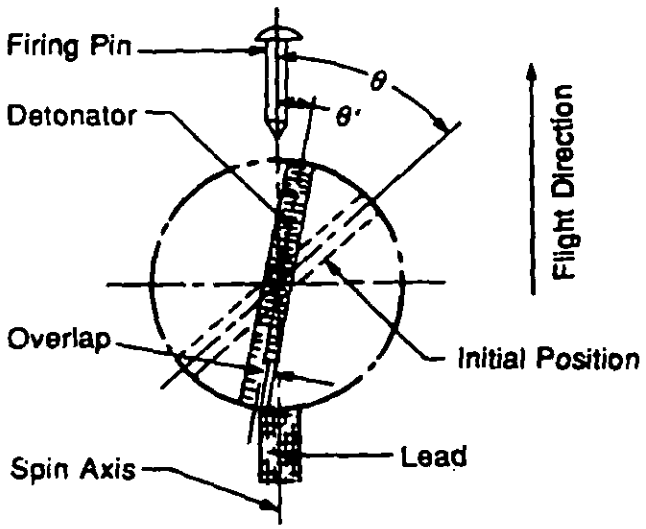


Figure 6-20. Detonator Overlap in Disk Rotor

The problem of designing a sequential leaf mechanism demands the use of as large a portion as possible of the area under the acceleration curve (velocity change) shown in Fig. 6-25. The differential equation of motion for a single leaf is

$$I_L\ddot{\theta} = W_L a'(t)\, r_{cg}\cos(\theta_i - \alpha_o) - (G_0 + k\theta_i) - G_f,\ \text{N·m (lb·ft)} \qquad (6\text{-}46)$$

where

W_L = weight of leaf, N (lb)

r_{cg} = radial distance from pivot to center of gravity of leaf, m (ft)

I_L = moment of inertia of leaf about axis of rotation, kg·m^2 (slug·ft^2)

$\ddot{\theta}$ = angular acceleration of leaf, rad/s^2

$a'(t)$ = applied acceleration, g-units

α_o = angle between perpendicular to direction of acceleration and line through the center of gravity of leaf and axis of rotation of leaf, rad

G_0 = torque due to prewinding of spring, N·m (lb·ft)

k = spring constant, N·m/rad (lb·ft/rad)

θ_i = angular displacement of leaf, rad.

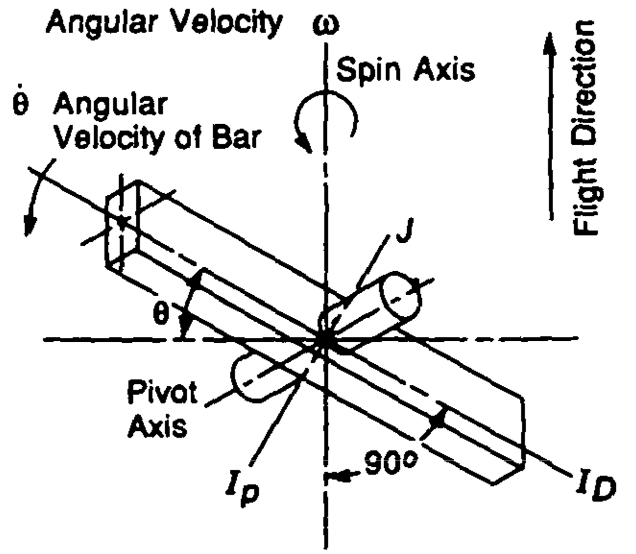


Figure 6-21. Centrifugal Pendulum

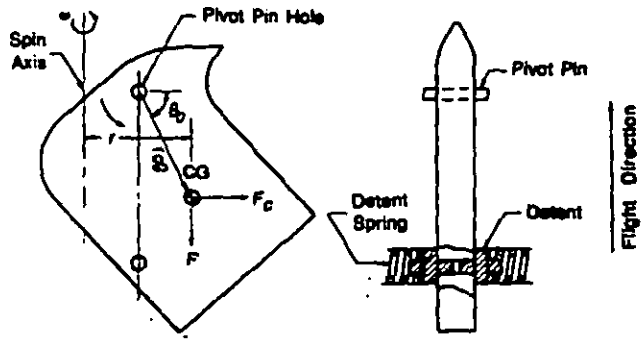


Figure 6-22. Semple Firing Pin

If leaf rotation is limited to the range of ±22.5 deg from the horizontal, $\cos(\theta_i - \alpha_o)$ can be assumed equal to unity without introducing serious error. Also the initial spring torque G_0 can be expressed as $Wr_{cg}a''$, where $a'' < a'$. Thus Eq. 6-46 becomes

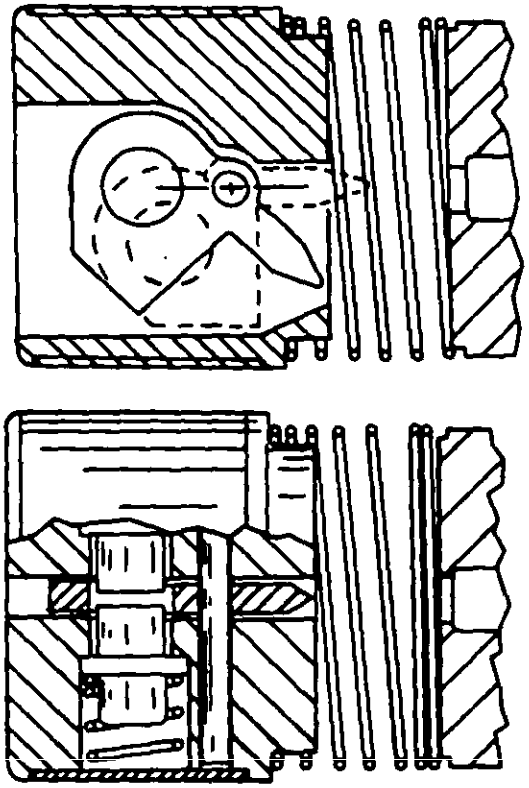


Figure 6-23. Semple Plunger and Firing Pin Performing as Centrifugal Pendulum

$$I_L\ddot{\theta} = W_L r_{cg}[a'(t) - a''] - k\theta_i - G_f, \text{N·m (lb·ft)} \quad (6\text{-}47)$$

where

a'' = design minimum acceleration assumed constant, g-units.

If it is assumed that

$$a'(t) = a', \text{ a constant}$$
$$\theta(0) = \dot{\theta}(0) = 0,$$

the solution of Eq. 6-47 is

$$\theta_t = \left[\frac{W_L r_{cg}(a' - a'') - G_f}{k}\right](1 - \cos\omega t), \text{ rad} \quad (6\text{-}48)$$

where

$$\omega = \sqrt{\frac{k}{I_L}}, \text{ rad/s.}$$

The arming time t_{1arm} for a single leaf is

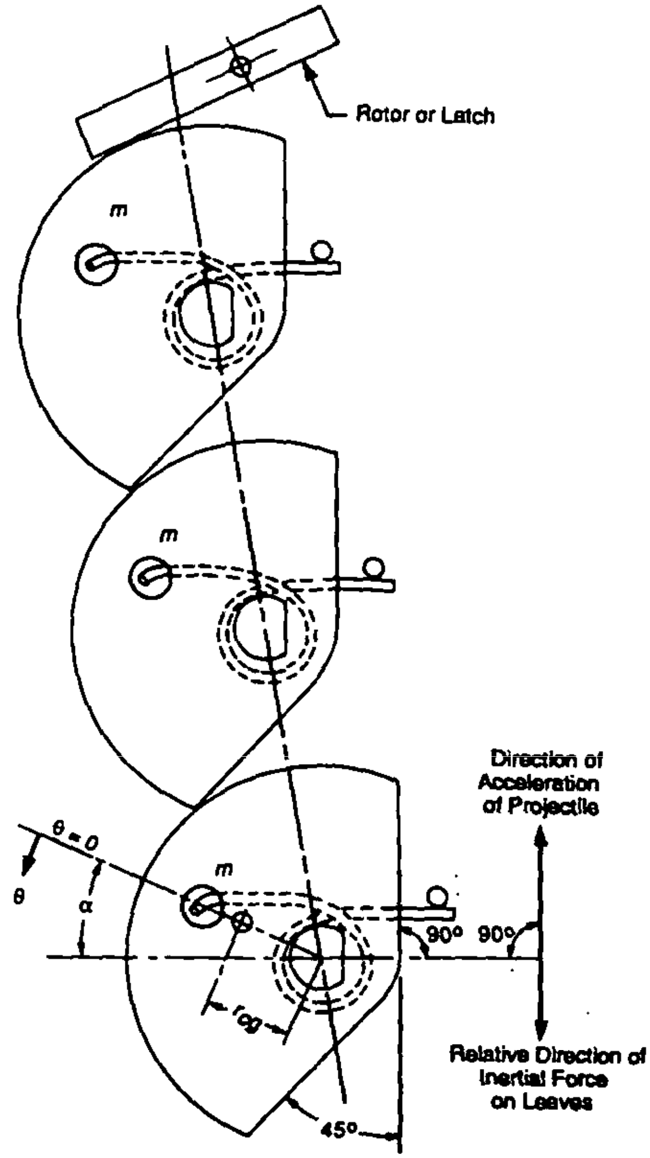


Figure 6-24. Sequential Leaf Mechanism

$$t_{1arm} = \frac{1}{\omega}\text{Cos}^{-1}\left[1 - \frac{k\theta_{arm}}{W_L r_{cg}(a' - a'') - G_f}\right], \text{ s} \quad (6\text{-}49)$$

where

θ_{arm} = angle through which leaf must rotate to arm, rad.

For sustained acceleration of a magnitude above the minimum magnitude a'', the arming time decreases with increasing acceleration magnitude. A consequence of this is that a sustained acceleration of magnitude greater than a'' might arm the mechanism, even though the acceleration lasts for less than the designed minimum arming duration. A

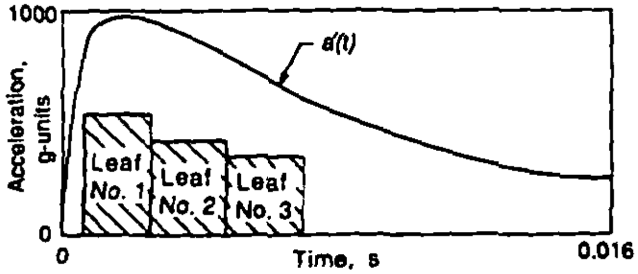


Figure 6-25. Setback Acceleration Curve

carefully designed mechanism can be made to avert arming only for drops up to a height for which the impact velocity is one-half the velocity change represented by the first integral of $a'(t)$.

Refer to the setback acceleration curve; each leaf would be designed to operate at a slightly different minimum acceleration by varying the thickness of the leaves. Fig. 6-25 shows a typical setback acceleration curve and the portions of the curve used for operation of each leaf.

There is very little to be gained by selecting a combination of leaves of different masses, i.e., by trying to choose the leaf mass to fit the particular segment of the acceleration function occurring while the leaf is rotating. For any combination of variable leaf masses designed to arm for the given applied acceleration and have the maximum drop-safety index, there is a set of equal-mass leaves that will also arm and have a drop-safety index that is no less than 3 or 4% below the index of the leaves of varying mass. Therefore, unless there are other reasons for leaves of unequal mass, there is little advantage to varying the mass from leaf to leaf. Also the design problem is greatly simplified by using leaves of the same mass (Ref. 13).

There are three noteworthy features of the leaf mechanism design shown in Fig. 6-24. The first feature is the "piggyback" nature of the interlock between each leaf. This provides intrinsic safety against missing parts such as the interlock pins used in coplanar leaf mechanism designs. The second feature is the long stroke, or 45-deg arming angle, of each leaf, which greatly increases the arming time and thereby the safety of the device. The third feature is the fact that the leaf is massive enough to do work, i.e., the last leaf can be used to release a heavy load by using a simple interlock device, such as the half shaft shown in Fig. 6-9.

6-5.4 ROTARY SHUTTER

The rotary shutter, or rotor, is illustrated in Fig. 6-26. It contains a detonator, which in the assembled position of the shutter is out-of-line with the rest of the explosive train. The plane of the shutter is perpendicular to the axis of the munition. It is important to note that the center of mass of the shutter is located neither at the pivot nor on the munition axis. For a fuze that spins, centrifugal effects will cause the shutter to turn after it is released by the centrifugal pin. It will turn until it reaches an orientation that puts it in-line with the other elements of the explosive train. The shutter is mechanically restrained from further motion when it reaches this position. The equation of motion is

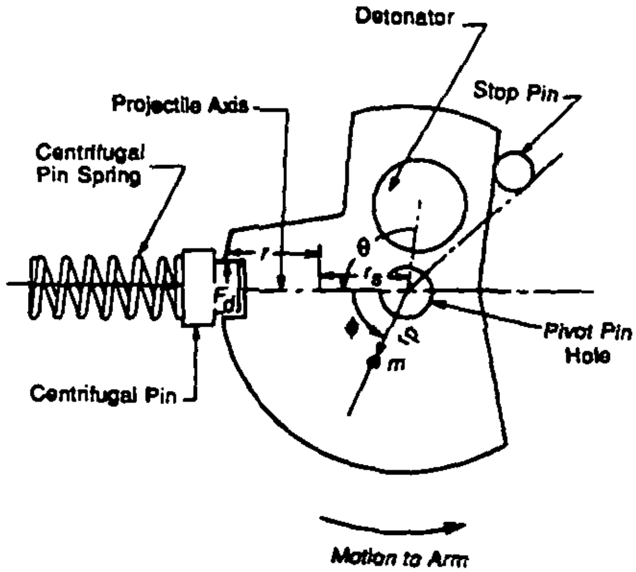


Figure 6-26. Rotary Shutter

$$I_s\ddot{\phi} = -m_s\omega^2 r_s r_p \sin\phi + G_f,\ \text{N·m (lb·ft)} \quad (6\text{-}50)$$

where

I_s = moment of inertia of shutter, kg·m^2 (slug·ft^2)
m_s = mass of shutter, kg (slug)
r_s = distance from the projectile axis to the center of the pivot pin hole, m (ft)
r_p = distance from the center of the pivot pin hole to the center of mass of the shutter, m (ft)
G_f = friction torque, N·m (lb·ft)
ϕ = angular displacement of shutter with ϕ_0 being initial position of shutter, rad.

The time t is that required to rotate through ϕ rad. At this angle the detonator is aligned with the munition spin axis. As before, the detonator could be initiated before it is exactly on center.

The safety of the system as depicted in Fig. 6-26 is inadequate according to MIL-STD-1316 and would require an additional lock, such as a setback pin, on the shutter.

6-5.5 BALL-CAM ROTOR

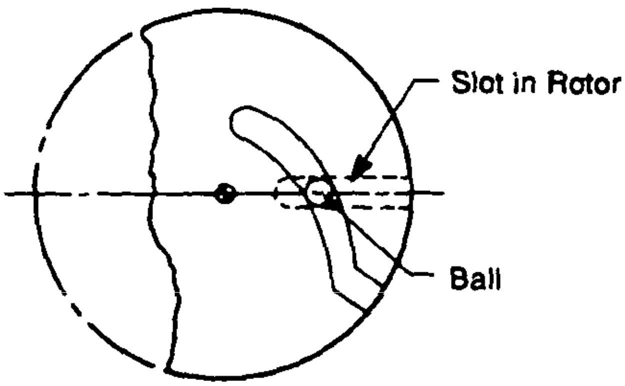
The ball-cam rotor uses a small mass to drive a rotary element that has a large inertia. It has a timing cycle that is inversely proportional to the rotational velocity of the fuze. The device consists of three parts: (1) a ball that moves in a centrifugal field, (2) a stationary part with a slot radial to the fuze spin axis in order to guide the ball, and (3) a rotor with a spiral slot, which turns as the ball moves radially. Fig. 6-

27(A) shows the ball in the slots of the rotor and stator. The forces on the spiral slot are shown in Fig. 6-27(B), and those on the ball, in Fig. 6-27(C). With the center of rotation on the spin axis, the torque equation for the rotor is

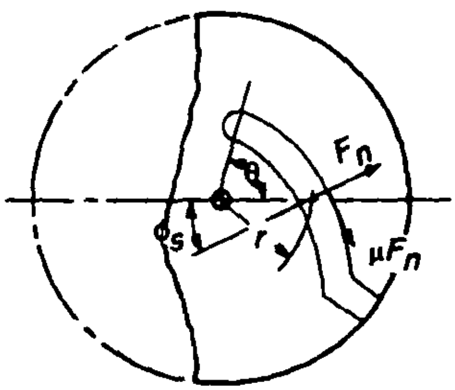
$$I_r\ddot{\theta} + \mu F_n r\cos\phi_s = F_n r\sin\phi_s, \text{ N·m (lb·ft)} \quad (6\text{-}51)$$

where

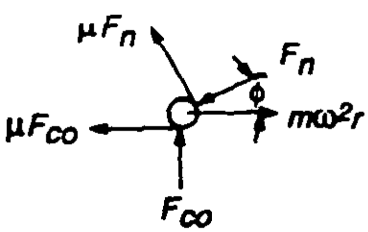
ϕ_s = slot spiral angle, rad
I_r = moment of inertia of rotor, kg·m^2 (slug·ft^2)
$\ddot{\theta}$ = rotational acceleration, rad/s^2
r = radial distance, m (ft) (See Fig. 6-27.)
F_n = normal force, N (lb).



(A) Ball-Cam Rotor Assembly



(B) Forces on Spiral Slot



(C) Forces on the Ball

Figure 6-27. Ball-Cam Rotor

The force equations for the ball are

$$m_b r\omega^2 - (F_n\cos\phi_s - \mu\sin\phi_s) - \mu F_{co} = m\ddot{r}, \text{ N (lb)} \quad (6\text{-}52)$$

and

$$F_{co} - F_n(\sin\phi_s - \mu\cos\phi_s) = 0, \text{ N (lb)} \quad (6\text{-}53)$$

where

$\ddot{r}$ = radial acceleration of ball, m/s^2 (ft/s^2)
m_b = mass of ball, kg (slug)
F_{co} = Coriolis force on ball, N (lb).

Combine Eqs. 6-51, 6-52, and 6-53 to eliminate F_{co} and F_n. Assume $r\omega^2 >> \ddot{r}$. Eq. 6-52 then becomes

$$m_b r^2\omega^2\tan\phi_s\left(\frac{1-(\mu/\tan\phi_s)}{1+2\mu\tan\phi_s-\mu^2}\right) = I\ddot{\theta}, \text{ N·m (lb·ft)}. \quad (6\text{-}54)$$

To solve Eq. 6-54 conveniently and obtain an approximate value,

1. Define $r = r'_0 + S_s\theta$ where S_s is spiral constant, m/rad (ft/rad).
2. Recognize that $r\tan\phi_s = dr/d\theta$.
3. Let $\dfrac{1-(\mu/\tan\phi_s)}{1+2\mu\tan\phi_s-\mu^2} = C$, dimensionless constant.

After making these substitutions, Eq. 6-54 can be written as

$$I\ddot{\theta} - m_b\omega^2 C s_s^2\theta = m_b\omega^2 C s_s r'_0, \text{ N·m (lb·ft)}$$

where

r'_0 = initial radius, m(ft)

from which

$$t = \frac{1}{\omega s_s}\sqrt{\frac{I}{m_b C}}\cosh^{-1}\left(\frac{r}{r'_0}\right), \text{ s} \quad (6\text{-}55)$$

is obtained.

This equation shows that the time to rotate the rotor is inversely proportional to the spin of the projectile.

6-5.6 BALL ROTOR

A ball rotor like that shown in Fig. 6-28 is often used to obtain arming delay in high-velocity, small caliber projectile fuzes. In the unarmed position the ball is oriented and held by detents so that the detonator is out-of-line with the firing pin. During the arming process, the detents move under spin forces and release the ball. The ball is then free to turn in its spherical seat until it reaches the armed position with the detonator aligned with the firing pin.

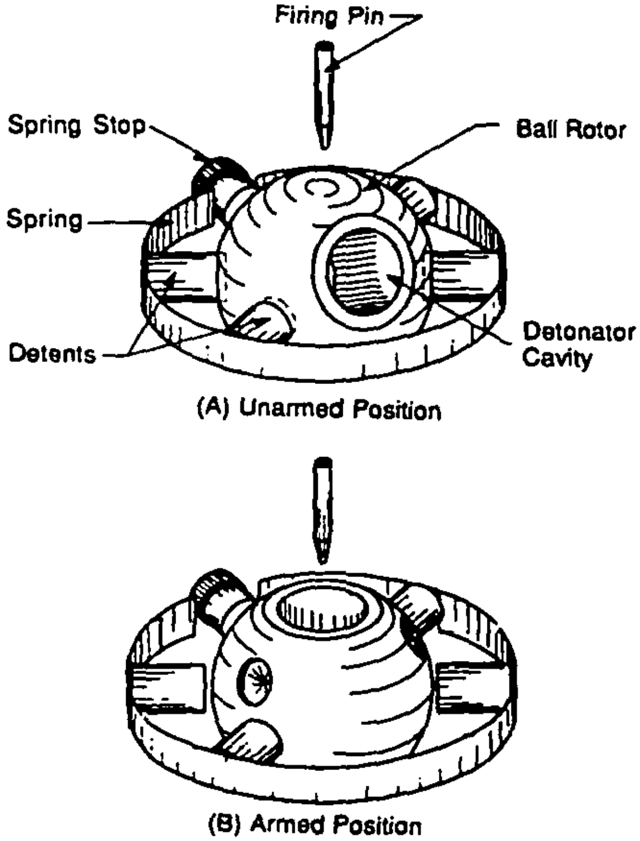


Figure 6-28. Ball Rotor

Fig. 6-29 shows other methods of detenting the ball rotor that are used in small caliber rounds with high spin rates. The arming distances usually range from 3 to 6 m (10 to 20 ft) in these calibers.

Mathematical analysis of the ball rotor is complex. Refer to Refs. 14 and 15. The motion of the detonator during the arming cycle is an orbiting action, i.e., the detonator spirals into the armed position. Clearance and friction between the ball and its cavity and the moments of inertia of the ball are the three most important parameters in achieving satisfactory operation. Theoretically, the ball would never arm if there were no friction. The higher the friction, the shorter the arming path and time to arm. An exception to this statement is that if friction exceeds a critical value, the ball will stop before the armed position.

6-5.7 ODOMETER SAFETY AND ARMING DEVICE (SAD)

The design concepts considered for the odometer (instrument for measuring distance) SAD attempt to achieve a fail-safe system by employing a balanced rotor pivoted about its center of mass, which lies on the axis of spin, i.e., the rotor becomes inertially passive in a constant spin environment. Thus centrifugal force exerts no driving torque on the rotor and will not drive it to the armed position if the rotor should disengage from the gear train. In this case a fail-safe condition, or dud, results.

Fig. 6-30(A) is a sketch of a motion-reversal gear train taken from Ref. 16. Gear A is initially engaged to Rack C, and counterclockwise rotation of Gear A drives Rack C from right to left. Gear A disengages the rack at E and simultaneously engages Gear B, which also meshes with Rack C. Thus Gear B acts as an idler gear between Gear A and Rack C and causes Rack C to reverse direction and move from left to right. When Point D engages the rack, the cycle of motion is repeated.

This mechanism was modified, as shown in Fig. 6-30(B). Initially, Gear A meshes with the pinion affixed to the rotor and with Gear B. However, the teeth on Gear B that would normally mesh with the rotor pinion at that point have been cut away. Thus both the rotor and Gear B initially turn in synchronization with Gear A. Gear A and the rotor continue to turn together until Point E, at which the remaining section of Gear A teeth that would normally mesh with the rotor pinion have been cut away. At that point Gear A remains engaged with Gear B, and Gear B engages the rotor pinion. Since Gear B is rotating counterclockwise, it will drive the rotor in the clockwise direction, so it acts as an idler between Gear A and the rotor pinion.

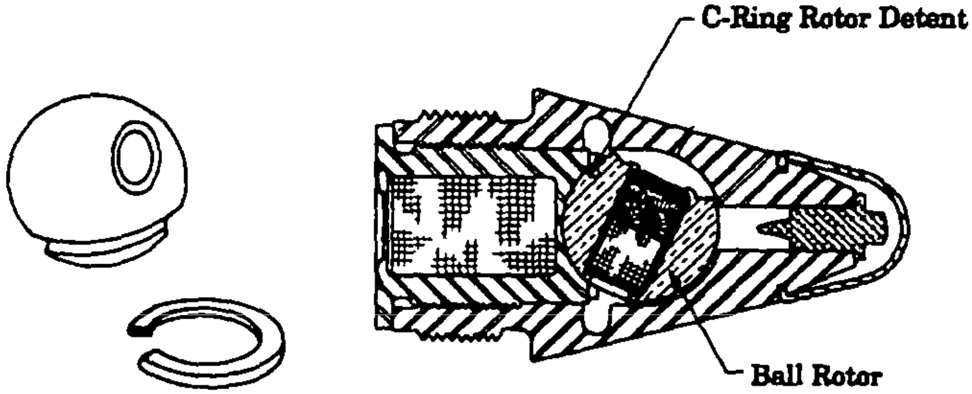
In actual operation, either Gear A or both Gear A and Gear B can be drive gears if their mass centers are displaced from their geometric centers. The centrifugal drive torque is generated from projectile spin about the longitudinal axis of the pinion. This torque drives Gear A clockwise and Gear B counterclockwise. The rotor then rotates back through its original position and on to the armed position, where the explosive lead in the rotor is in line with the explosive train. This design is referred to as rotation counterrotation (RCR). Ref. 17 gives the equation of motion.

The design gives an essentially constant arming distance irrespective of muzzle velocity. In ballistic tests models gave a nominal arming distance of 236 m (773 ft).

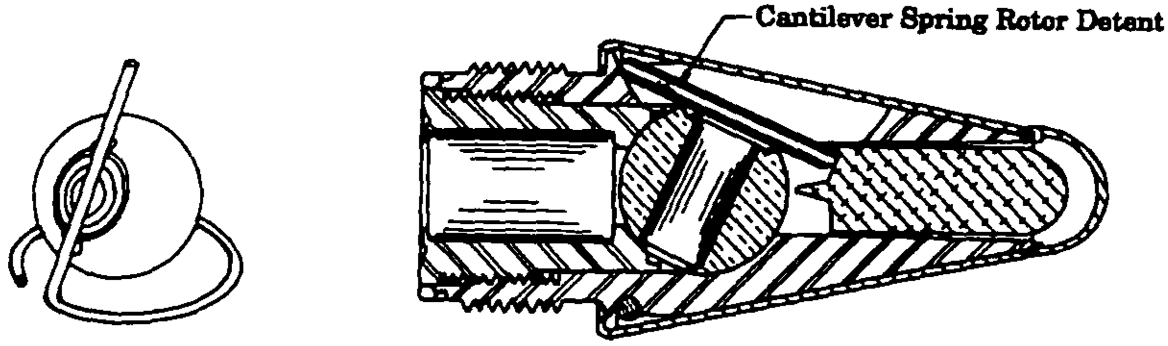
The balance of the rotor is important, and the rotor must be mounted on two miniature ball bearings to obtain reliable operation under off-center spin conditions.

6-6 MECHANICAL TIMING DEVICES

Clockwork is used to obtain a time interval for functioning a munition at the target or to achieve a safe separation arming distance. A timer has many parts, but only the escapements and gear trains are discussed in detail here and covered in Refs. 18 through 22. The design features of gears, bearings, and shafts are described in standard design texts (Ref. 23). Note that conventional gear designs are generally not applicable to timing devices. Fuze clockwork gears transmit decreasing levels of torque at increasing speed rates. In addition, space limitations require the use of small pinions with few teeth, usually eight. The environment is severe (See par. 9-2.1.), special lubrication prob-



(A) 20-mm Fuze, M505A3



(B) 20-mm Fuze, T195EII (Ref. 12)

Figure 6-29. C-Ring and Cantilever Spring Methods of Holding Ball Rotor

lems exist, and the relation of the setting and indicating devices is critical.

6-6.1 ESCAPEMENT TYPES

Escapements are used to "escape" an energy source at a controlled rate and thereby regulate time function. There are three types of escapement regulating devices:

1. *Untuned, Two-Center Escapements.* A pivoted mass driven by an escape wheel. Physically, this is a mass oscillating without a spring by depending on its own inertia to control its motion. An example is a runaway escapement.
2. *Tuned, Two-Center Escapements.* A combination of a pivoted balance and a mass restoring spring, pulsed twice per cycle by an escape wheel. Physically, this is a mass on a spring executing simple harmonic motion. An example is a Junghans escapement.
3. *Tuned, Three-Center Escapements.* A mass and an escape wheel with an intermediate link placed between the escape wheel and the oscillating mass to improve the precision of impulse delivery and to minimize drag torque. An example is a detached lever escapement.

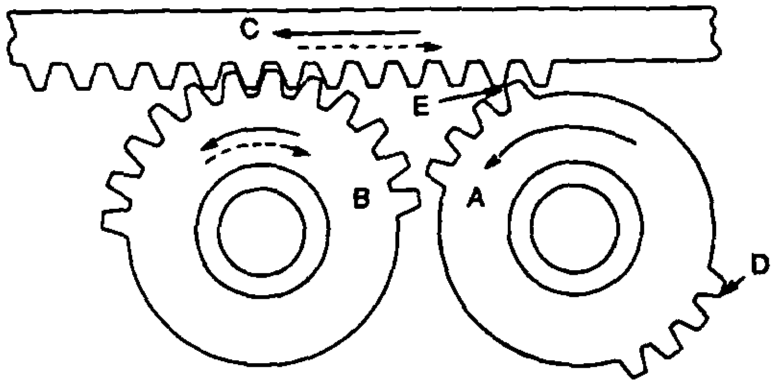
These escapements are discussed in the paragraphs that follow.

6-6.1.1 Untuned, Two-Center Escapement

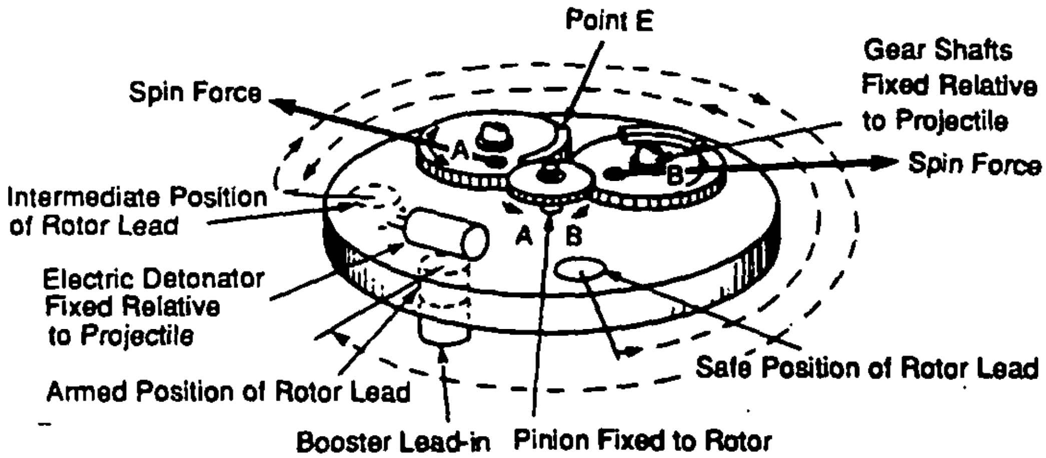
6-6.1.1.1 General

An untuned, or runaway, escapement is a device with a cyclic regulator that does not execute simple harmonic motion. The system has two parts: (1) a toothed escape wheel actuated by an applied torque and (2) a pallet. The pallet is a mass oscillating without a restoring force. One common form of the pallet has two teeth or pins (also called pallets). Fig. 6-31 illustrates one shape for an escape wheel. It differs from that in the tuned escapement because it must always drive the pallet. When the escape wheel turns, one pallet tooth (pin) is pushed along the escape wheel tooth. After that pin reaches the end of the escape wheel tooth, the other pallet tooth or pin is driven into engagement with an escape wheel tooth, thus stopping or slowing down the escape wheel. The pallet will then turn in the opposite direction. A constant torque applied to the escape wheel will cause the oscillating system to run at a generally constant rate (±10%). Changes in the drive torque will alter the rate of operation of the runaway escapement.

The angular velocity versus time history of an escape wheel in a runaway escapement generally appears as in Fig. 6-32 for two half-cycles. Phases of Motion I and III are



(A) Mechanism for Transmitting Uniform Reciprocating Motion to Rack C from Rotating Intermittent Gear A (Ref. 16)



(B) Rotation Counterrotation Odometer S&A Mechanism (Ref. 17)

Figure 6-30. Schematic of Rotation Counterrotation Odometer S&A Mechanism

essentially the same with the exception that the wheel drives the pallet lever clockwise in Phase I and then counterclockwise in Phase III. During Phases II and IV the escape wheel is temporarily unlinked from the pallet lever allowing it to accelerate more rapidly. Generally, Phases II and IV can be considered to contribute little to the overall time delay.

The frequency f_n of pallet oscillation can be related to the torque G on the escape wheel if the following assumptions are made: (1) the half-cycles of the pallet are equal in time, (2) the driving torque is constant, (3) the impacts are inelastic, and (4) friction is negligible.

The equation for f_n is

$$f_n = \frac{1}{2\pi}\sqrt{\frac{(G_1 r_p / r_w)}{2I_m \theta_p}}, \text{Hz} \qquad (6\text{-}56)$$

where

θ_p = angle between extreme positions of pallet, rad

I_m = moment of inertia of oscillating mass (pallet), $kg \cdot m^2$ $(slug \cdot ft^2)$

r_p = radius of the pallet, m (ft)

r_w = radius of the escape wheel, m (ft)

G_1 = torque, N·m (lb·ft).

Eq. 6-56 indicates that the frequency varies directly as the square root of escape wheel torque. When designing the gear train, the designer must remember that G is the actual rather than the theoretical torque. As a first approximation, use 30% of the theoretical torque.

To meet safety requirements, a fuze must not become armed until it has traveled a certain minimum safe distance from the launcher. A runaway escapement device can be

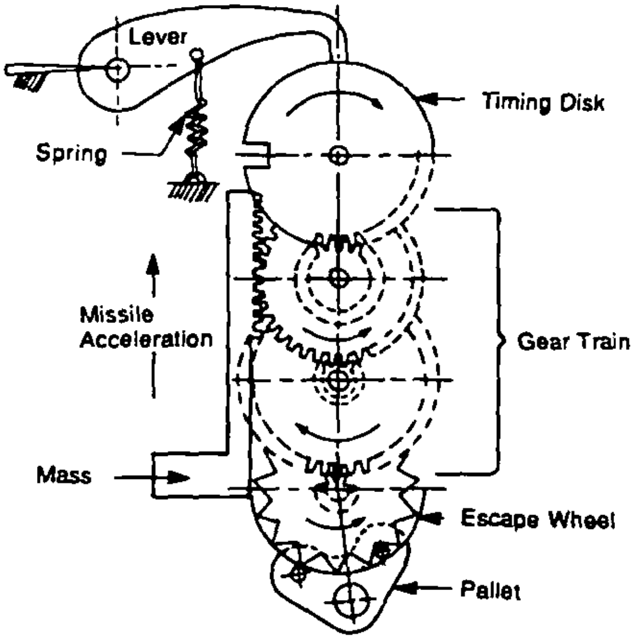


Figure 6-31. Runaway Escapement

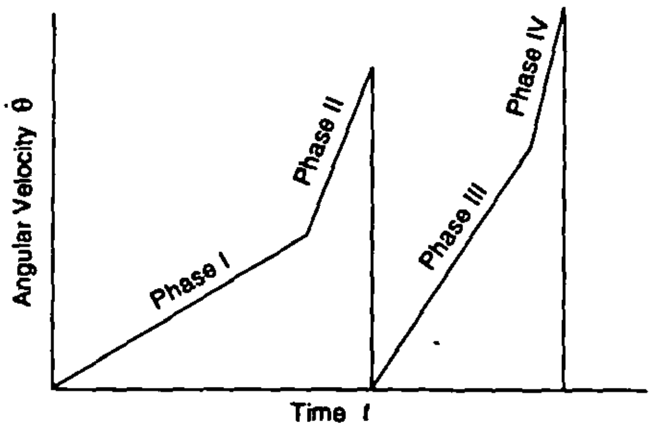


Figure 6-32. Escape Wheel Velocity vs Time (Ref. 24)

used to provide a time interval that is directly related to the distance traveled by a munition fired at different velocities or acceleration levels.

The acceleration vs time diagram for rockets is not the same, even for all those of one type. Fig. 6-33 shows the influence of rocket motor temperature at the time of firing upon the acceleration vs time diagram.

Suppose, for example, that it is desired to arm the rocket at a nominal distance of 213 ± 31 m (700 ± 100 ft) from the launcher. Fig. 6-34 shows that the arming time must vary with the acceleration of the rocket to hold the arming distance within the specified tolerance. Thus a fixed-time timer could not be used to produce a fixed arming distance.

If a runaway escapement is driven by a device that derives its power from the acceleration of the rocket, the escapement can be designed to effect arming at the same distance even under differing values of acceleration. Fig. 6-31 shows a device in which the torque applied to the escapement will be proportional to the setback acceleration.

The time t to arm can be expressed as

$$t = \frac{1}{k_1 f_n}, \text{ s} \qquad (6\text{-}57)$$

where

k_1 = proportionality constant, dimensionless

because the time depends upon the number of oscillations of the pallet and therefore upon frequency f_n of the pallet. If constant acceleration is assumed, the distance S along the trajectory that the rocket will travel during the arming time is

$$S = \frac{1}{2} a_r t^2, \text{ m (ft)} \qquad (6\text{-}58)$$

where

a_r = rocket acceleration, m/s^2 (ft/s^2).

The torque G is given by

$$G = m' a_r r_g k_2, \text{ N·m (lb·ft)} \qquad (6\text{-}59)$$

where

m' = mass of driving force on Fig. 6-31, kg (slug)
r_g = radius of gear driven by translating mass, m (ft)
k_2 = gear ratio (constant) between escape wheel pinion and gear driven by translating mass, dimensionless.

By combining Eqs. 6-56 through 6-59, a constant arming distance can be expressed as

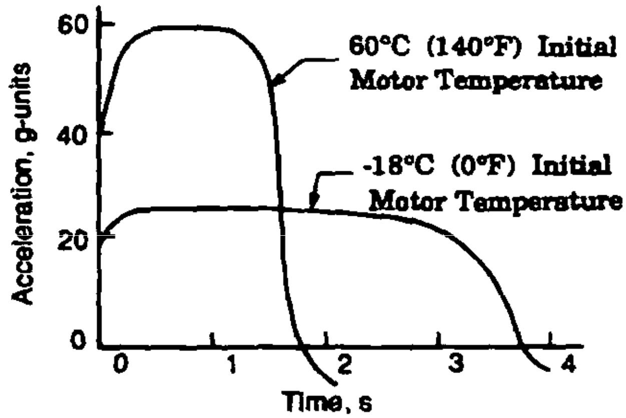


Figure 6-33. Typical Rocket Accelerations

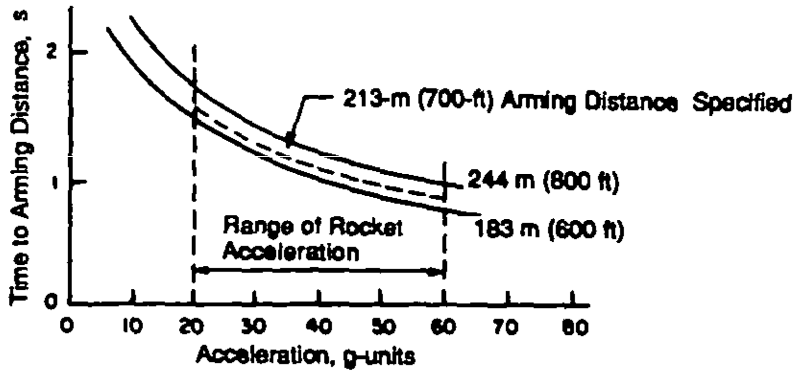


Figure 6-34. Variation in Rocket Arming Time

$$S = \frac{4\pi^2 r_w I_m \theta_p}{m' r_g k_2 k_1^2 r_p}, \text{ m (ft)} \qquad (6\text{-}60)$$

in which all terms on the right are independent of the ballistics of the rocket.

The runaway escapement can be employed to establish a constant arming distance in this circumstance.

Design guides for the runaway escapement are in Ref. 18. Refs. 20 and 21 present computer simulations of the performance of various types of runaway escapements. Refs. 19, 22, 23, and 25 also address runaway escapements. Ref. 22 also considers the influence of the aeroballistic environment.

6-6.1.1.2 Gearless Safety and Arming Device (SAD)

In safety and arming devices for spin-stabilized artillery projectiles, the interrupter (rotor) is designed so that spin force acts directly on it to move it from the safe to the armed position. The time at which this arming movement is completed (after firing) is governed by a gear train and runaway escapement, as shown in Fig. 6-35(A). As shown, two gears and two pinions are used. In wartime, production of these gears could be a supply problem because they are difficult to manufacture.

Efforts to develop a gearless mechanism to accomplish the same purpose have been successful (Ref. 26). Fig. 6-35(B) shows one arrangement.

The gearless SAD consists mechanically of a large runaway escapement, which is essentially one rotational element (the rotor-escape wheel) turning another (the pallet lever). The two elements, however, are mechanically intermeshed in such a way that the pallet element must reverse direction to escape each tooth on the rotor. This reversing action brings the angular velocity of the driving element to zero many times during the arming cycle.

6-6.1.2 Tuned, Two-Center Escapements

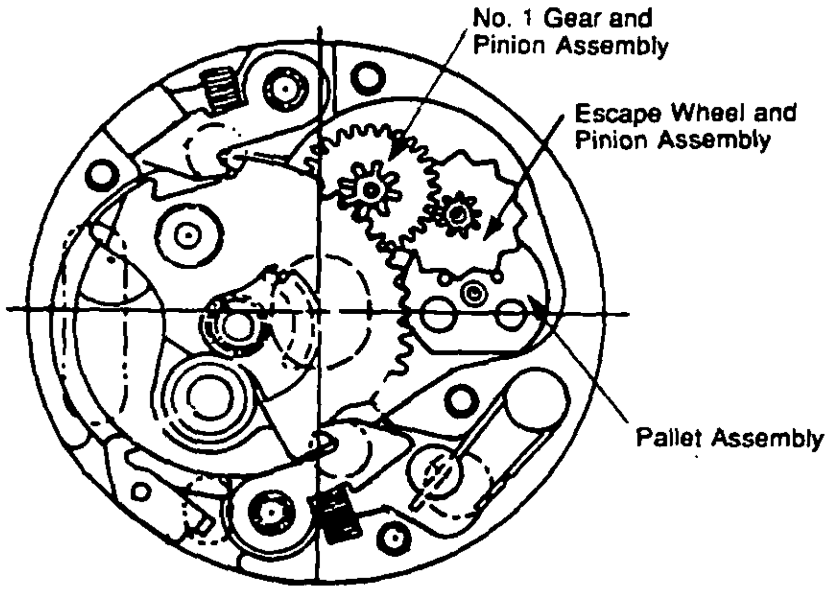
When spring mass systems vibrate, the amplitude of the oscillation decreases to zero, according to Eq. 6-9. Friction damps out the oscillations so that force impulses must be applied to the system to maintain its oscillation. If this driving force adds energy in phase, the frequency of oscillation will not be changed. The natural frequency, however, is dependent upon the frictional forces, usually undetermined, so the designer must approach the problem carefully.

Tuned escapements consist of a combination of a pivoted pallet and a mass-restoring spring pulsed twice per cycle by the escape wheel. It is the part of a timing device that counts the number of oscillations executed by the oscillating mass (pallet), and that feeds energy to the oscillating mass. The pallet controls the rotation of the escape wheel while it receives energy that maintains the oscillation. Since the pallet teeth trap and release escape wheel teeth, the rotation of the escape wheel depends upon the frequency of the oscillations of the pallet.

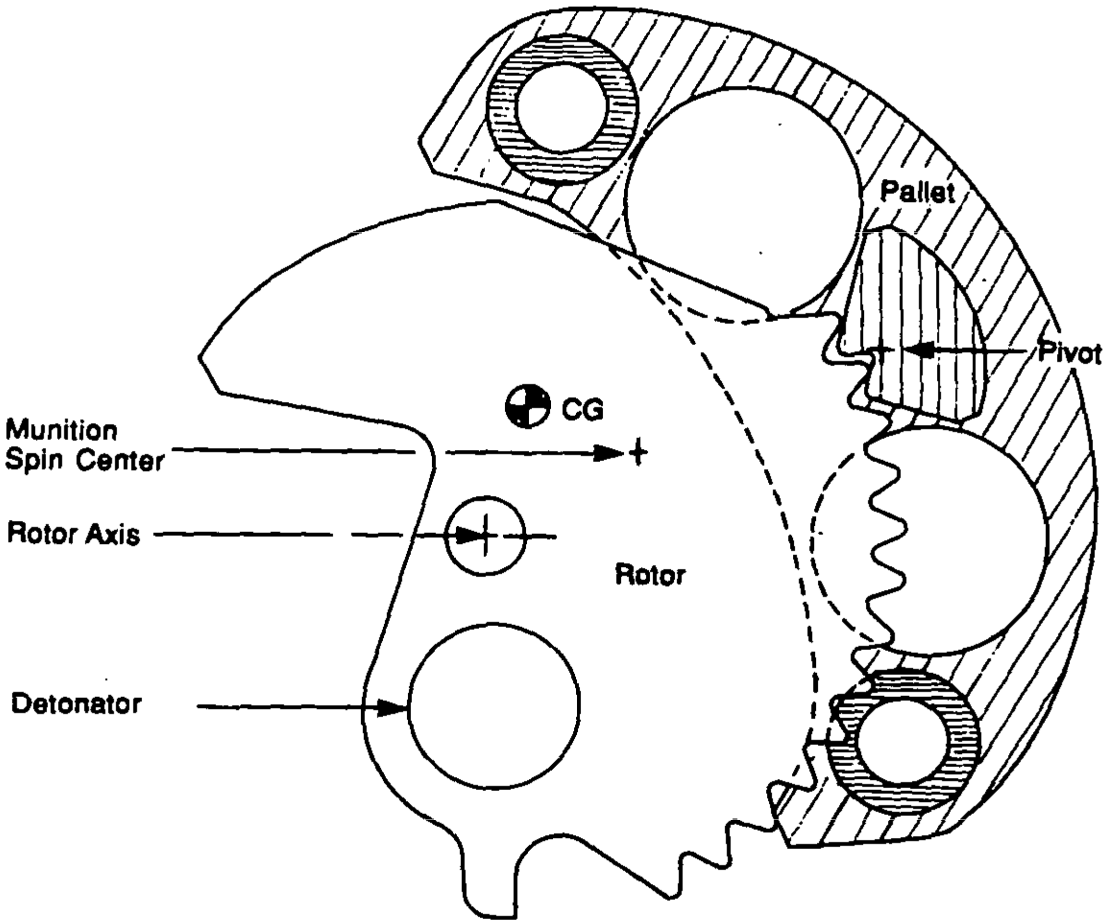
6-6.1.2.1 Description of Cylinder Escapement Mechanisms

Cylinder escapements used in fuzes are often called Junghans escapements, which are named for the German company that first employed them in World War I. Fig. 6-36 shows such an escapement.

Fig. 6-36(A) shows Tooth A falling on pallet Tooth A′. In Fig. 6-36(B) the pallet is passing through the equilibrium point in its oscillation, which is where Tooth A is about to be released by the pallet. During this phase of motion, energy is imparted to the pallet by the escape wheel. In Fig. 6-36(C) the escape wheel Tooth C has fallen onto the pallet Tooth B′, which is the opposite part of the cycle from Fig. 6-36(A). If the line of action of the impulse passes through the pivot of the pallet, the motion of the pallet will not be altered. As Tooth B′ slides beneath Tooth C, the escape wheel stops. In Fig. 6-36(D) the pallet has returned to its equilibrium position and is being driven by the escape



(A) S&A Mechanism With Gears (Ref. 11)



(B) Gearless Mechanism (Ref. 24)

Figure 6-35. Conventional S&A Mechanism vs Gearless Mechanism

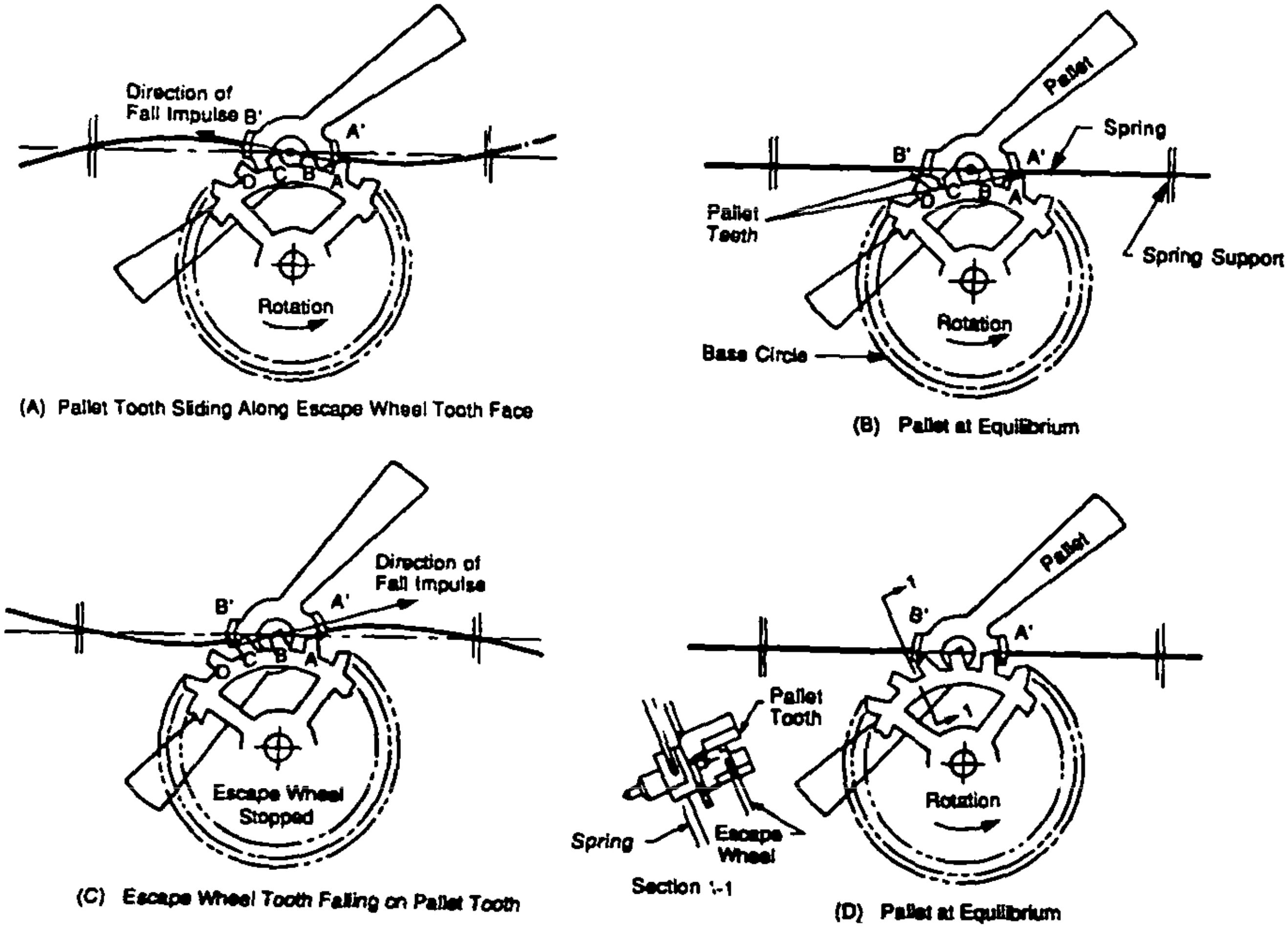


Figure 6-36. Action of Junghans or Deadbeat Escapement

wheel, as shown in Fig. 6-36(B). If energy is added as the pallet passes through its equilibrium position, the frequency of the oscillating mass (regulator) is least affected. Wheel teeth are undercut to allow the pallet to swing to its fullest extent.

The Junghans escapement has been modified by Dock (Ref. 27) and by Popovitch (Ref. 28) to improve performance. The Dock modification uses a round wire escapement spring in place of the spring of rectangular cross section to reduce the spin sensitivity of the mechanism and to obviate straightening of the spring after it is inserted into the pallet. The Popovitch modification, shown in Fig. 6-37, uses two outboard leaf springs instead of a spring passed through a hole in the arbor to reduce spin sensitivity of the mechanism.

6-6.1.2.2 Description of Spring Design

The natural frequency f_n of the escapement, neglecting friction, is

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{I_m}}, \text{Hz} \qquad (6\text{-}61)$$

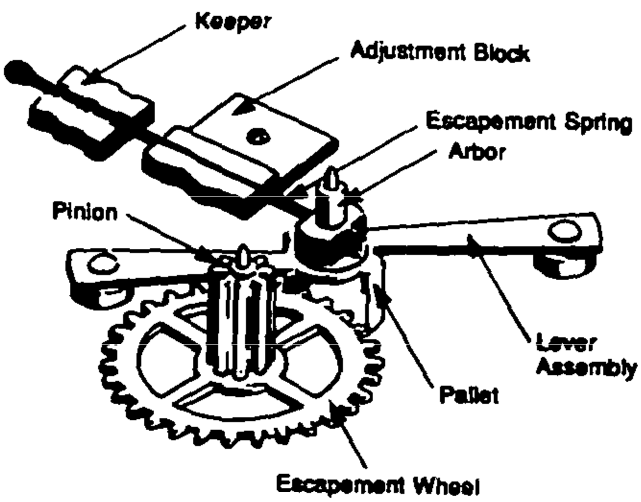


Figure 6-37. Popovitch Modification of Junghans Escapement (Ref. 28)

6-7 OSCILLATING DEVICES DRIVEN BY RAM AIRFLOW

Several mechanisms used as sensors of the ram air environment present in nonspin munition flight employ oscillating members. These members provide two important functions: (1) the extraction of energy to be used in arming and/or powering the fuze and (2) the provision of a time base to be used in safe separation, i.e., delayed arming, by means of their natural frequency as spring-mass systems. As transducers, their energy can be taken off as either mechanical or electrical energy. Rotors can be unlocked or moved incrementally to the armed position, switches can be closed or opened, capacitors can be charged, and electric actuators or detonators can be initiated.

Many configurations are possible, such as spring-tempered diaphragms vibrated by air turbulence, a ball in a whistle, a spring-biased plate fluttering like a traffic sign in a strong wind, and a vibrating, taut wire.

Two such systems have been developed for fuzes and are described and illustrated in Chapters 1, 2, and 3 and in subpars. 6-7.1 and 6-7.2.

6-7.1 FLUIDIC GENERATOR

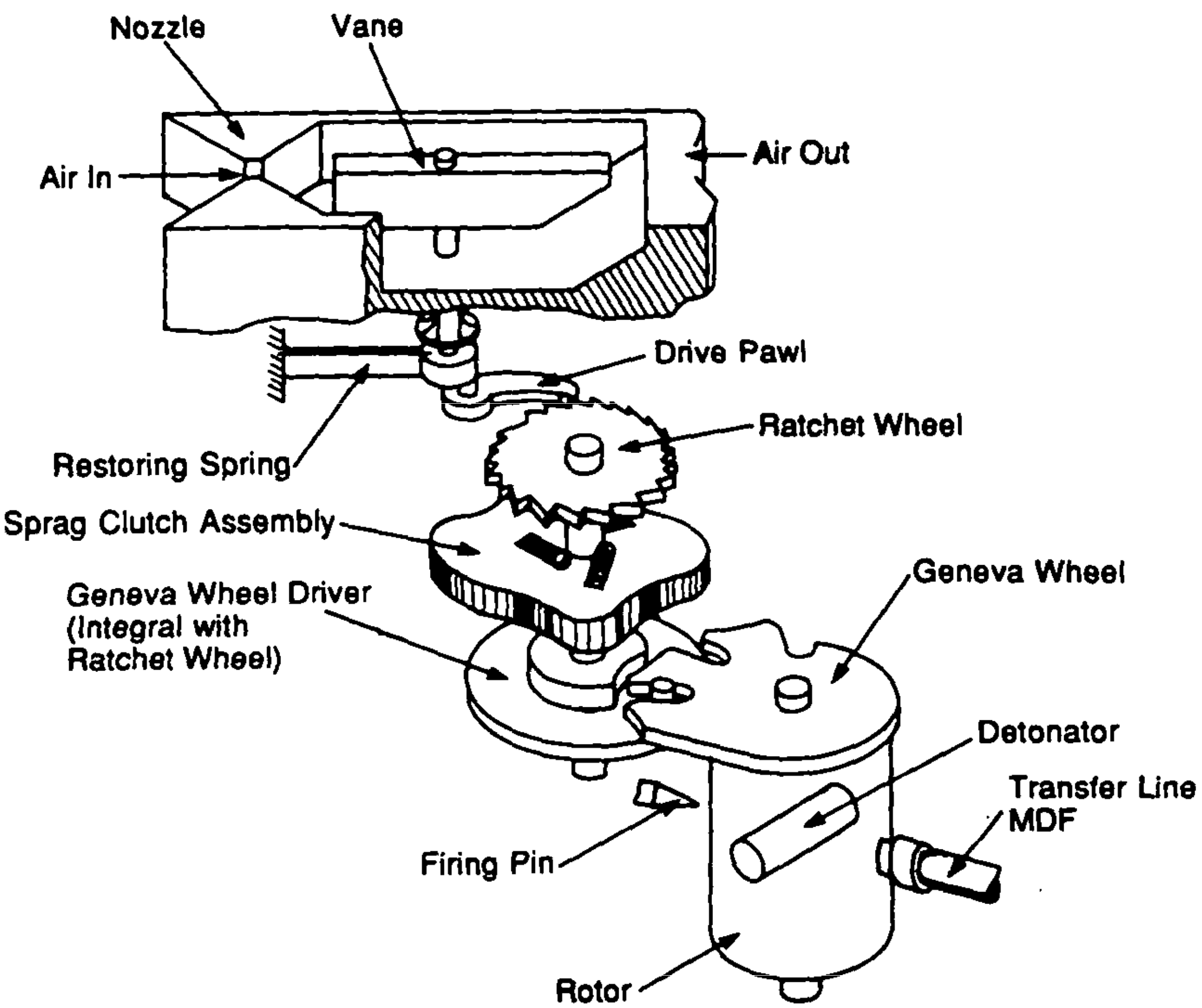
This mechanism is an electrical generating device that uses basic fluidic principles for its operation, as described in Ref. 34. Its construction, operation, and applications are covered in subpar. 1-9.2, par. 2-10, subpar. 3-5.2.2, and in Fig. 2-7. This generator has been incorporated in a fuze to serve as a power source and a timer in order to provide safe separation delay arming.

6-7.2 FLUTTER ARMING MECHANISM

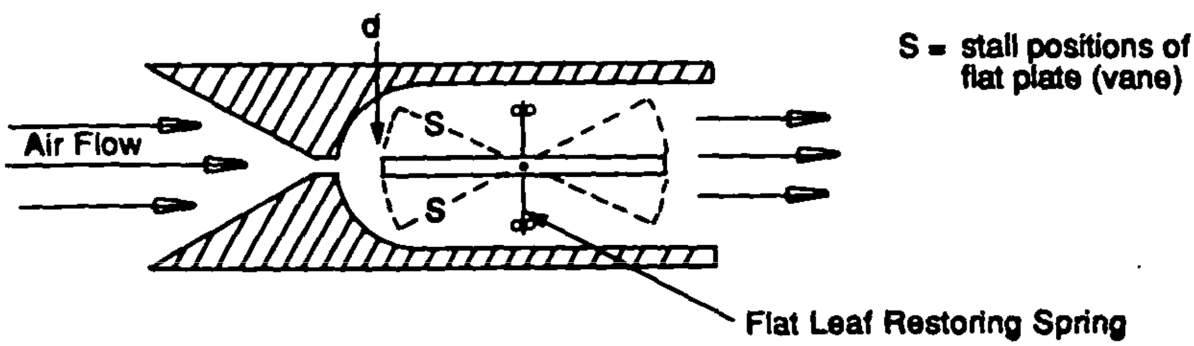
This oscillating mechanism is a spring-biased plate responsive to the ram air environment. (See Fig. 6-40.) It produces a mechanical output that arms the fuze by means of a ratchet and pawl system. The system is not only a timer that controls the safe separation distance. It is also airspeed discriminatory, i.e., it will not operate below a predetermined threshold speed. This threshold discrimination can be used to prevent arming in the event of loss of the submunition from the aircraft at the speeds encountered during takeoff and landing.

True flutter, e.g., a traffic sign or an improperly designed aircraft wing, produces a nearly constant frequency, but each movement increases in amplitude until the mechanism is eventually destroyed (Fig. 6-41(A)). The condition depicted in Fig. 6-41(B), in which both frequency and amplitude are constant, was achieved with the flutter arming mechanism by semienclosing the flat plate and providing channeled ram airflow, which cause the plate to lift and go out of the airstream into the stall position. Energy stored in the restoring spring returns the plate to the centerline and beyond where lift begins in the opposite direction. The cycle therefore is repeated in a controlled fashion.

The aerodynamic housing (nozzle) enclosing the flutter plate is telescoping, and when secured in the compressed position by stacking within the munition canister, it secures the flutter plate and the rotor to prevent arming caused by transportation vibration. Upon release of the submunition from the canister, the detenting nozzle, which is spring loaded, moves forward and disengages from the flutter and rotor. At a predetermined airspeed, chosen to be above the landing and takeoff speeds of the delivery aircraft, aerodynamic lift on the flat plate overcomes the restoring moment and the oscillator vibrates. Thus with a simple spring-mass system suitably channeled and oriented edgewise to the airstream, a velocity discrimination is obtained without the necessity of a mechanical clutch.

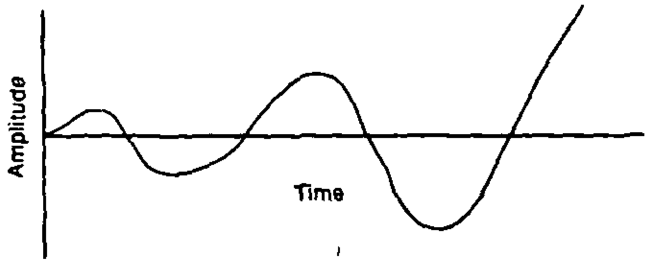


(A) Flutter S&A Mechanism

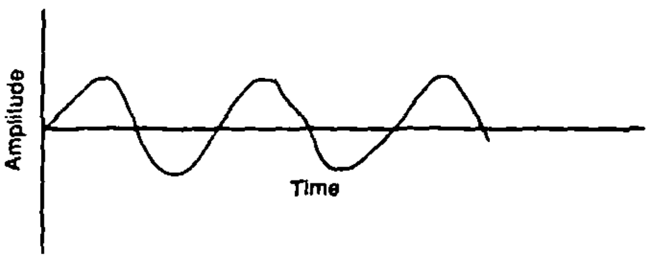


(B) Nozzle and Spring Biased Flutter Plate

Figure 6-40. Flutter Arming Mechanism (Ref. 33)



(A) Unstable Divergent Motion, "True Flutter"



(B) Unstable Oscillating Motion, "Controlled Flutter"

Figure 6-41. True Flutter vs Controlled Flutter (Ref. 28)

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CHAPTER 7
ELECTRICAL ARMING, SELF-DESTRUCT, AND FIRING DEVICES

Advances in the state of the art of electronics have provided the fuze designer with many new, unique, and cost-effective means of performing accurate timing and numerous and complex fuzing control and logic functions. This chapter discusses the use of electronic, electrochemical, and micromechanical circuits and devices in present-day electronic fuzes. Typical applications of electrically operated components, such as switches and electroexplosive devices, are described and illustrated. The use of electronic logic to perform safety functions, e.g., fast-clock monitoring, sensor interrogation, and safety and arming (S&A) monitoring, is discussed. Examples of circuits and logic diagrams used to perform these functions are provided. The theory and current technology base for digital timers and for the components of a digital timing system (power supply, time base, and counter) are covered in detail. Numerous circuits and semiconductor devices are presented to illustrate the impact of state-of-the-art integrated circuits on fuze technology. The final output of most electronic fuzes is the firing of an electroexplosive device. Examples of high- and low-energy firing circuits, design guides, and equations for calculating the energy output of a capacitive discharge firing circuit are provided. Microcomputers are becoming more prevalent in complex fuzing systems that require multiple timing and safety logic functions. A general description and the operational characteristics of several microcomputers suitable for use with fuzing systems are discussed. Recent advances in the field of microelectronic chips have led to the development of micromechanical sensors of environmental factors, i.e., acceleration, pressure, and force. A micromechanical accelerometer design is described, and size, performance, and sensitivity data are presented. Electrochemical timers, capable of performing timing from seconds to months, are described, and their advantages for fuzing applications are discussed. Design techniques for achieving a reliable design in electronic fuzes are cited, and the relative merits of commercial vs military high-reliability electronic components are compared.

7-0 LIST OF SYMBOLS

C = capacitance, F or μF
C_T = capacitance across transistor, μF
C_o = output capacitance, μF
E = stored electrical energy, erg
f = frequency, Hz
f_{OUT} = output frequency of oscillation, MHz
g = acceleration due to gravity, m/s^2 (ft/s^2)
I_p = peak point current, μA
$I_r(MAX)$ = maximum value of I_p, μA
I_R = run current, A
I_s = stop current, A
I_v = valley current, μA
$K = \dfrac{R_s}{R}$, dimensionless
P' = average power dissipated by basic inverter, μW
R = resistance, Ω
R_A = resistance A, Ω
R_B = resistance B, Ω
$R_G = \dfrac{R_2R_1}{R_2+R_1}$, Ω
R_L = resistance L, Ω
R_S = resistance S, Ω
R_T = resistance T, Ω
R_1 = resistance 1, Ω
R_2 = resistance 2, Ω
R' = required bleed resistor, Ω
T = period of simplest RC multivibrator, μs
T_A = period of oscillation at pin 13, s
T_B = period of oscillation at pins 10 and 11, s
T_1 = period of modified RC multivibrator, μs
T' = period of oscillation, μs
t = time, s
V = supply voltage, V
V_A = $V_S + V_T$, V
V_{CAP} = EED no-fire voltage, V
V_{CC} = circuit positive voltage, V
V_D = diode forward voltage drop, V
V_{DD} = power supply voltage, V
V_{IN} = input voltage, V (See Fig. 7-20.)
$V_{NO-FIRE}$ = no-fire voltage across bleeder resistor, V
V_0 = output voltage, V
V_P = stop voltage, V
V_R = run voltage, V
V_S = set voltage determined by $R1/R2$ ratio, V
V_{SS} = circuit negative ground, V
V_T = offset voltage, typically 0.4 V
V_{TR} = transfer voltage at switching point of inverter, V
V_V = valley voltage, ≈ 0.6 V
V_s = stop voltage, V
η = duty cycle, dimensionless

7-1 INTRODUCTION

Since 1970, a wide variety of new electronic devices has become available to the electronic fuze designer. These new devices have made previously used electronic components obsolete, including vacuum tubes, cold cathode diodes, and square loop magnetic cores. The electronic fuzes of today rely heavily on the functional complexity available in standard and custom integrated circuits. The dominant integrated circuit (IC) technology used today is complementary metal oxide semiconductor (CMOS) because of its high-noise immunity and low-power consumption. Major advances have also been made in resistors, capacitors, crystals, inductors, and in the packaging of these components. They are now available in ultraminiature packages, which are attached to a substrate or to a printed circuit board by surface mount technology. These advances have led to extremely small, very rugged circuit designs.

Other IC technologies that might be considered by the fuze designer include

1. HCMOS—high-speed CMOS
2. TTL—transistor transistor logic
3. LSTTL—low-power Schottky TTL
4. ECL—emitter-coupled logic
5. I^2L—integrated injection logic
6. FAST—Fairchild advanced Schottky TTL
7. SOS—silicon-on-sapphire
8. GaAs—gallium arsenide.

CMOS originally could not compete with the speed of TTL logic, but today CMOS is able to match the speed. In fact, CMOS replacements for many TTL ICs are available in the HCMOS family group.

The influx of new information and technologies presents a problem to writing a handbook that is to contain the latest circuits and techniques because the electronic technologies of today will be superseded by newer ones in the very near future. The best that can be done is to give the designer background information and to impress upon him the need to review the current literature before selecting a circuit.

7-2 COMPONENTS

7-2.1 SWITCHES

Switches used in safety and arming devices (SAD) must be small and rugged, must close (or open) in a specified time, and must remain closed (or open) long enough to do their job. Switches can be operated by setback, centrifugal force, or impact.

A typical trembler switch, as illustrated in Fig. 7-1, is essentially a weight on a spring. When the velocity of a munition changes, inertial forces cause the weight to deflect the spring so that the weight makes contact with the case. The switch shown has a current rating of 100 mA and operates at accelerations of 40 to 100 *g*.

Ideally, the sensitivity of an impact switch should remain constant as the switch is rotated about its longitudinal axis, but tests on cantilevered switch designs, like those shown in Figs. 7-1 and 7-2, show wide variations in tolerances. The variations in switch sensitivity are generally due to eccentricities between the contact and contact housing and variations in the spring constant.

The design of the impact switch in Fig. 7-2 is less susceptible to tangential accelerations than the switch in Fig. 7-1

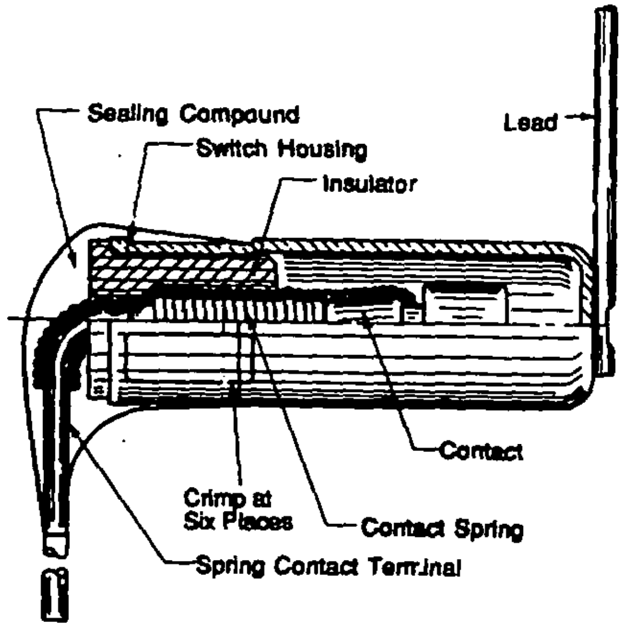


Figure 7-1. Trembler Switch

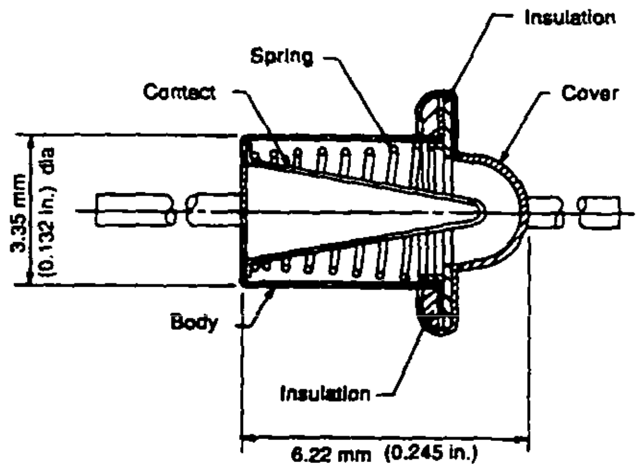


Figure 7-2. Low-Cost Biased Impact Switch (300-1000 *g*)

and has improved resonant resistance to in-flight vibrations and oscillations.

Switches that sense setback, spin, and impact are currently being developed as micromechanical cantilever beams of silicon, silicon dioxide, or photoetched metal with dimensions of a few microns.

Impact sensitivity and reliability can be improved by mounting two or more switches radially in spinning munitions or mutually perpendicular in nonspinning rounds, as shown in Fig. 7-3. If possible, electronic logic should be incorporated in fuzes employing impact-operated switches to prevent the fuze from functioning if closure is sensed prior to arming. Also to enhance overhead safety, the switch should be out of the detonator firing circuit as long as is

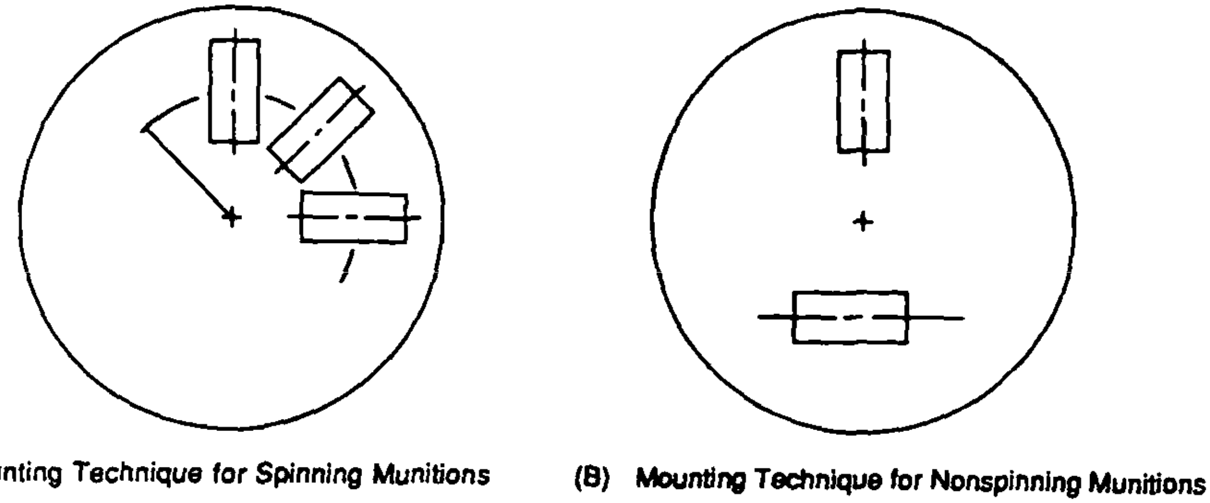


Figure 7-3. Mounting Techniques for Impact Switches for Spinning and Nonspinning Munitions (Ref. 1)

practicable, consistent with the operational requirements of the munition.

Fig. 7-4 shows a mercury-operated centrifugal switch. As the munition spins about its axis, mercury in the right compartment penetrates the porous barrier to open the circuit. The switch has an inherent arming delay that depends on the porosity of the barrier among other factors. Mercury switches should not be used at temperatures below −40°C (−40°F).

Heat generated in thermal batteries can be used to activate simple, reliable time-delay mechanisms that permanently close an electrical circuit at some specified temperature. Performance of these devices as delay elements depends upon close control of the rate of heat transfer from the battery to the thermal switch. Their application generally is limited to relatively short time delays (up to a few seconds) and to applications for which high accuracy is not required. Two switches of this type are shown in Figs. 7-5 and 7-6. These fusible-link thermal switches are used to provide the electrical arming delay and the self- destruction delay in the M217 Hand Grenade fuze. Both switches operate over an ambient temperature range of −40° to 52°C (−40° to 125°F).

The arming delay switch, shown in Fig. 7-5, closes within 1.0 to 2.4 s after initiation of the thermal battery. The switch contains a cadmium-lead-zinc alloy disk having a melting point of about 138°C (280°F). This disk is adjacent to a larger fiberglass disk, which is perforated with a number of small holes. When the metallic disk melts, the molten metal flows through the holes in the fiberglass, bridges the gap between the contacts, and closes the switch. Coating the fiberglass insulator with a wetting agent to improve the flow of the molten metal gives more uniform switch closure.

The self-destruction switch, shown in Fig. 7-6, has an average functioning time of 4 to 6 s. Closure times range from 3.5 s at 52°C (125°F) to 7.0 s at −40°C (−40°F). Its thermally activated element is a pressed pellet of mercuric iodide, which has insulating characteristics at normal temperatures but becomes a good electrical conductor at its

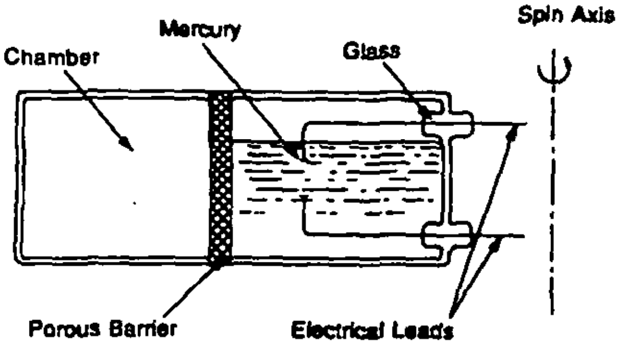


Figure 7-4. Switch for Rotated Fuzes

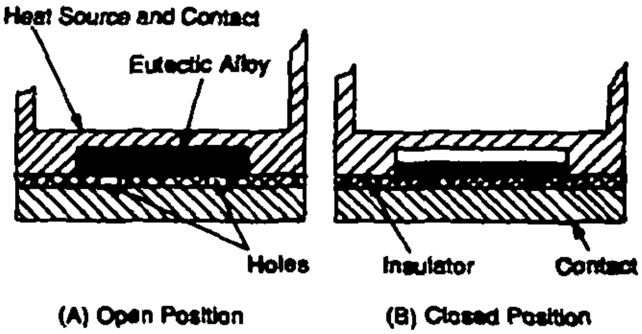


Figure 7-5. Thermal Delay Arming Switch (Ref. 2)

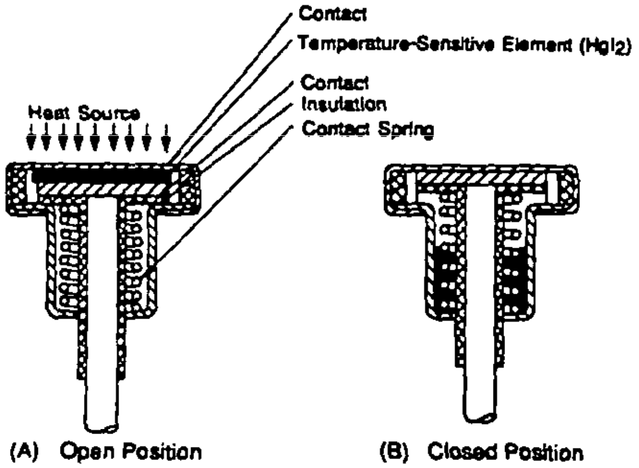


Figure 7-6. Thermal Delay Self-Destruction Switch (Ref. 2)

melting point, 260°C (500°F). More uniform switch closures are obtained by spring loading one of the switch contacts. This brings the contacting surfaces together sharply when the iodide pellet melts and reduces contact resistance in the closed switch to a few hundredths of an ohm.

Although other thermal-sensitive devices, such as bimetals, can be feasible for thermal switch applications, the fusible link appears to possess the advantages of simplicity, safety, and reliability. Its compactness and rugged design make it resistant to damage or malfunction caused by rough handling, shock, or vibration. Also there is little variation in the temperature at which the switch closes because the temperature is determined by the melting point of the fusible link. Bimetallic thermal switches often must be individually calibrated and adjusted and thereafter may be subject to deformation or premature closure. Cost and size also favor the fusible-link design. The primary disadvantage of fusible link switches is that they are one-shot devices that cannot be tested or reused.

Ambient temperature variation can greatly affect the function time of a thermal switch. Care should be taken to install the switches so that their ambient temperature is kept as nearly constant as possible. The following precautions will aid in reducing the adverse effects of variations in ambient temperature:

1. Place the thermal switch as close to the heat source as practicable.
2. Minimize the mass of thermal switch components and of any components interposed between the heat source and the thermal switch.
3. Use materials with low specific heat wherever possible.
4. Control the quantity and calorific value of the heat-producing material.
5. Control the thermal insulation of the assembly.
6. Control the manufacturing tolerance of components.
7. Control the uniformity of assembly, including assembly pressure of components and intimacy of contact between mating surfaces.

7-2.2 ELECTROEXPLOSIVE ARMING DEVICES

7-2.2.1 Explosive Motors

Explosive motors are devices that produce gas at high pressure in short periods of time in a closed volume for the purpose of doing work. They are small, reliable, one-shot devices well-suited to remote control of small movements, such as switch closures. Most explosive motors are electrically initiated. Hence their initiation mechanism and their input characteristics are the same as those of the electric initiators described in par. 4-3.1.4.

A dimple motor, as shown in Fig. 7-7, is similar in construction to an electric detonator, except that the bottom is concave and the explosive is a small gas-producing charge. The pressure of the gas liberated by the reaction inverts the concave end to a convex surface. A typical dimple motor imparts a 2.54-mm (0.10-in.) movement against a 35.6-N (8.00-lb) load. Careful design of the relatively complex curvature of the dimple and accurate control of the metal condition are necessary for reliable and satisfactory functioning (Ref. 3).

Bellows motors, as illustrated in Fig. 7-8, consist of a number of convolutions, which expand under the gas pressure produced by the motor charge. They are used where a longer (up to 25.4 mm (1.0 in.)) or angular stroke is required. They are capable of producing forces of up to 44.5 N (10 lb) or torques to 3.39 N·m (30 ft·lb).

Piston actuators, as shown in Fig. 7-9, are another form of explosive motor used in many modern munitions. The extendable version shown is capable of shearing a 1.27-mm (0.05-in.) pin over a minimum travel of 5.1 mm (0.20 in.). Other piston actuators are available with outputs up to 1335 N (300 lb). There are also retractable versions and a rotary version called a ROTAC.

Explosive motors may be used to move, lock, or unlock an arming device, or they may be used to operate a switch. Dimple motors are often used to close an electric contact, as described in par. 7-2.2.2.

7-2.2.2 Electroexplosive Switches

Explosive switches use a dimple motor or piston to drive a contact assembly to perform a mechanical switching operation. In the design shown in Fig. 7-10, the piston contact is displaced by a dimple motor; this displacement unshorts the two spring-loaded contacts and closes a second pair of contacts. The switching time for this device is less than 15 ms. Although this design is used in currently stockpiled fuzes, cheaper and more reliable switching methods are available in solid-state electronics.

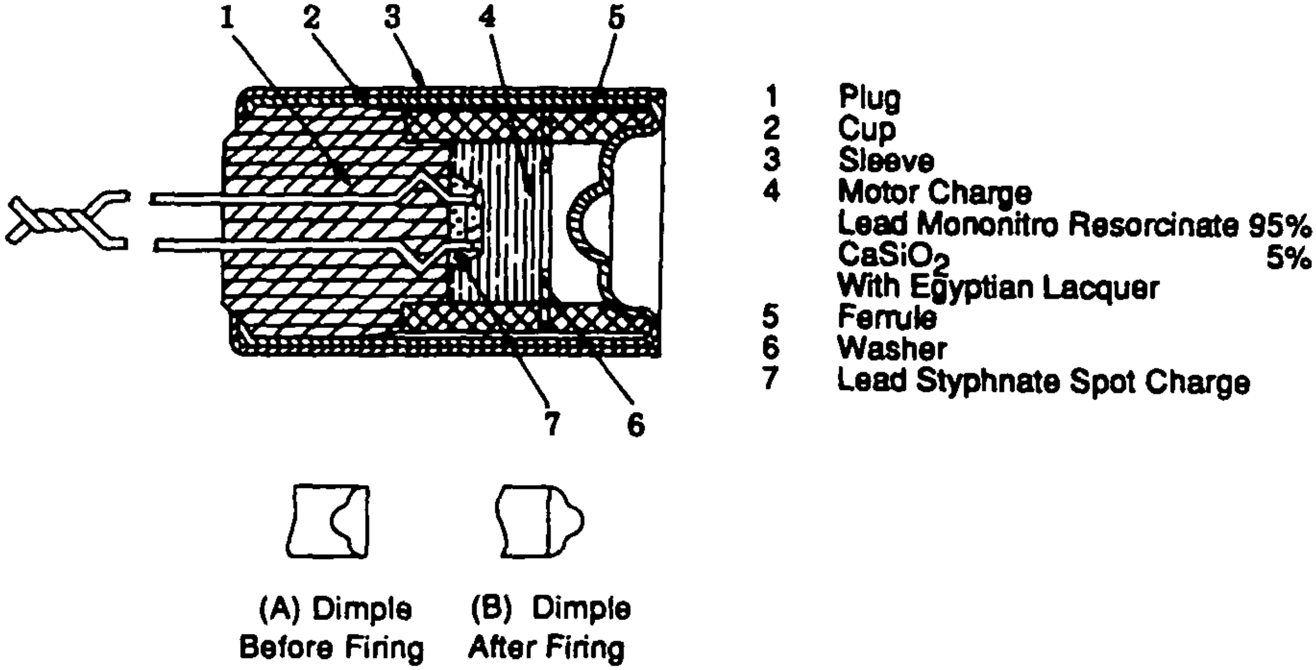


Figure 7-7. Dimple Motor T3E1

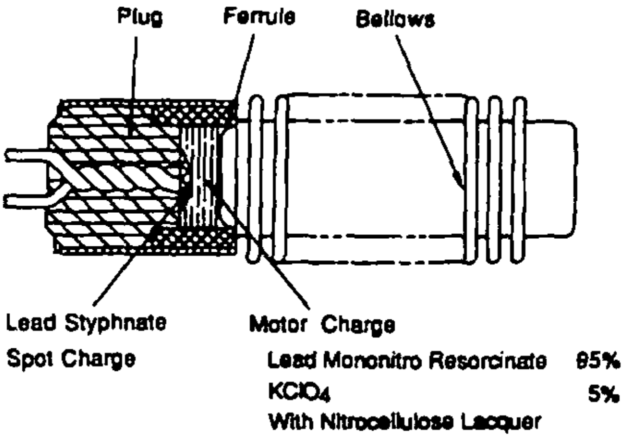


Figure 7-8. Bellows Motor, T5E1

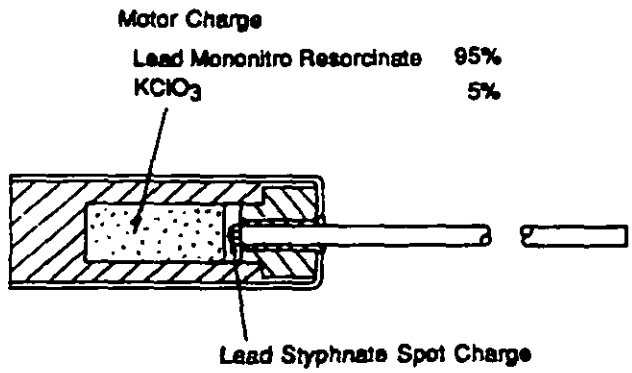


Figure 7-9. Piston Actuator Used in M762 Fuze (Ref. 4)

7-2.3 ELECTRONICALLY CONTROLLED FUZING FUNCTIONS

In electronic fuzes, the electronics section of the fuze may be required to

1. Arm the fuze after a selected time delay
2. Detonate the fuze after any of the following conditions: impact, delay after impact, after a preselected time delay, or after receipt of a signal from a target proximity sensor.
3. Perform functions such as time gating, switch status monitoring, AND/OR functions, and sequence monitoring.

It is critically important that the fuze not prematurely arm or detonate. To prevent premature arming or detonating, design safeguards are included in the electronic fuze design. Some typical safeguards are a fast-clock monitor to prevent premature arming and sensor interrogation to prevent premature detonation.

7-2.3.1 Electronic Logic Devices

Electronic logic devices can be used in conjunction with a system clock and some form of counter to perform a variety of logic and control functions. The technology most commonly used in ordnance applications is CMOS. The simplest CMOS logic element is the inverter, which contains two metal oxide semiconductor (MOS) transistors (a "P" type and an "N" type) connected in series, as shown in Fig. 7-11. The reason for its extremely low static, or quies-

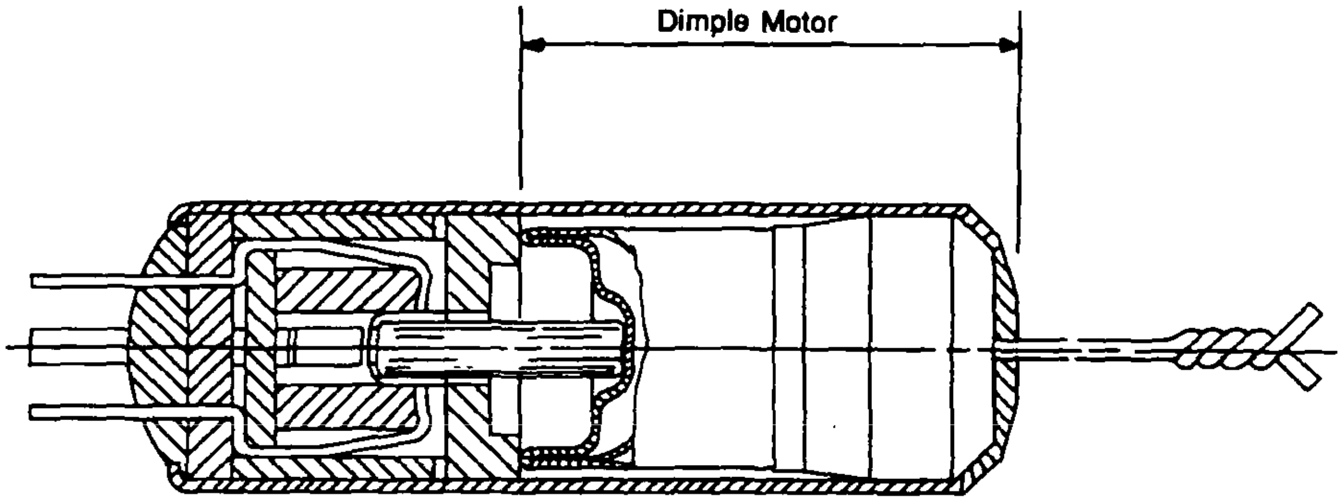


Figure 7-10. Switch, Electroexplosive, MK 127 MOD 0 (Ref. 4)

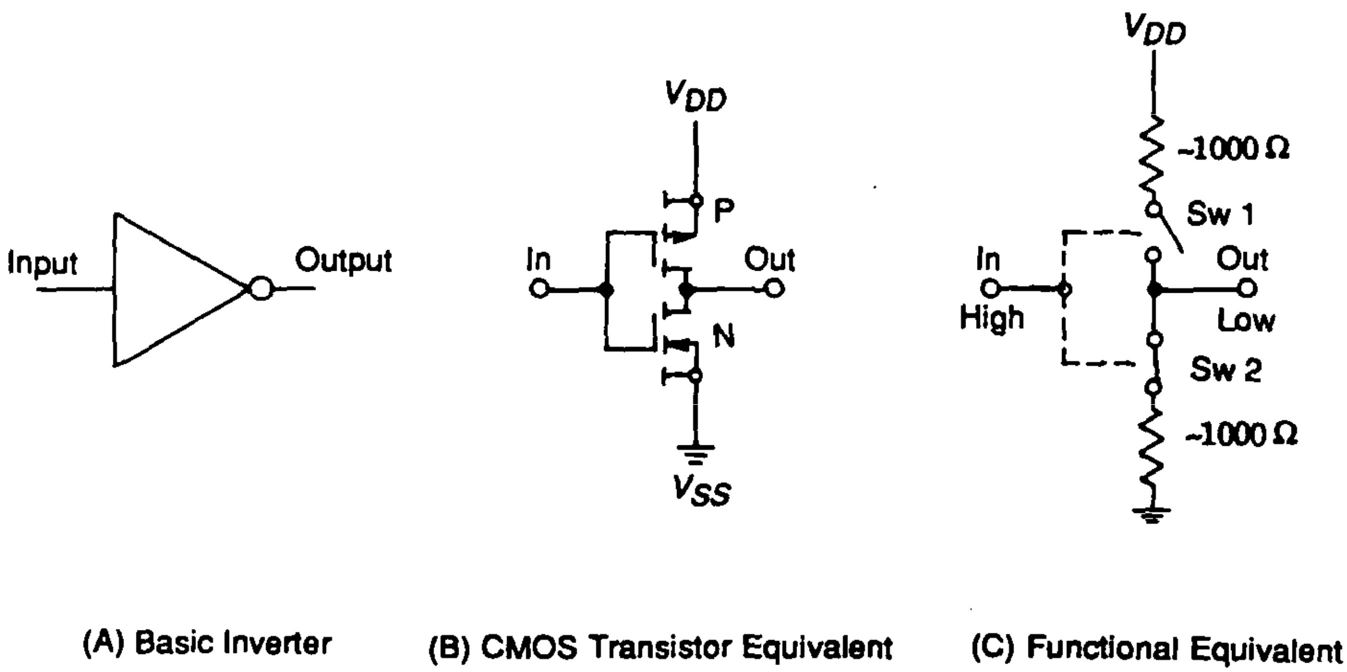


Figure 7-11. Basic Logic Inverter

cent. current drain is that for either logic level input (1 = +V or 0 = ground (GND)) to the inverter, one or the other MOS transistor is off. Therefore, virtually no current flows through the inverter. For example, the maximum input current for a CD 40100B (32-stage static left/right shift register) is specified as 100 nA at 18 Vdc and 25°C (77°F). The inverter changes states as the input signal rises and falls. The typical switching point is within 45 to 55% of positive dc power supply voltage V_{DD}. There is a momentary period during the switching process in which both the "P" and "N" transistors are simultaneously on, and this condition gives a make-before-break action. During this period a resistive load of approximately 2000 ohms is placed across the power supply. This load constitutes one of the elements that make up the dynamic current drain of the CMOS inverter. The other two elements that contribute to dynamic current drain are parasitic node capacitances and any load capacitance. For a capacitive load the average power P' dissipated by the basic inverter, if driven with a square wave input, is given by

$$P' = C_o V^2 f, \ \mu\text{W} \tag{7-1}$$

where

C_o = output capacitance, μF
V = supply voltage, V
f = frequency, Hz.

The basic *two-transistor inverter* can be used to construct more complicated logic devices (gates). For example, a *quad-two input* NOR gate is shown symbolically and schematically in Fig. 7-12. Sixteen "P" and "N" transistors are required to construct this device. A more complex device, such as a 64-bit static shift register, can contain more than 1000 transistors.

7-2.3.2 Typical Application of Electronic Logic

Fig. 7-13 presents a logic diagram of a generic bomb fuze. The generic fuze is for illustrative purposes only to show how a variety of logic devices can be combined to perform some of the functions listed in par. 7-2.3. The fuze provides three arming times:

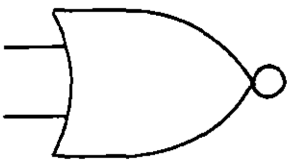
1. Retard—2.625 s
2. Dive—5.500 s
3. Level—10.000 s.

The fuze also provides four impact-delay times:

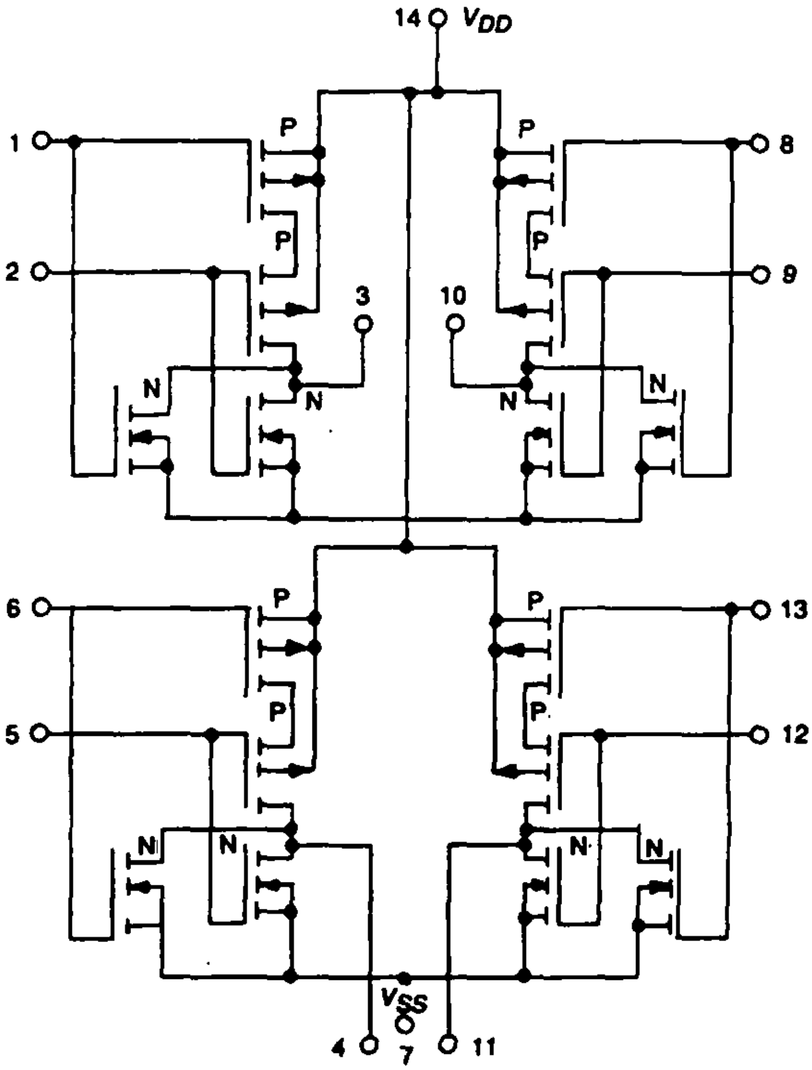
1. Instantaneous
2. Short—10 ms
3. Medium—25 ms
4. Long—60 ms.

The fuze contains

1. Fast-clock monitor
2. Arm switch monitor
3. Target-detecting device (TDD) monitor
4. Impact switch monitor.



(A) Single Two-Input NOR Gate



(B) Schematic Representation of CD 4001

Figure 7-12. Quad-Two Input NOR Gate

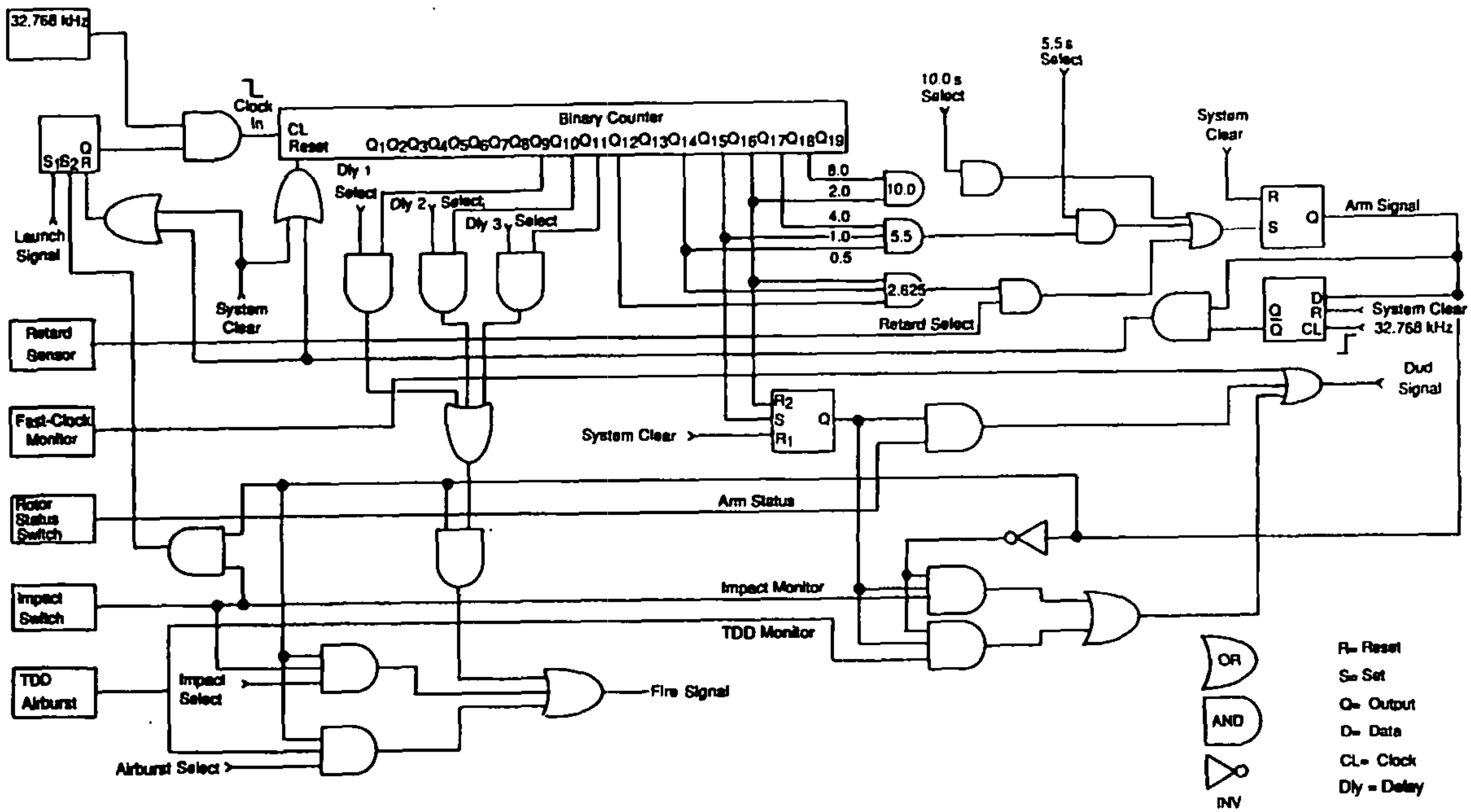


Figure 7-13. Generic Bomb Fuze Logic Diagram

A fast clock (defined in par. 7-2.3.3) or an improper TDD or impact switch output will cause a dud as will a fuze that is armed before 1.0 s after launch.

7-2.3.3 Fast-Clock Monitor

The fast-clock monitor is intended to safeguard against a system clock that has changed frequency so that it is running at a significantly higher frequency than desired. If the system arming time is being derived from a master clock, dangerously shortened arming times can result if the clock runs fast. Some techniques for safeguarding against the hazards created by a runaway system clock are

1. A narrow band phase lock loop (PLL), shown schematically in Fig. 7-14, which can be used to monitor the master clock. If the master clock frequency is outside the PLL lock range (high or low), the PLL will indicate this fact, and an appropriate logic decision can be made.

2. Two redundant timers running in parallel. If the outputs of both are not simultaneous at some point, the system will fail to function or will accept the clock that has the longer time period. The circuitry of these timers is shown in Fig. 7-15.

3. Use of a simple resistor capacitor (RC) network to determine whether the master clock frequency is proper.

7-2.3.3.1 Fast-Clock Monitor Circuits

The fast-clock monitor circuit of Fig. 7-16 operates as follows:

1. The system clock frequency of 32.768 kHz is gated after launch via AND gate 1 into the binary counter.

2. At launch, flip-flop (FF)1 is set and capacitor C charges via resistor R. After 3.7 ms, inverter (INV) goes low and disables AND gate 2.

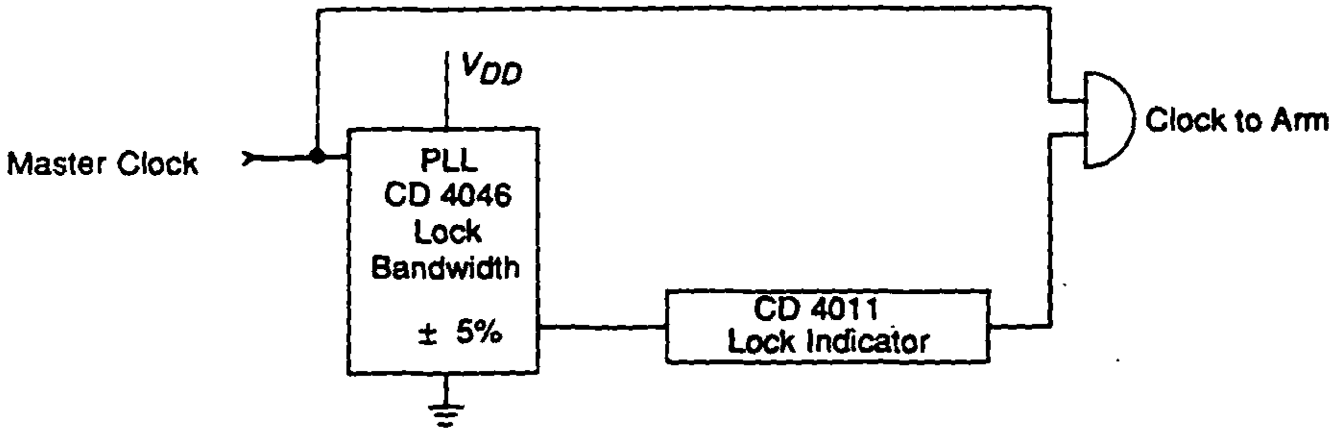


Figure 7-14. Phase Lock Loop Fast-Clock Monitor

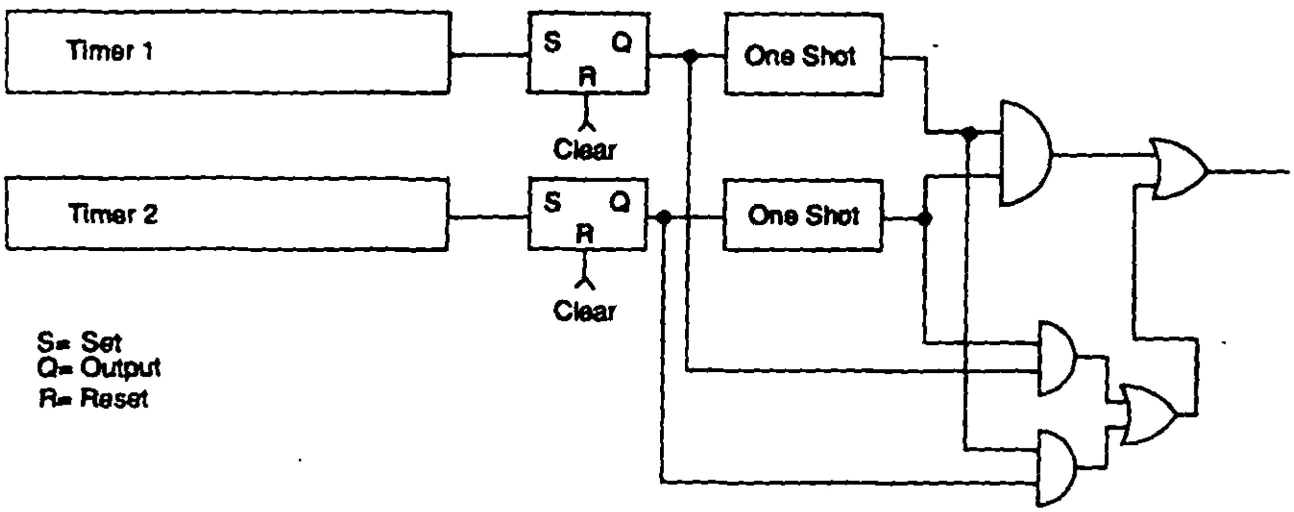
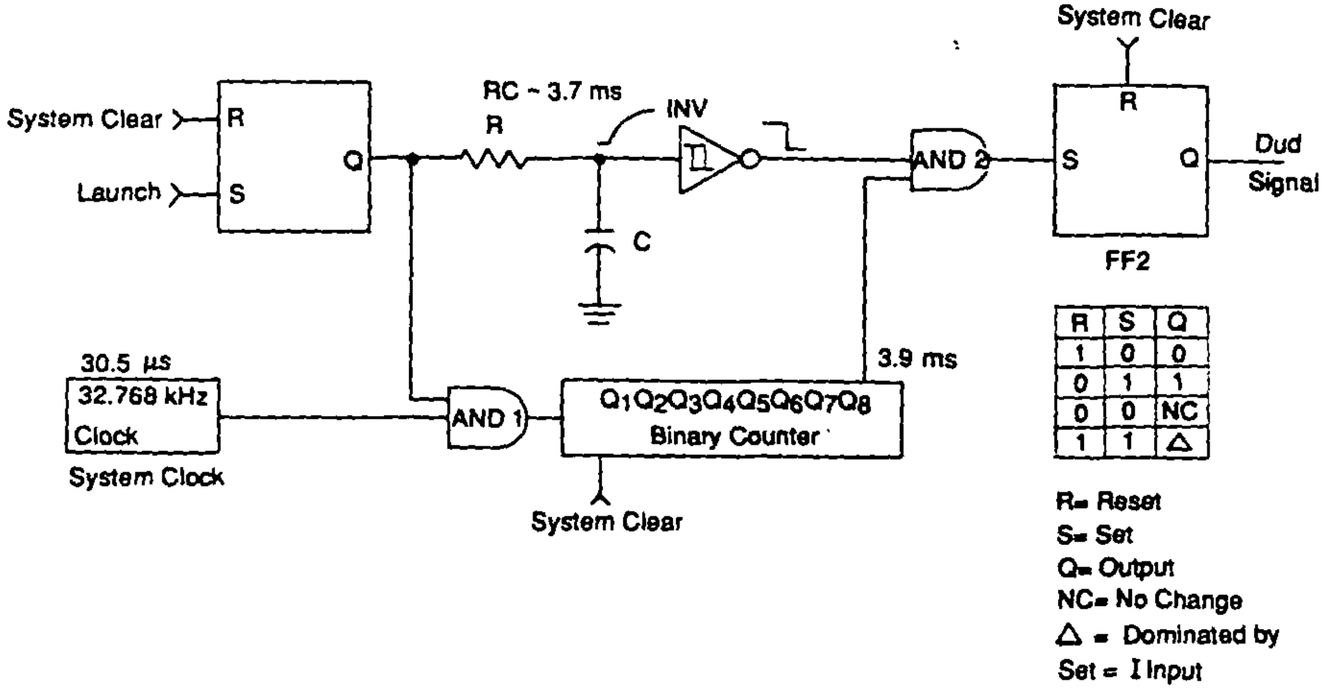


Figure 7-15. Redundant Timers



R	S	Q
1	0	0
0	1	1
0	0	NC
1	1	Δ

Figure 7-16. Fast-Clock RC Monitor Circuit

3. If the system clock is operating correctly, Q8 of the binary counter will go high 3.9 ms after launch, but it will not be able to pass through AND gate 2 because AND gate 2 was disabled at 3.7 ms by the RC circuit. However, if the system clock runs fast enough to cause Q8 to go high before 3.7 ms, then the output of AND gate 2 will go high, set FF2, and result in a dud signal.

The fast-clock monitor circuit of Fig. 7-17 operates as follows. An independent RC multivibrator running at 35 kHz is used to monitor the 32.768-kHz, crystal-based system clock. At launch AND gates 1 and 2 are enabled permitting the 35-kHz and 32.768-kHz clocks to drive binary counters 1 and 2. If the crystal clock is operating correctly, Q8 of counter 2 will go high before Q8 of counter 1, and the

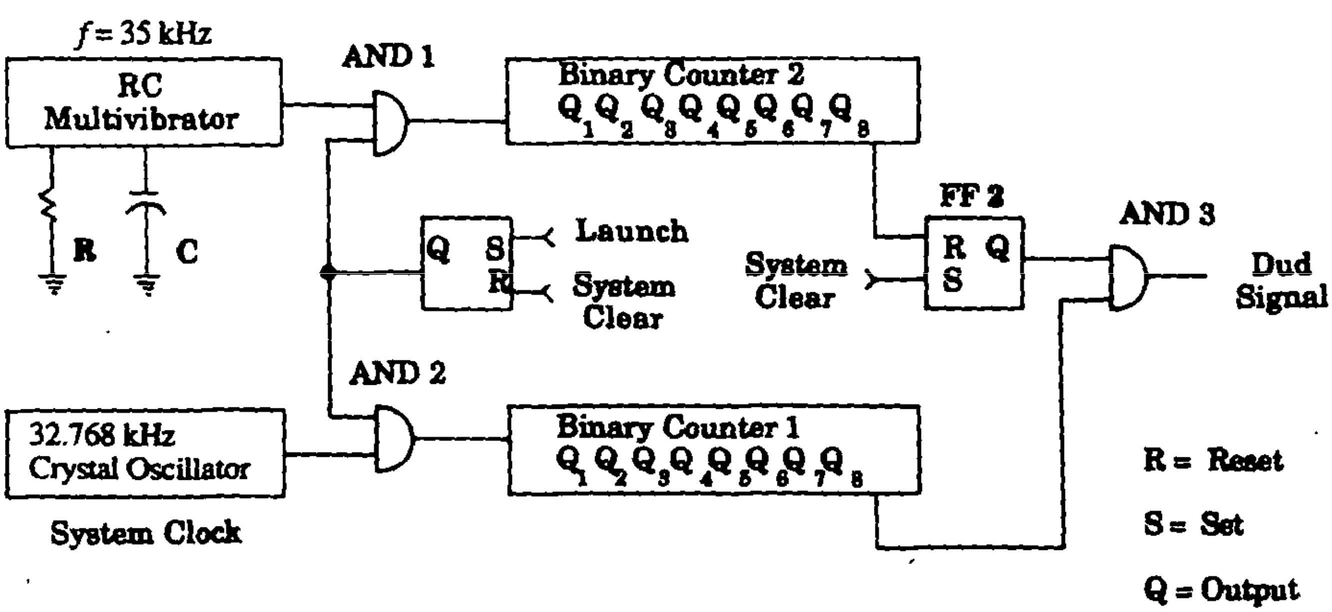


Figure 7-17. Fast-Clock Multivibrator Monitor Circuit

output of FF2 will be reset, will disable AND gate 3, and will prevent a dud signal from occurring. If the crystal clock is operating at a higher frequency than 35 kHz, however, then Q8 of counter 1 will go high before FF2 can be reset, and a dud signal will occur.

7-2.3.4 Sensor Interrogation

A wide variety of sensors can be used to initiate the detonation of a high-explosive warhead. Typical devices used to initiate detonation on target impact are trembler switches, inertial switches, ingestion switches, crush switches, capacitance switches, and piezoelectric crystals. Other, more sophisticated devices are used to provide some standoff from the target when the warhead is detonated. Some examples of standoff sensors are (1) mechanical probes, both extendable and fixed, which can provide standoffs of several centimeters to several meters, and (2) electronic sensors, i.e., radio frequency (RF), infrared (IR), capacitive, and optical, which can provide standoffs of a few centimeters, a few meters, or hundreds of meters.

Although a premature initiation of the warhead usually would not be harmful to the launching vehicle because of the SAD, overhead safety could be compromised and/or warhead effectiveness could be reduced to zero. Sensor interrogation is the use of an electronic timer and electronic gates and logic to determine the status of a target sensor prior to and after arming and to adjust fuze operation to compensate for a defective sensor. The logic diagram depicted in Fig. 7-18 contains two sensor interrogation schemes: one for a TDD (RF, optical, or probe) and one for an impact switch.

The STINGER fuze M934, described in par. 1-3.3.2 and Ref. 5, contains numerous safety and status sensor logic circuits to detect duration of launch acceleration, rocket motor staging, safety and arming (S&A) rotor status, impact switch, and hard-target switch interrogation.

The launch sensor is a simple spring-mass system similar to that illustrated in Fig. 7-1. This switch is monitored for the first 40 ms after launch, and if it remains closed for more than 20 ms, the S&A counter is activated. If the switch does not remain closed for the required 20 ms, no fuze timing function occurs.

Separation of the launch motor from the missile (staging) is sensed by a simple shorting clip. Upon staging the clip is broken; this action enables the flight motor ignition relay, the arming actuator, and the flight motor timer. Absence of proper staging results in the fuze not functioning.

During the first second of flight, the S&A rotor status is monitored by an electronic abort switch (photoelectric cell). If rotor motion occurs during this period, the abort switch senses it and provides an initiation signal to an explosive piston actuator, which fires and permanently blocks arming of the rotor.

At arming, which occurs one second after launch, a signal is generated by the main fuze timer, which enables the impact switch circuitry and interrogates the hard-target-sensor circuit. Impact switch closure prior to this time is ignored. Interrogation of the hard-target-sensor circuits consists of determining the state of the sensor and generating corresponding enable or disable signals.

7-3 DIGITAL TIMERS

7-3.1 THEORY AND CURRENT TECHNOLOGY BASE

A digital timer system is generally comprised of a power supply, a time base (clock, oscillator), at least one frequency counter, various logic elements, a preset circuit (for programmable timers), and check circuitry (either self-check or external check). A digital timer can be constructed from various clocks and digital ICs (counters and logic) to provide the desired output times and control logic. If size is not a constraint, these various devices can be purchased in standard packages (dual in-line package (DIP) and single in-line package (SIP)) and assembled on a printed circuit board. If size is a constraint, packaging options are available to permit the designer to shrink the circuitry. Some examples of packaging options are

1. *Small Outline Integrated Circuits (SOIC)*. These devices occupy one-fourth to one-third of the circuit board area occupied by an equivalent conventional DIP.
2. *Small Outline Transistors (SOT)*. These devices occupy one-tenth to one-fourth of the board area of an equivalent conventional T018 or T05 transistor.
3. *Leadless Carriers*. An IC chip can be purchased from many manufacturers and assembled into a leadless chip carrier with a dramatic decrease in required space, e.g., a 16-pin device is 6.35 × 6.35 mm (0.25 × 0.25 in.) and replaces a 16-pin DIP, which is 7.6 × 20 mm (0.3 × 0.8 in.).
4. *Quasi-Custom Integrated Circuits (gate arrays, standard cells)*. A timer design requiring several DIP devices can very often be integrated into one or two quasi-custom integrated circuits at relatively low cost and can yield a truly dramatic reduction in the board area required.
5. *Fully Custom Integrated Circuits*. A fully custom IC yields the ultimate in space savings because each custom device is tailored to the designer's requirements. This technique permits integration of the timer functions in the smallest volume. It is more efficient than quasi-custom designs because there is no wasted space. Quasi-custom designs generally have a utility factor of 80 to 90%.
6. *Microprocessors*. Very often, the most economical implementation of a digital timer can be designed by using a microprocessor with on-board programmable read-only memory (ROM). The ROM can be mask programmed to meet individual user requirements, or it can be an electrically erasable programmable ROM (EEPROM), which permits the user to modify the program if system requirements change.

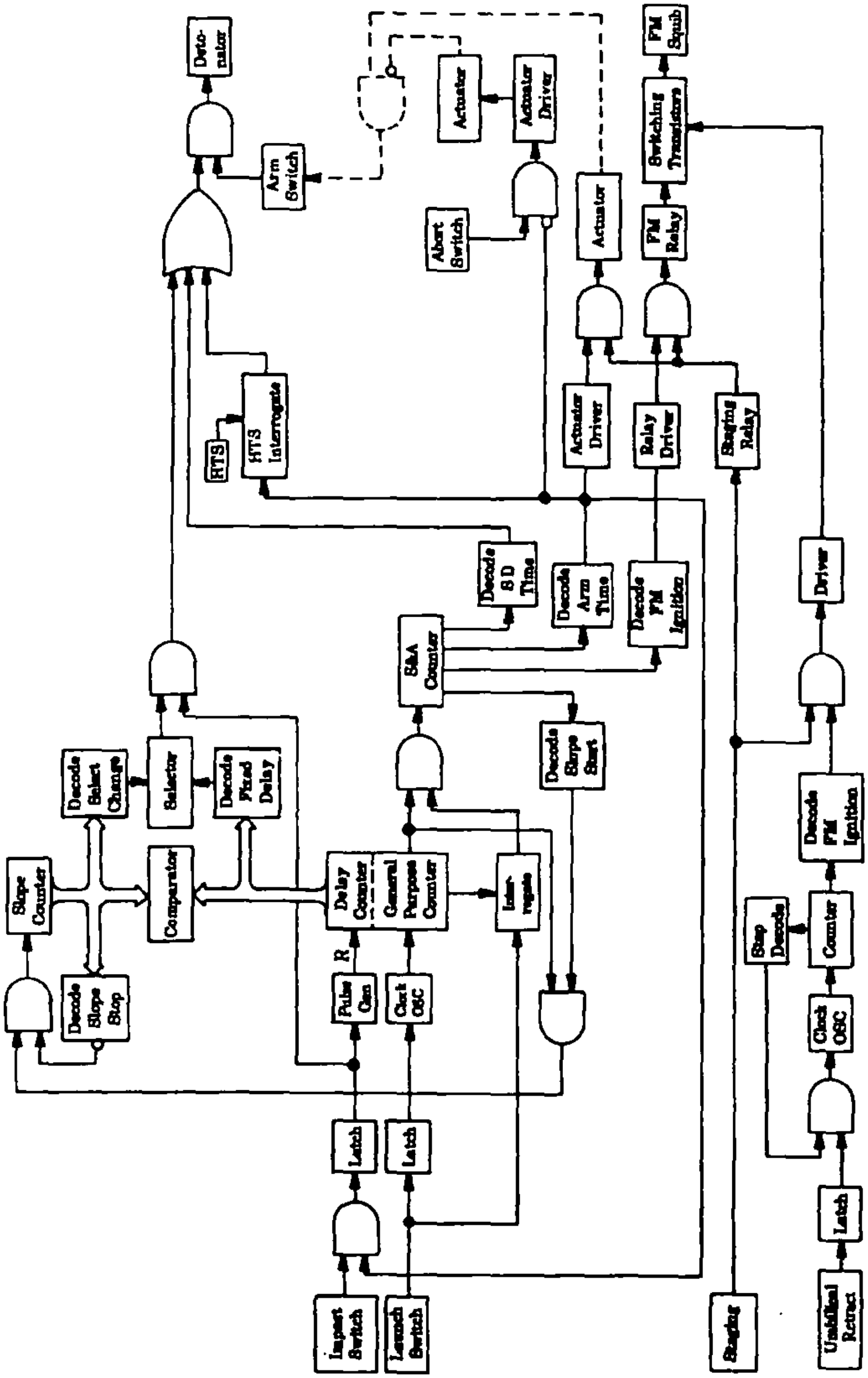


Figure 7-18. M934 STINGER Prototype C Fuze Functional Diagram (Ref. 5)

The design techniques using discrete ICs are very different from the techniques using a microprocessor. With the discrete ICs the designer creates his own architecture and must be familiar with various logic families to minimize the number of DIPs required. With the microprocessor, its internal architecture already exists, so the designer must write a program which most efficiently uses that internal architecture in order to achieve his system requirements. Microprocessor systems require a higher system clock frequency than discrete designs and more input power. Most microprocessors run at 5.0 Vdc, which may not be true for discrete timers.

Fig. 7-19 is a schematic of a typical digital 16-s precision timer with high-energy output.

7-3.2 POWER SUPPLIES

As mentioned earlier, most recent digital timers for fuze applications are constructed from some type of CMOS technology because CMOS is currently the most energy efficient IC technology, especially at lower frequencies (<1 MHz). The fact that space is usually at a premium in a fuze dictates minimum power supply volume. Examples of power sources for ordnance applications are discussed in detail in Chapter 3.

Very small power supplies generally contain enough energy and current capacity to power a CMOS timer for much more than 200 s. The designer must provide a battery output of 3 to 18 Vdc and must consider the activation time of the battery if timing accuracy is critical. Concern about activation time is important if the timer derives its start signal when the output voltage of the battery rises to the threshold of a voltage level sensor. This activation time of the battery then becomes an error term in defining the true accuracy of the timer. This error time can be eliminated if the battery is activated before launch or if a charged capacitor can power the timer during the first 25 to 50 ms of postlaunch operation while the battery is activating. In this case, the timer start signal could be provided by a setback or spin switch that closes within a few milliseconds of launch. This assumes a power supply is available prior to or during launch to charge the capacitor.

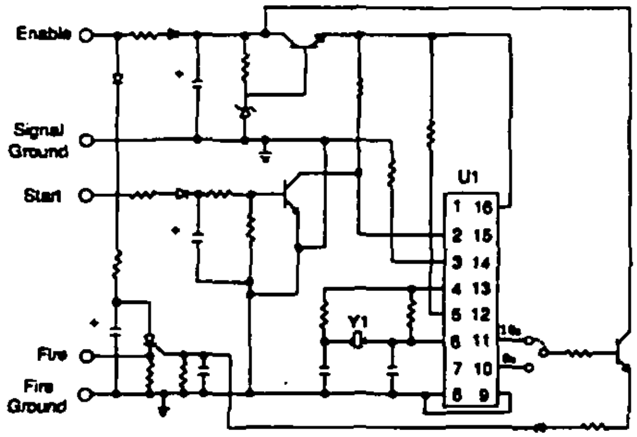


Figure 7-19. 16-Second Precision Ordnance Timer

Supercapacity capacitors are a relatively new technology. They have been advertised as "keep-alive" power sources for nonvolatile random access memory (RAM). These "supercaps" contain one farad or more of capacity and, if charged to 5 Vdc, can power a CMOS timer for an extremely long time.

7-3.3 TIME BASES (OSCILLATORS) FOR DIGITAL TIMERS

Oscillators are used as time bases for digital timers and, for most current digital timing applications, can be broken down into four types: relaxation oscillators, RC multivibrators, quartz crystal oscillators, and ceramic resonator oscillators. The capabilities and limitations of each type are discussed in the paragraphs that follow, and schematics are presented.

7-3.3.1 Relaxation Oscillator Using a Programmable Unijunction Transistor (PUT)

A schematic of a PUT oscillator is shown in Fig. 7-20. The period of oscillation T' is given by

$$T' = R_T C_T \ln \frac{V_{IN}}{V_{IN} - V_A}, \mu s \quad (7\text{-}2)$$

where

C_T = capacitance across transistor, µF

$$V_A = V_S + V_T, V \quad (7\text{-}3)$$

V_S = set voltage determined by $R1/R2$ ratio (See Fig. 7-20.), V
R_1 = resistance 1 (See Fig. 7-20.), Ω
R_2 = resistance 2 (See Fig. 7-20.), Ω
V_T = offset voltage, typically 0.4 V
V_{IN} = input voltage, (See Fig. 7-20.), V
R_T = resistance T (See Fig. 7-20.), Ω.

Conditions for sustained oscillation are

$$1.\ \frac{V_{IN} - V_A}{R_T}(MAX) > I_p(MAX) \quad (7\text{-}4)$$

where

I_p = peak point current, µA
$I_p(MAX)$ = maximum value of I_p, µA

2. $$\frac{V_{IN} - V_V}{R_T}(MAX) < I_V \quad (7\text{-}5)$$

where

I_V = valley current, μA
V_V = valley voltage = 0.6 V

3. $$1 - \frac{R_2}{R_2 + R_1} >> \frac{V_T}{V_{IN}}. \quad (7\text{-}6)$$

Parameters (i.e., I_p, I_V, and V_T) are specified in the data sheet for a particular PUT device. One such device is the 2N6120 for which the specified values for I_p, I_V, and V_T are

I_p = 1.0 μA MAX, @ R_G = 10 K, V_s = 10 V
I_V = 25 μA MIN, @ R_G = 10 K, V_s = 10 V
V_T = 0.2 V MIN to 0.6 V MAX, @ R_G = 10 K, V_s = 10 V

where

$$R_G = \frac{R_2 R_1}{R_2 + R_1}, \Omega.$$

The output frequency of oscillation f_{OUT} in Fig. 7-20 of a PUT oscillator is a series of pulses reflecting the capacitive discharge nature of the oscillator. Each pulse represents the discharge of C_T through R_L to ground.

7-3.3.2 RC Multivibrator Using Integrated Circuit Inverters

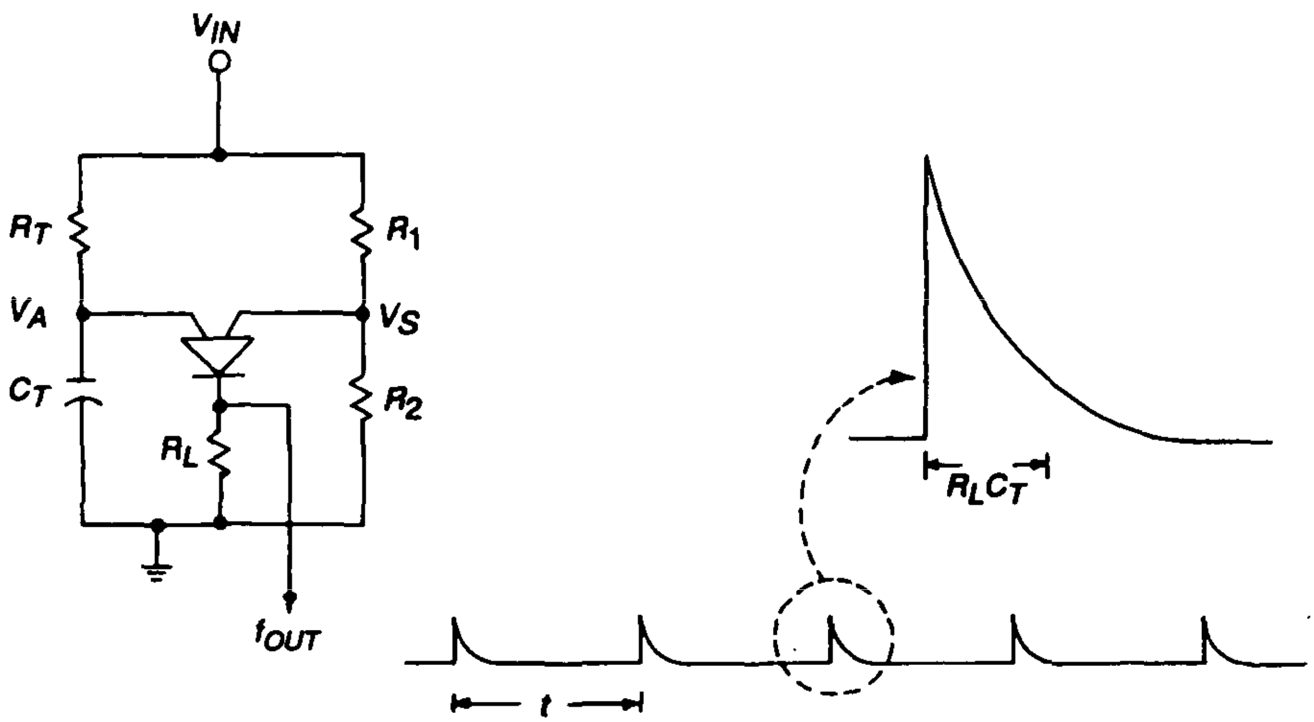
The RC multivibrator in its simplest form is any of the configurations shown in Fig. 7-21 less resistor R_S. The period T of the simplest RC multivibrator is given by

$$T = -RC\left[\ln\left(\frac{V_{DD} - V_{TR}}{V_{DD}}\right) + \ln\left(\frac{V_{TR}}{V_{DD}}\right)\right], \mu s \quad (7\text{-}7)$$

where

R = resistance, Ω
C = capacitance, μF
V_{TR} = transfer voltage at switching point of inverter, V
V_D = diode forward voltage drop, V.

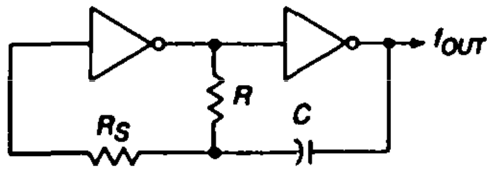
The period of this multivibrator is sensitive to variations in V_{DD} as well as to variations in V_{TR}. The addition of R_S to the simplest RC multivibrator form results in the forms shown in Fig. 7-21. The addition of R_S greatly reduces the



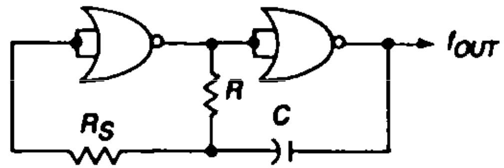
(A) Schematic of a PUT Oscillator

(B) Output Frequency of Oscillator

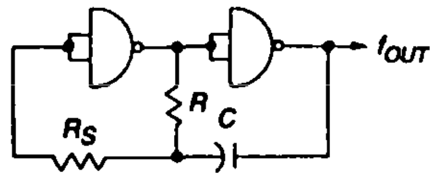
Figure 7-20. Programmable Unijunction Transistor (PUT) Oscillator



(1) Two Inverter Circuit, 1/3 CD4069

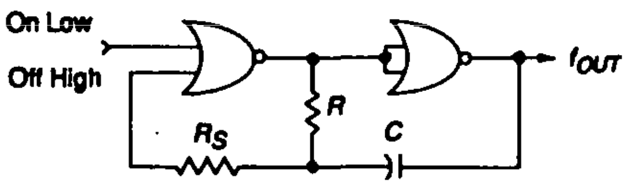


(2) Two NOR Gate Circuit, 1/2 CD4001

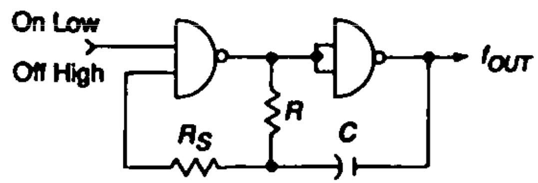


(3) Two NAND Gate Circuit, 1/2 CD4011

(A) Ungated RC Multivibrator Configurations



(4) Two NOR Gate Circuit



(5) Two NAND Gate Circuit

(B) Gated RC Multivibrator Configurations

Figure 7-21. RC Multivibrator Configurations Using Integrated Circuit Inverters

sensitivity of the period to variations in V_{DD} and V_{TR}. The period of the modified RC multivibrator T_1 is given by

$$T_1 = -RC\left[\ln\left(\frac{V_{TR}}{V_{DD}+V_{TR}}\right)+\ln\left(\frac{V_{DD}-V_{TR}}{2V_{DD}-V_{TR}}\right)\right], \mu s \quad (7\text{-}8)$$

provided $R_s \geq 10R$.

A good approximation of Eq. 7-8 is $T_1 = 2.2\,RC$, with $K = 10$. Either (2) or (3) of Fig. 7-21 can be converted into a gateable oscillator by using one input of the first inverter as a control input.

7-3.3.3 RC Multivibrator Using CD 4047 Integrated Circuit

An RC multivibrator using a CD 4047 integrated circuit is shown schematically in Fig. 7-22. The periods T_A at pin 13 and T_B at pins 10 and 11 of the oscillator are given by

$$T_A = \frac{1}{f_{OUT}} = 2.20\,RC, \text{s} \quad (7\text{-}9)$$

$$T_B = \frac{2}{f_{OUT}} = 4.40\,RC, \text{s} \quad (7\text{-}10)$$

where

T_A = period of oscillation of pin 13, s (See Fig. 7-22.)

T_B = period of oscillation at pins 10 and 11, s (See Fig. 7-22.)

f_{OUT} = output frequency of oscillation, MHz.

7-3.3.4 RC Multivibrator Using a 555-Type Integrated Circuit

An RC multivibrator using a 555 IC timer is shown schematically in Fig. 7-23. The output frequency of oscillation f_{OUT} of this oscillator is given by

$$f_{OUT} = \frac{1.46}{(R_A + 2R_B)\,C}, \text{MHz} \quad (7\text{-}11)$$

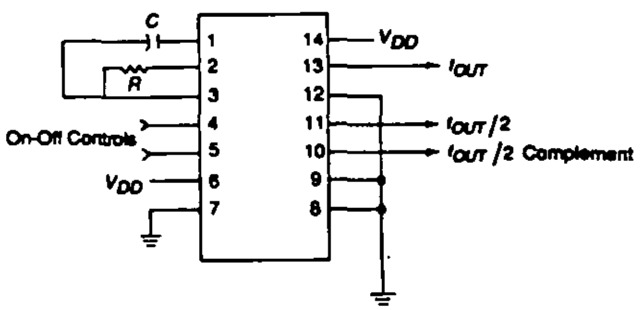


Figure 7-22. RC Multivibrator Using CD 4047

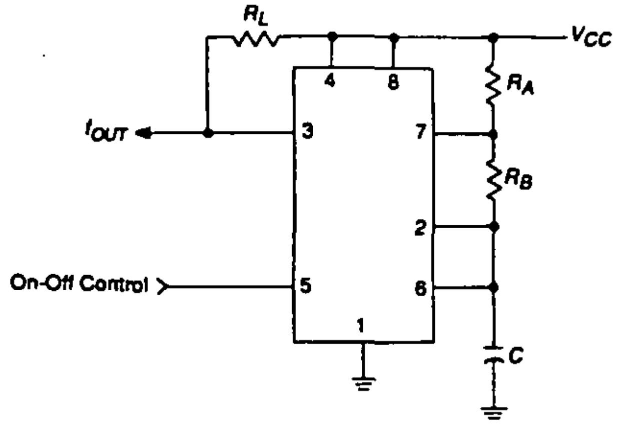


Figure 7-23. RC Multivibrator Using a 555 Timer Chip

where

R_A = resistance A, Ω

R_B = resistance B, Ω

and the duty cycle η, which is that portion of the period where the output is high, is given by

$$\eta = \frac{R_B}{(R_A + 2R_B)}, \text{dimensionless.} \quad (7\text{-}12)$$

7-3.3.5 Ceramic Resonator Oscillator

A ceramic resonator oscillator is shown schematically in Fig. 7-24. The frequency of oscillation is determined by the resonant characteristics of the ceramic resonator. Typically, ceramic resonators are available in the frequency range of 380 kHz to 12 MHz.

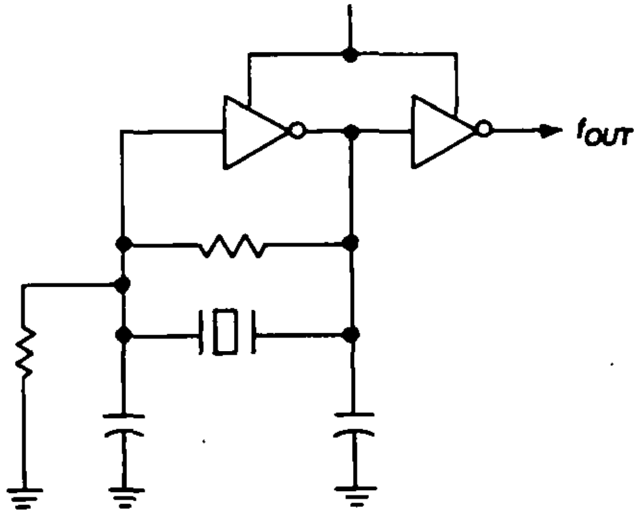


Figure 7-24. Ceramic Resonator Oscillator (380 kHz to 12 MHz)

7-3.3.6 Quartz Crystal Oscillators Using Discrete Crystals

Two examples of quartz crystal oscillators using discrete crystals are shown in Fig. 7-25. The frequency of oscillation is determined by the resonant characteristics of the crystal and the mode in which it is operated (fundamental or overtone). Typically, quartz crystals are available in the frequency range of 10 kHz to 100 MHz. Some crystals are cut in the shape of a tuning fork in order to obtain very low-frequency oscillations for watches and time fuzes.

7-3.3.7 Integrated Quartz Crystal Oscillators, Fixed Frequency and Programmable

Integrated quartz crystal oscillators are available in either fixed frequency or programmable forms and are able to interface directly with either CMOS or TTL logic families or microprocessors. The oscillators also may contain built-in frequency dividers. Oscillators with built-in frequency dividers span the frequency range of 0.005 Hz to 1 MHz. Fig. 7-26 shows a block diagram for one such device, which is available in a standard 16-pin DIP.

7-3.3.8 Time Base Accuracy

The PUT oscillator is among the simplest of oscillator configurations, but it provides the poorest performance of any of the types discussed because of the relatively large variation in V_T at ambient temperature and over the temperature range. Typically, V_T will change from 0.65 to 0.17 V over the temperature range of −40° to 75°C (−40° to 167°F).

The various RC multivibrators have slightly better performance characteristics but are still not very accurate. Therefore, generally RC multivibrators should not be used in systems requiring an accuracy of 2% or better. By selecting an R and a C that are very stable and whose temperature characteristics are opposite, e.g., +100 ppm and −100 ppm, and by adjusting the value of one or the other at ambient temperature to achieve the exact frequency desired, however, it is possible to obtain oscillator performance of better than 1%. This performance level is best accomplished by using hybrid microelectronic techniques by which chip capacitors can be obtained with a desired temperature characteristic and the frequency-determining resistor can be dynamically trimmed by laser to achieve the exact frequency desired. Also the temperature coefficient of the resistor can be adjusted to compensate for the temperature coefficient of the capacitor.

The ceramic resonator oscillator provides better accuracy than RC types but should not be used in systems requiring an accuracy of 0.5% or better. Crystal oscillators are the most accurate of all oscillator types; accuracies range from 0.002 to 0.05%. Complete crystal oscillators are available in leadless carrier packages measuring 12.7 × 12.7 mm (0.50 × 0.50 in.) and, if desired, tested to the requirements of MIL-STD-883 (Ref. 7).

7-3.4 COUNTERS

There are many counter types, but some of the more common types are Binary, Decade, Programmable, Binary Coded Decimal (BCD), Up/Down, and Presettable.

A counter, such as the CD 4040, which is a 12-stage binary counter, divides the input clock frequency by two for each binary stage. The switching action takes place on the high-to-low transition of the clock waveform. The clock input rise and fall times are unlimited because the clock input of the counter has Schmitt trigger action. When the counter is used in the ripple mode, the first low-to-high transition takes place on the $2^{(n-1)}$ clock pulse, whereas on a repetitive basis, the low-to-high or high-to-low transitions take place on the 2^n clock pulse. For example, a seven-stage binary counter (CD 4024) has a 2^7 (128) division capability on a repetitive basis, but the first low-to-high transition for

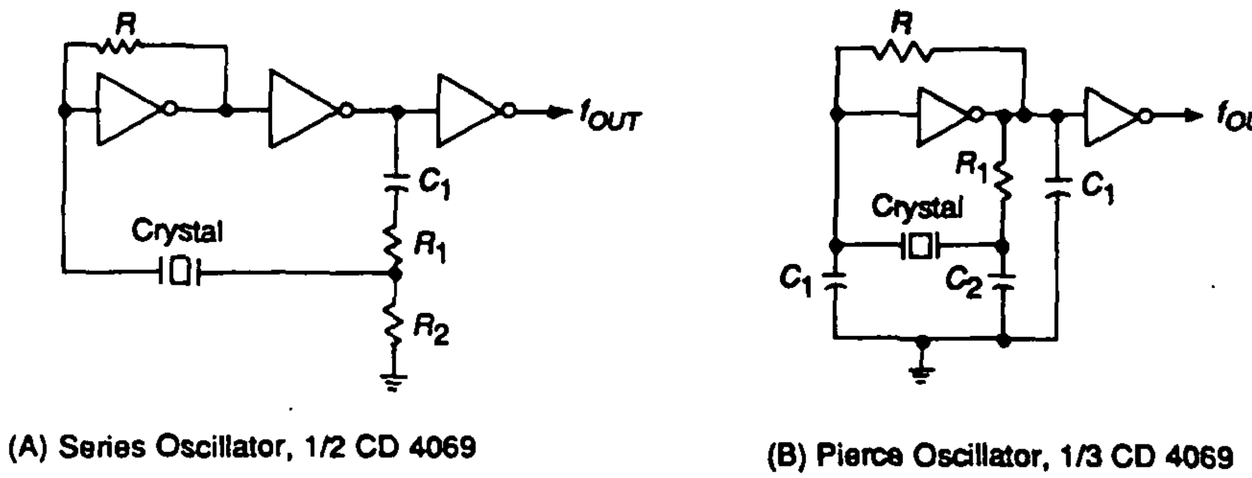


Figure 7-25. Quartz Crystal Oscillators (10 kHz to 2.2 MHz)

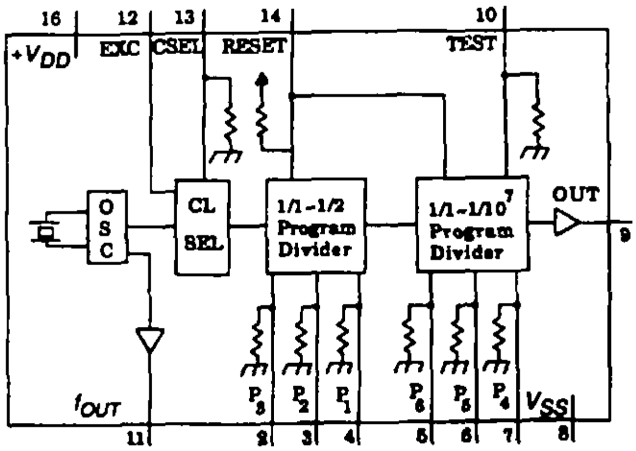


Figure 7-26. Integrated Quartz Crystal Oscillator, Fixed Frequency and Programmable (Ref. 6)

the Q_7 output occurs after 2^6, or 64, clock pulses. By proper choice of clock frequency and by selecting an appropriate counter stage, a wide variety of system clock frequencies is achievable. For example, Fig. 7-27 shows a crystal clock of 40.96 kHz driving a CD 4040 counter. A decade counter—CD 4017, CD 40160, or CD 40162—divides the input clock frequency by a factor of 10.

A programmable counter—CD 4018, CD 4059, MC 14522, and MC 14526—can be programmed via certain control inputs to divide the input clock frequency by different amounts depending on the input code. The CD 4018 can be programmed to divide by 10, 8, 6, 4, or 2, and with the addition of a CD 4011, it can be programmed to divide by 9, 7, 5, or 3. The CD 4059 can be programmed to divide the input clock frequency by any number "*n*" from 3 to 15,999. The MC 14522 is a 4-bit BCD counter, which can be programmed to divide by 1 to 10. The MC 14526 is a 4-bit binary counter, which can be programmed to divide by 1 to 16.

A variety of other counters is available for performing digital timing functions. A partial list of digital counters includes

1. CD 4029—Presettable Up/Down Counter, Binary or BCD Decade
2. CD 4510—Presettable 4-Bit BCD Up/Down Counter
3. CD 4016—Presettable 4-Bit Binary Up/Down Counter
4. CD 40102—Presettable 2-Decade BCD Down Counter
5. CD 40103—Presettable 8-Bit Binary Down Counter
6. CD 40160—Decade Counter With Asynchronous Clear
7. CD 40161—Binary Counter With Asynchronous Clear
8. CD 40162—Decade Counter With Synchronous Clear
9. CD 40163—Binary Counter With Synchronous Clear
10. CD 4045—21-Stage Binary Counter With Oscillator Amplifier
11. CD 4536—24-Stage Programmable Timer With Oscillator Amplifier

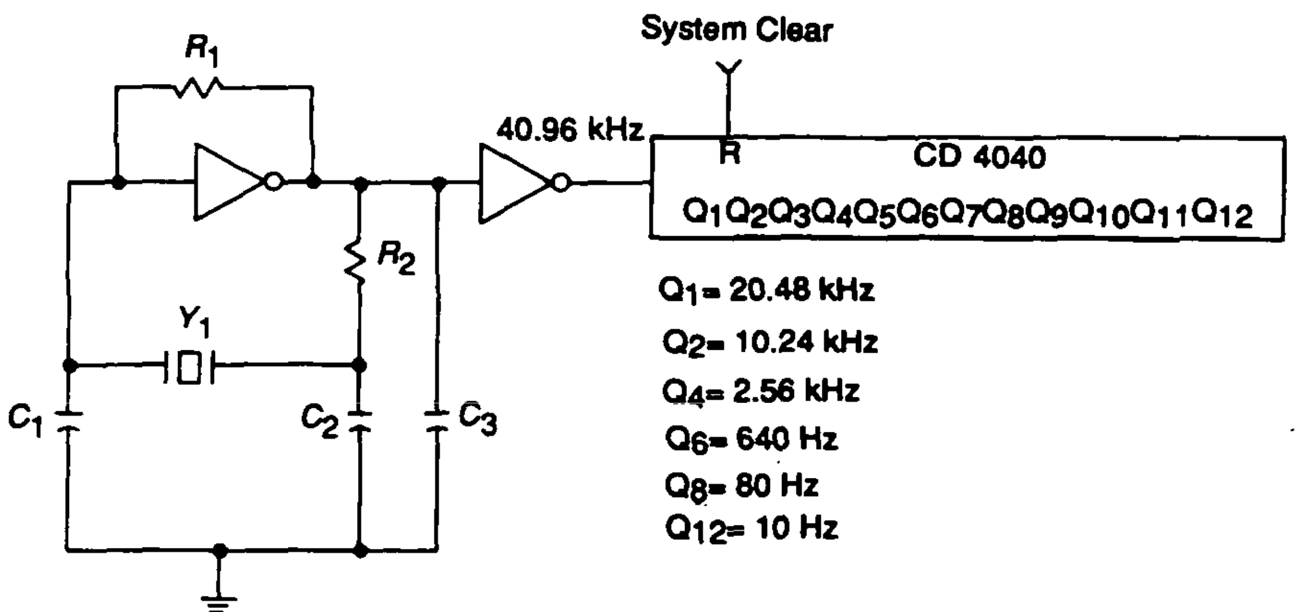


Figure 7-27. A Crystal Clock (40.96 kHz) Driving a CD 4040 Counter

12. MC 14521—24-Stage Frequency Divider With Oscillator Amplifier.

7-4 OUTPUT CIRCUITS

The output of a digital timer is usually a pulse, often one clock pulse period wide, which may be positive or negative going, i.e., ground to +V or +V to ground. In some applications the pulse may be adequate to meet system requirements, but in others the timer output may be latched to give a *continuous* voltage level after the timer output has occurred. The output from the timer may not have enough energy to perform the desired function; if it does not, the timer output must be buffered or isolated through use of a transistor amplifier. Some examples of timers are presented in Figs. 7-28 through 7-32.

In the example shown in Fig. 7-28 and Table 7-1, the CD 4536 is used as a programmable timer. The timer output pulse width can be programmed through components *R* and *C*.

In the example shown in Fig. 7-29 and Table 7-2, the CD 4536 output is used to set a flip-flop. The timer output is then latched and will stay high until a system clear pulse is applied to the latch.

The decode out selection table, or truth table, shown in Tables 7-1 and 7-2, shows the outputs available from the "decode out" terminal when various combinations of 1's and 0's are applied to the 8 bypass and to inputs A, B, C, and D. A logic 1 on the 8 bypass input enables a bypass of the first eight stages and makes stage 9 the first counter stage (labeled "1" under the column headed "8 Bypass = 1"). Selection of any of the 16 outputs is accomplished by the decoder and the inputs A, B, C, and D.

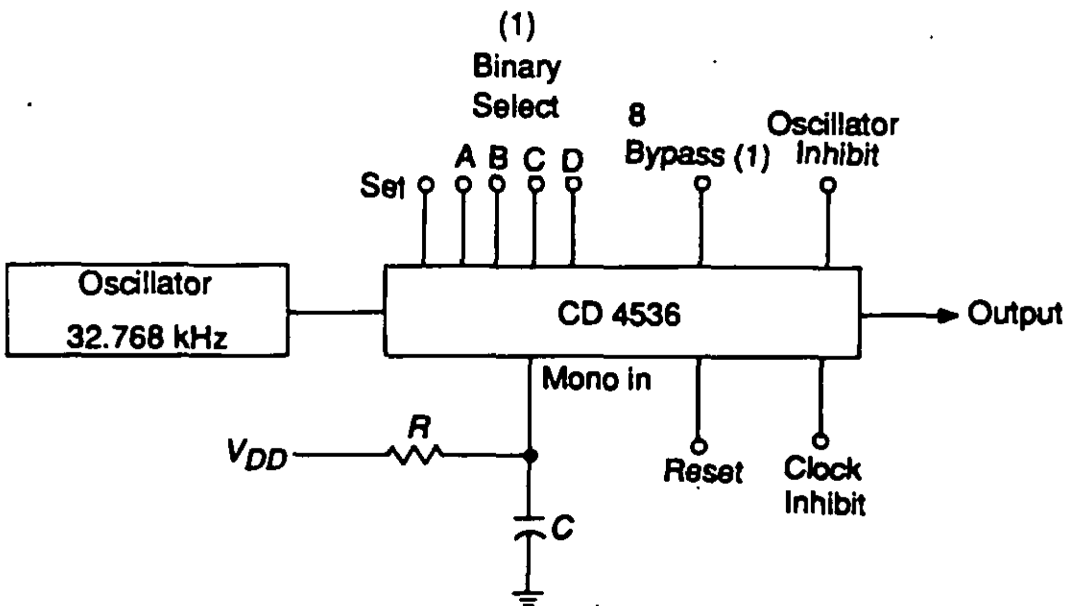
Example 1. Refer to Table 7-1 and set a logic 1 on the 8 bypass; then, by setting A and B = 1 and C and D = 0, an output pulse is obtained from the decoder output terminal. This output comes from the twelfth stage of the 24 ripple-binary counter stages and is the fourth in the list of 16 possible input combinations shown in the table.

Example 2. Refer to Table 7-2 and set A, B, C = 0 and D = 1, with 8 bypass = 0. The seventeenth stage will give a time-out delay of 2 s.

In the example shown in Fig. 7-30, the MC 14521 is used as the timer. The timer output at 4.0 s is latched with a flip-flop, and the latched output is buffered with a two-transistor level shifter to drive a 28-Vdc relay coil.

In the example shown in Fig. 7-31, a CD 4020 is used with a 32.768-kHz crystal oscillator to generate an output 0.25 s after the system clear signal goes low. The time delay output is buffered with an NPN transistor to drive a high-energy, capacitive discharge firing circuit. The CD 4020 cannot supply enough current to turn on the silicon-controlled rectifier (SCR) directly.

In the example shown in Fig. 7-32, the CD 4020 provides the same 0.25-s delay as the circuit shown in Fig. 7-31,



Note: See Table 7-1 for Explanation of the Use of the 8 Bypass and Binary Select Inputs

Figure 7-28. Programmable Timer With Pulse Output

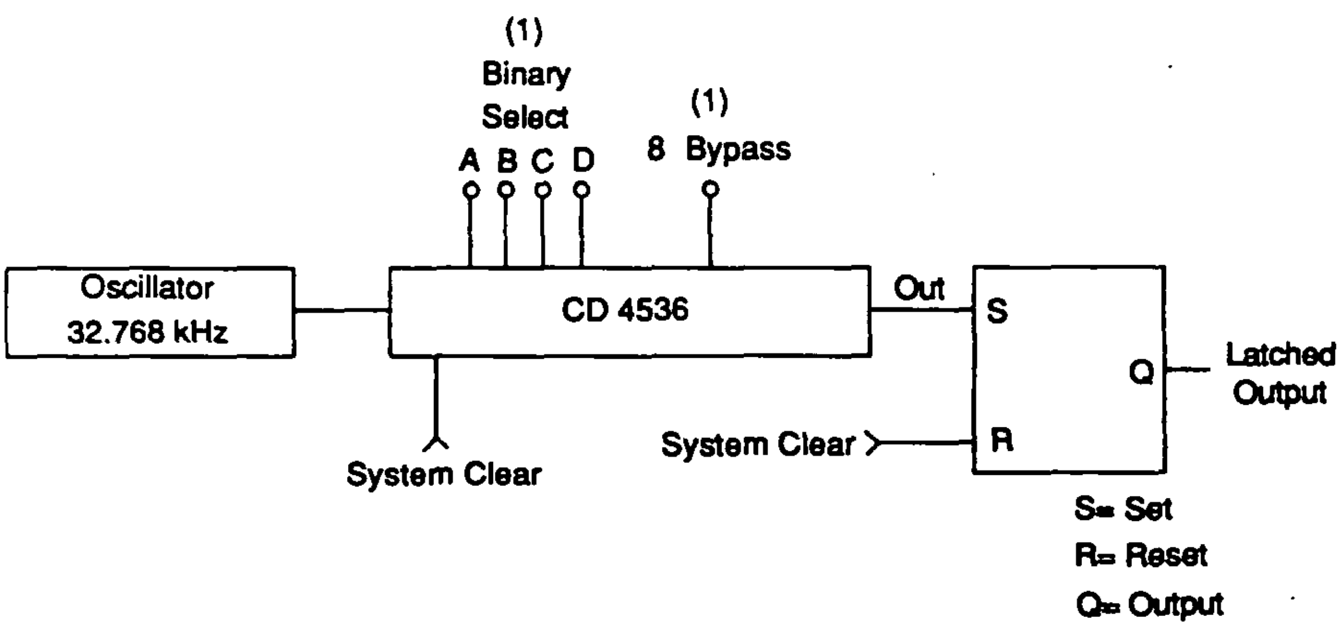
TABLE 7-1. PROGRAMMABLE TIMER WITH PULSE OUTPUT

D	C	B	A	NUMBER OF STAGES IN DIVIDER CHAIN	
				8 Bypass = 0	8 Bypass = 1
0	0	0	0	9	1
0	0	0	1	10	2
0	0	1	0	11	3
0	0	1	1	12	4
0	1	0	0	13	5
0	1	0	1	14	6
0	1	1	0	15	7
0	1	1	1	16	8
1	0	0	0	17	9
1	0	0	1	18	10
1	0	1	0	19	11
1	0	1	1	20	12
1	1	0	0	21	13
1	1	0	1	22	14
1	1	1	0	23	15
1	1	1	1	24	16

except that the output pulse occurs only once and is a short pulse of 244-μs duration. The output pulse sets a flip-flop, which resets the timer. The output buffer uses a two-transistor level shifter that delivers energy to the load for 244 μs.

In the examples shown in Fig. 7-33, a high-energy and a low-energy capacitive discharge firing circuit are shown. The low-energy circuit contains 1.36×10^{-3} J of energy, and the high-energy circuit contains 0.321 J of energy. Neither circuit can deliver the full amount of energy to the electro-explosive devices (EED) because of circuit losses, particularly in the storage capacitor and SCR. Aluminum electrolytic capacitors are available, which outperform tantalum capacitors in energy transfer efficiency.

EEDs can vary in firing energy requirements. In some applications, a very insensitive EED is required. There is a class of EEDs, known as 1-AMP, 1-WATT, NO-FIRE devices. These devices can dissipate 1 W of power in the bridgewire and not fire. The firing energy required to guarantee EED firing is called the "all fire" and is usually specified as an ampere-second product. That is, a constant current applied for the proper amount of time is guaranteed to fire the EED. If this technique is used, a design margin should be allowed to account for component tolerances in the firing circuit. A more common method for firing EEDs, however, is to use the capacitive discharge method, which involves storing energy E on a firing capacitor according to the equation



Note: See Table 7-2 For Explanation of the Use of the 8 Bypass and Binary Select Inputs

Figure 7-29. Programmable Timer With Flip-Flop and Latched Output

TABLE 7-2. PROGRAMMABLE TIMER WITH LATCHED OUTPUT

SELECTION TABLE

D	C	B	A	8 Bypass	Number of Stages
0	0	0	0	0	9
0	0	0	0	1	1
0	0	0	1	0	10
0	0	0	1	1	2
1	0	0	0	0	17
1	0	0	0	1	9
1	0	1	0	0	19
1	0	1	0	1	11
1	1	1	1	0	24
1	1	1	1	1	16

STAGE SELECTED	TIME OUT, s
15	0.5
16	1.0
17	2.0
18	4.0
19	8.0
20	16.0
21	32.0
22	64.0
23	128.0
24	256.0

$$E = 5CV^2, \text{erg} \quad (7\text{-}13)$$

where

C = capacitance, μF.

Statistical test methods exist to determine the all fire energy requirement for a particular EED using the capacitive discharge firing method. Firing energy data are available for current procurement EEDs in MIL-HDBK-777 (Ref. 4).

Firing circuits for a low-energy EED (5×10^{-4} J) and a high-energy EED (1 AMP, 1 WATT, NO-FIRE) are shown in Fig. 7-33. Normally, a firing margin of two or more should be allowed, especially if the circuit is expected to operate reliably over the temperature range of −54° to 71°C (−65° to 160°F). At −54°C (−65°F), the value of the firing capacitor may be reduced by 10 to 40% or more, and the internal impedances of the firing capacitor (effective series resistance (ESR)) and the SCR may be increased significantly and thereby reduce the amount of energy available to the EED.

Some designers prefer not to use SCRs in EED firing circuits for fear that system noise spikes might cause them to fire prematurely and latch on. For an out-of-line EED the SCR latch-up would not create a hazard, but the firing circuit would be rendered inoperative. This latch-up problem can be avoided by making R (470 Ω in Fig. 7-33(A) and 10 Ω in Fig. 7-33(B)) large enough to starve the SCR, i.e., lower the current through R to a value less than the minimum holding current value of the SCR. If the system cannot tolerate the RC charge time constant, some other scheme may have to be employed to fire the EED. The technique shown in Fig. 7-33 would be appropriate since the firing circuit in this example is activated only as long as the timer output pulse is present. If the timer output pulse width is too long, it can be shortened by using a one-shot multivibrator whose period can be programmed to be virtually any value and is independent of the timer output pulse width. The 470-Ω resistor and 0.01-F capacitor from the SCR gate-to-ground of each of the circuits of Fig. 7-33 help immunize the SCR from system noise. A resistor from the SCR cathode-to-ground could also be helpful if the SCR and EED are separated in the system by 76.2 mm (3.0 in.). This extra resistor is shown with a dashed connecting line in the two circuits in Fig. 7-33.

There are alternative output switching devices, which could be used in place of an SCR. Some examples include power metal oxide semiconductor field-effect transistor (MOSFET), Darlington transistors, and a combination of PNP and NPN transistors, such as is shown in Fig. 7-32. These alternatives have the advantage of not latching on; they also provide very high current gain (output signal amplification).

7-5 STERILIZATION CIRCUITS

It is a safety requirement in most ordnance devices that the firing capacitor have an energy bleed resistor placed across it. The system requirement usually dictates the minimum "safing" period. Fig. 7-34 shows a typical firing circuit. If the EED has a "No-Fire" energy of 500 ergs, then from Eq. 7-13

$$V_{NO-FIRE} = \sqrt{\frac{E}{5C}} = \sqrt{\frac{500}{50}} = 3.2 \text{ V}.$$

If the system requires a "safing" period of 1 h, then from the following relationship

$$R' = \frac{t}{C \ln\left(\frac{V_{IN}}{V_{CAP}}\right)} = \frac{3600}{10^{-5} \ln \frac{30}{3.2}} = 1.61 \times 10^8 \ \Omega \quad (7\text{-}14)$$

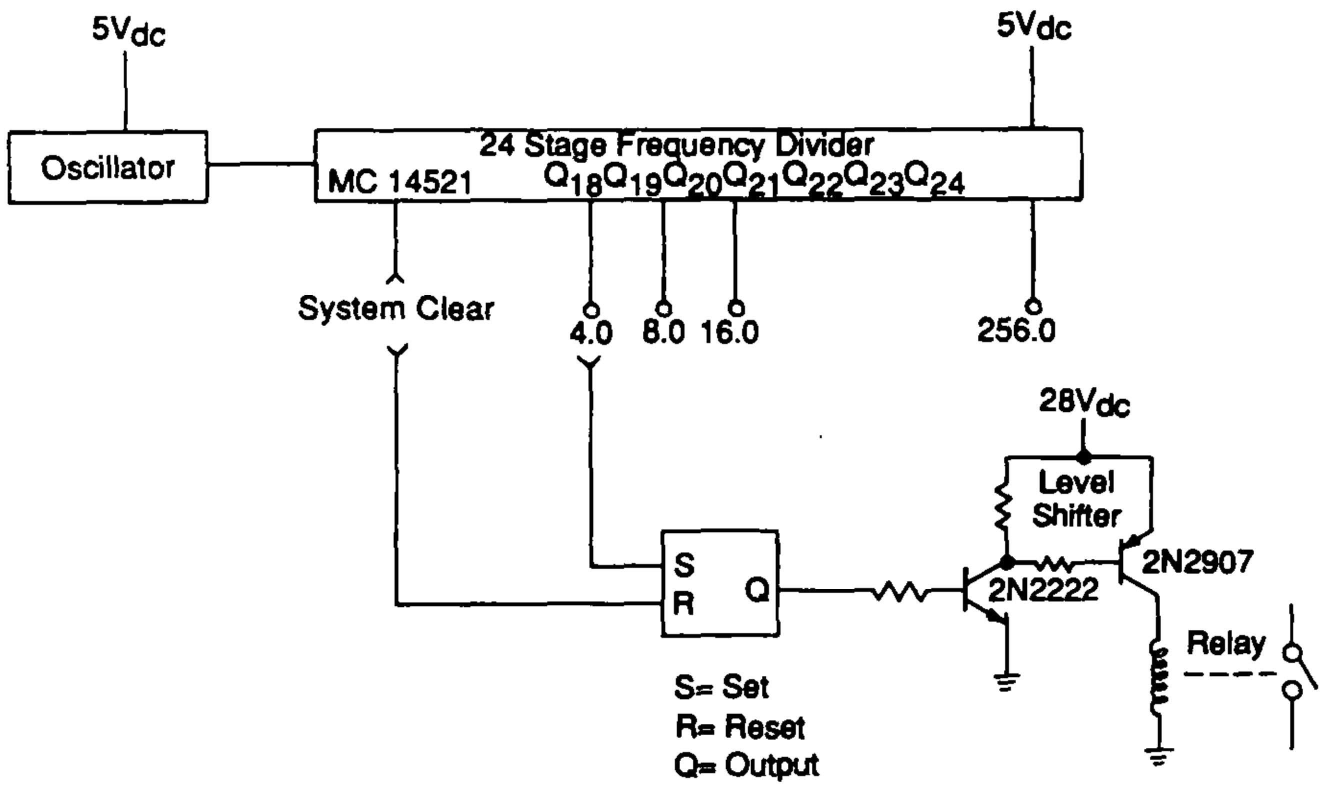


Figure 7-30. MC14521 Timer Output Latched With Flip-Flop and Transistor Buffer

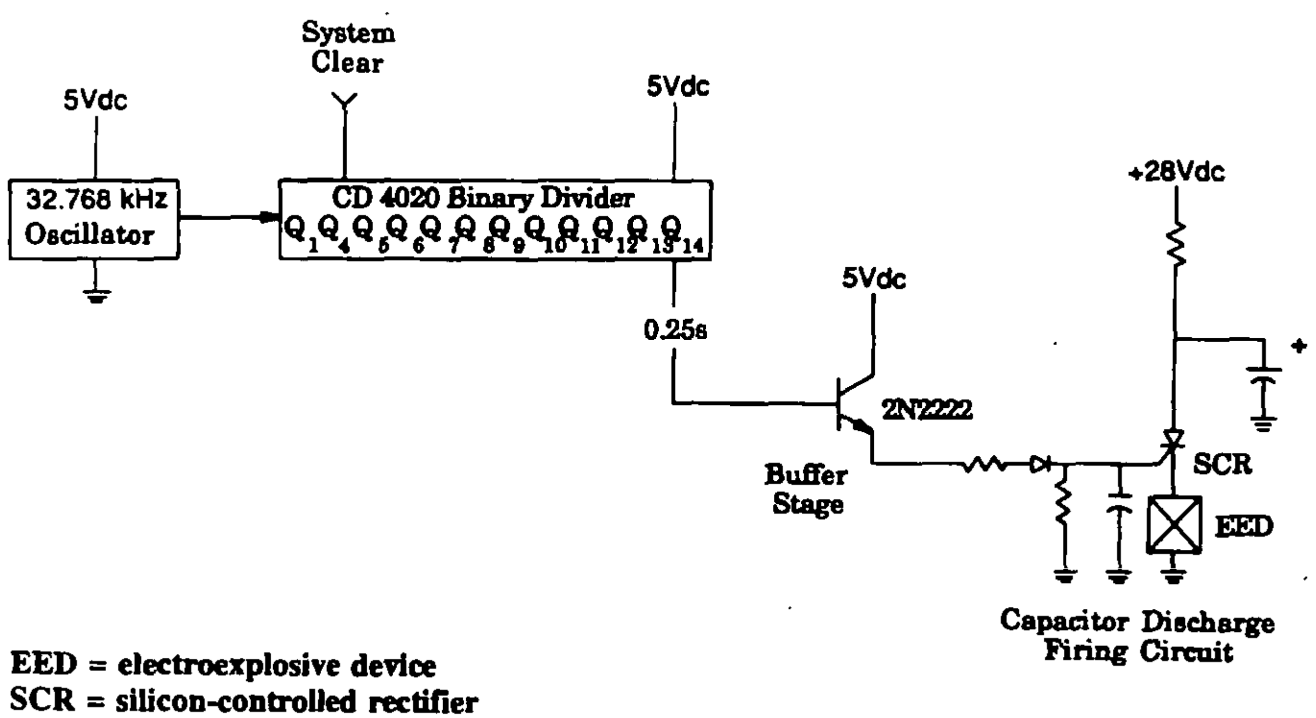


Figure 7-31. Firing Circuit With Transistored Buffered Capacitor Discharge Output

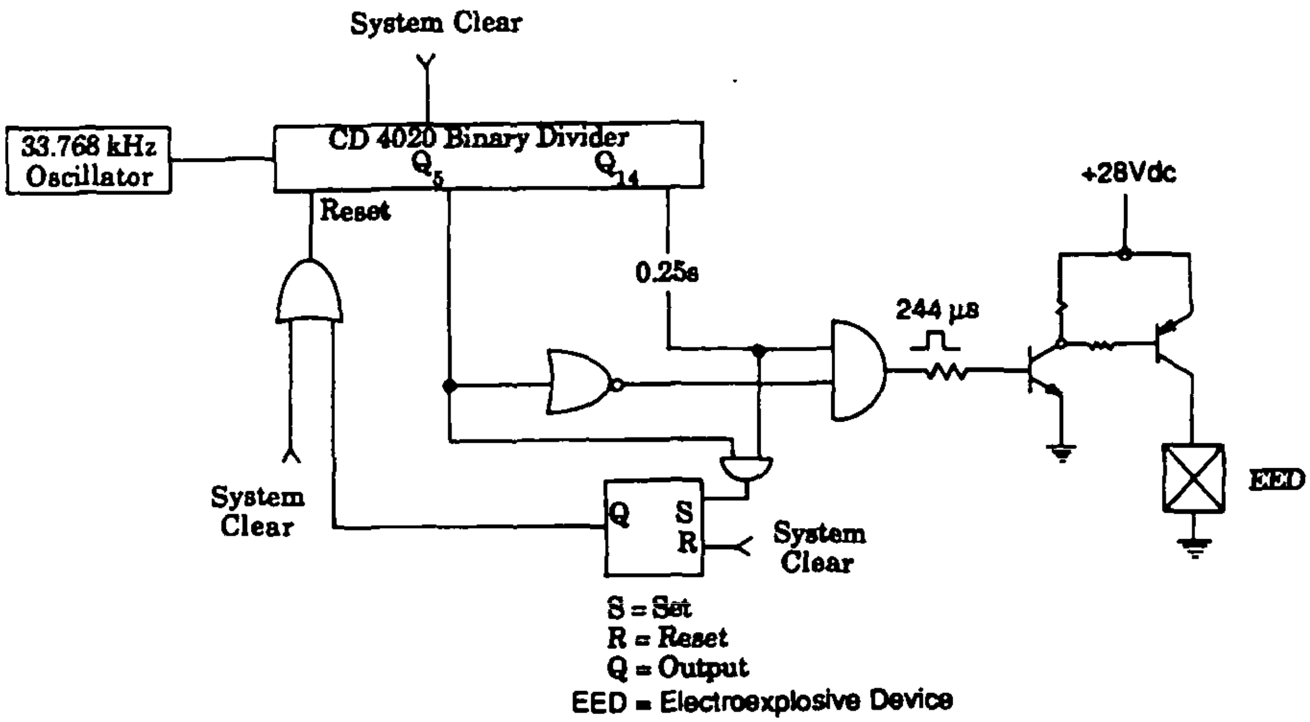


Figure 7-32. Firing Circuit With Short Duration Output

where

R' = required bleed resistor, Ω
C = capacitance, F
t = time, s
V_{CAP} = EED no-fire voltage, V.

The energy bleed requirement exists so that, in the event of a dud piece of ordnance, an explosive ordnance disposal (EOD) team can recover or remove the ordnance with the assurance that the electrical firing circuit is safe.

7-6 MICROPROCESSORS

Microprocessors are being used in a variety of fuzing applications to provide numerous programmed functions including timing, sensor monitoring, self-checking, sensor control, and signal processing. The advantages of using a microprocessor in fuzing applications are that hardware design is minimized and fairly complex fuzing algorithms can be implemented routinely. One disadvantage is that current microprocessors usually run at a maximum clock frequency of 10 to 20 MHz or less, and their actual signal processing speed is considerably less. This speed limitation could preclude using a microprocessor in a fuze for very high-speed target encounters.

Virtually all timing and logic functions required of an electronic fuze can be performed by any of the many microprocessors currently available. The choice of a particular microprocessor is determined by power, speed, size, and cost restrictions imposed by the system on the fuze. Single-chip microcomputers and microcontrollers are particularly well-suited to fuzing because they require the least number of peripheral circuits and their internal architecture is suited to timing and control applications.

Two eight-bit microprocessors that are widely used in fuzing applications are the MC 146805G2 and the 80C48, -49, -50, and -51 family. Both are fabricated from high-performance silicon gate CMOS technology.

The MC146805G2 will operate up to 4 MHz and has a set of 61 basic instructions. The 80C48 and 80C49 can operate in a single-step mode or up to 11 MHz and each has a set of 111 basic instructions.

One advantage to using the 80C48-51 family is that the microprocessors share a common instruction set. Thus a designer can start with an 80C48 (least RAM and ROM memory space) and expand upward in memory space as system requirements grow without having to perform a major rewrite of program software.

Functional block diagrams of the MC146805G2 and the MSM80C48 microprocessors are presented as Figs. 7-35 and 7-36, respectively.

7-7 ELECTRONIC SAFETY AND ARMING SYSTEMS

One emerging technology that is being pursued by all branches of military service is the use of electronic safety and arming devices in missiles and smart weapons. Basically, an electronic SAD can be defined as an S&A system that contains neither primary explosives in the explosive

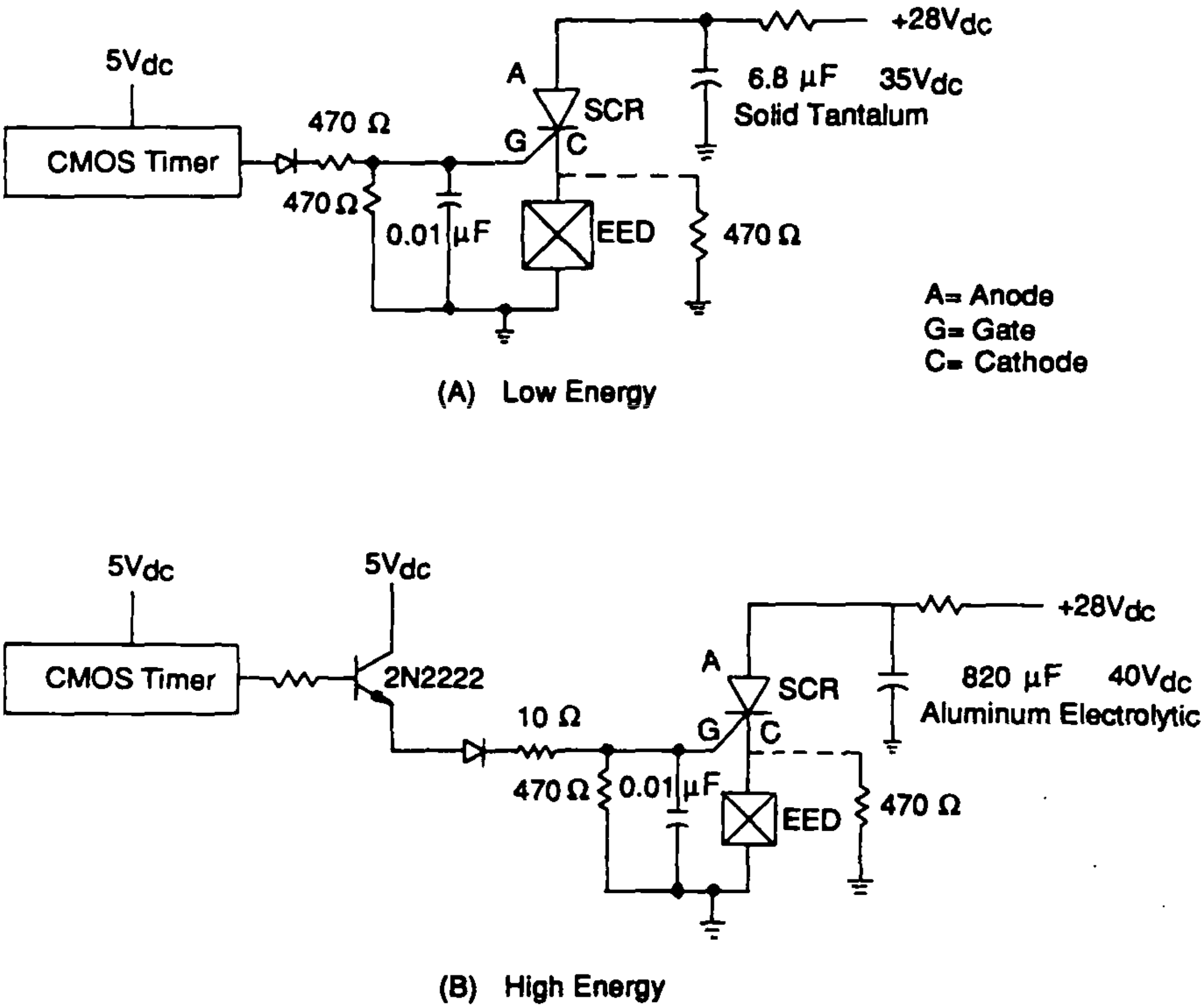


Figure 7-33. High- and Low-Energy Capacitive Discharge Firing Circuits

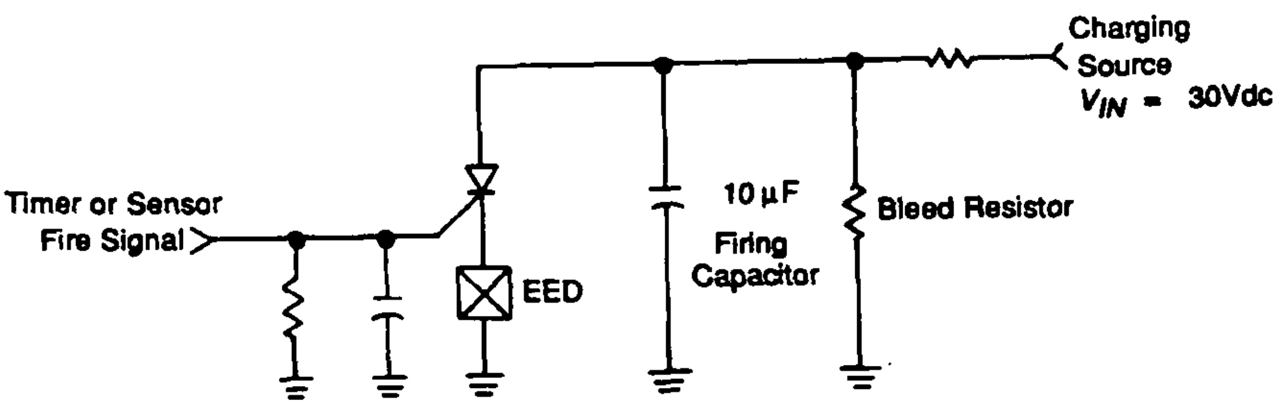
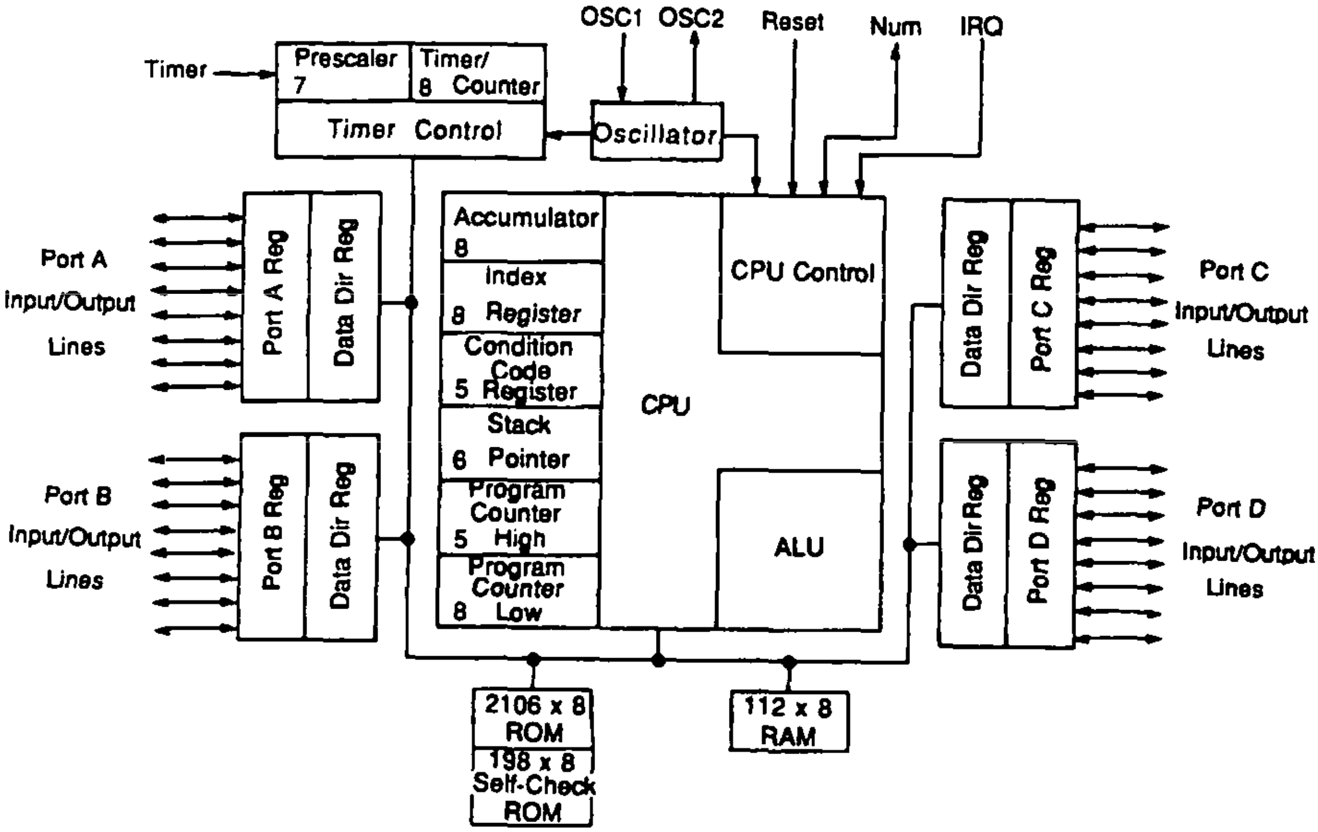


Figure 7-34. Energy Bleed Resistor Example



Courtesy of Motorola, Inc.

Figure 7-35. Functional Block Diagram MC14680G2 8-Bit Microcomputer (Ref. 8)

train, nor an interrupted explosive train, nor a mechanical energy interrupter, but does have access to an energy source sufficient for warhead detonation. It is a no-moving-parts, solid-state unit employing a slapper detonator explosive train. Therefore, it is expected to provide significant advantages in safety, reliability, size, cost, and other performance features compared to SADs based on existing technology.

A block diagram of a generic electronic SAD is shown in Fig. 7-37. It is basically a single-channel, single-point-initiation unit having two connectors: a multipin connector for inputs and monitors and an output connector for attachment to a slapper detonator. It does not contain any explosive and can be fully tested including the firing of disposable slapper detonators. This SAD has a microcontroller or similar large scale integration (LSI) element that will enable it to be factory programmable for a wide range of applications. Environmental sensors are part of the S&A system, but they are shown as external inputs because they are usually unique to each application. The SAD is capable of being used with a wide variety of sensors, such as launch signals, fin deployment signals, and command-arm signals. Some of the safety features illustrated by Fig. 7-37 are

1. The use of two separate IC elements, neither of which can arm the SAD independently
2. The use of two dc switches and one dynamic switch in the arming power path
3. The use of dc switches on both sides of the converter drive
4. The use of transformer coupling between the high- and low-voltage sections.

Two advantages of this arrangement are that application of power to any point in the circuit cannot result in arming and that shorting any or all of the arming switches does not result in arming.

The SAD firing capacitor can be designed for single- or multiple-point output to fire slapper detonator(s). The slapper detonator and HNS-4 explosive pellet are external to the SAD housing and are connected by cabling.

The technology to produce electronic S&A is maturing, and a fully developed system is being used by the US Army in the Fiber-Optic Guided Missile (FOGM). There are still problems to be solved, e.g., establishment of safety criteria for electronic S&A; development of service-accepted logic and environmental sensors; and reduced cost and size, but the potential is great for next generation SADs for missile and smart weapon application.

Additional information on electronic S&A systems is included in Ref. 10.

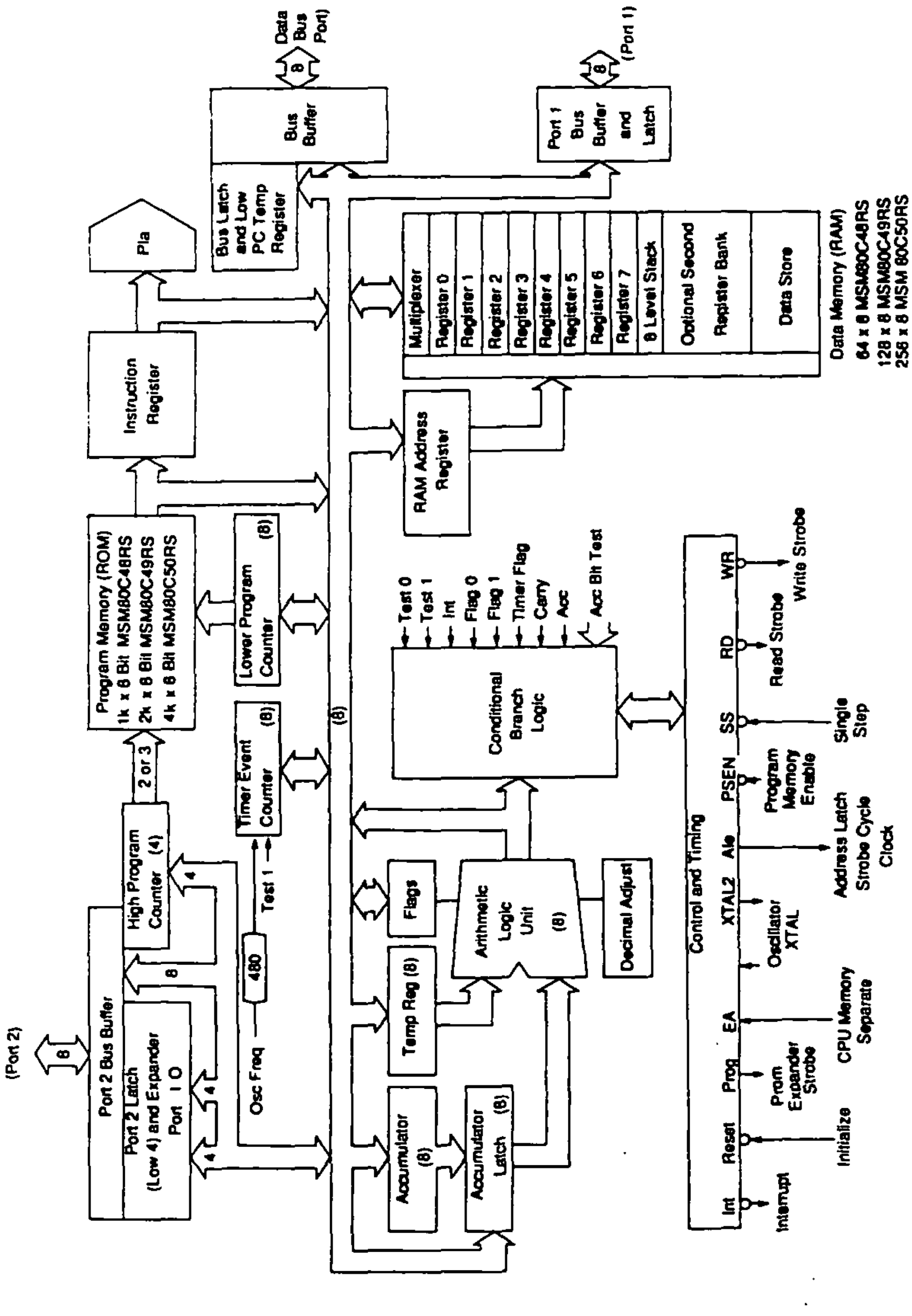


Figure 7-36. Functional Block Diagram MSM80C48 Family 8-Bit Microcomputer (Ref. 9)

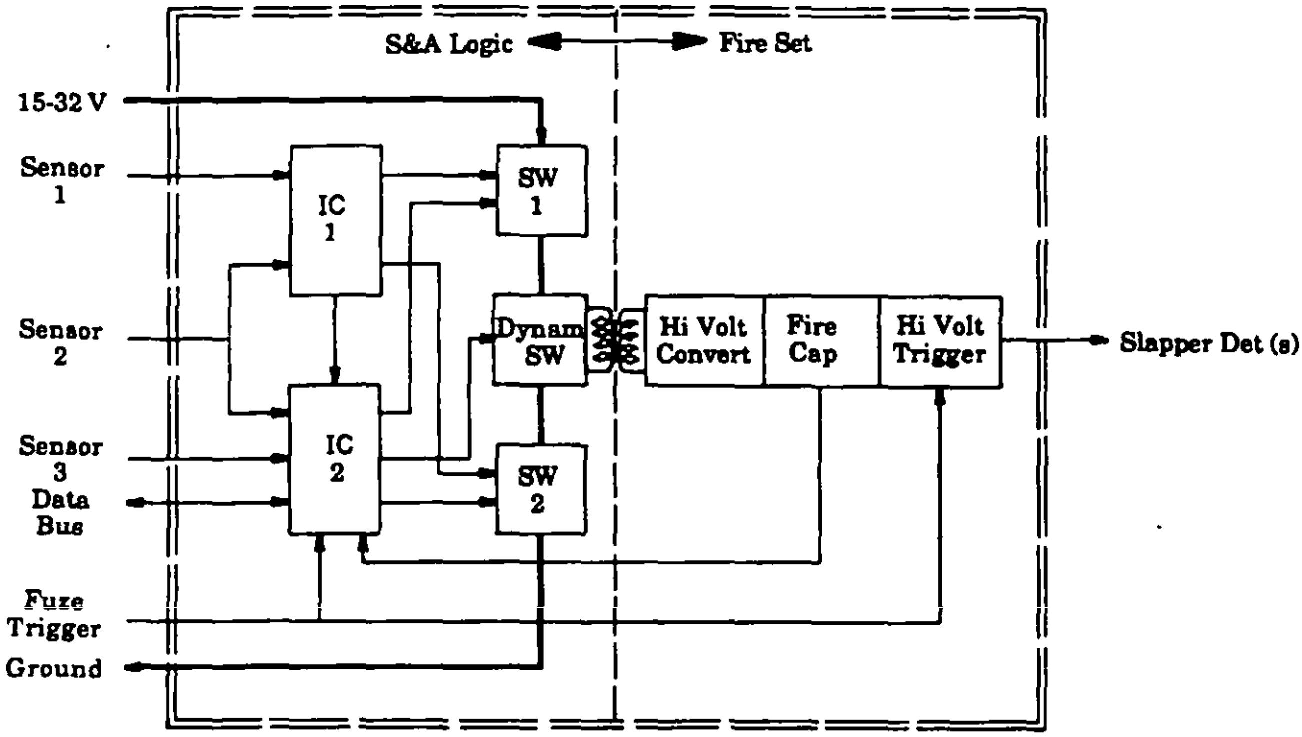


Figure 7-37. Generic Electronic Safety and Arming Device (Ref. 10)

7-8 MICROMECHANICAL DEVICES

Recent advances in the technology of microelectronic chips have led to the development of a new technology called micromachining, which allows silicon mechanical devices to be made almost as small as microelectronic devices (Ref. 11). Chemical etching techniques are added to micromachining to form three-dimensional shapes that can be used as switches and as sensors for environments such as force, pressure, and acceleration. The excellent physical properties of silicon, the small size of micromachined silicon devices, and its adaptability to high-volume CMOS manufacturing techniques make this technology cost-effective for fuzing applications.

Accelerometers with an on-board amplifier have been designed and fabricated on chips as small as 17.4 $mm^2 \times 0.5$ mm thick (0.027 $in.^2$ × 0.021 in. thick). A silicon oxide beam is formed over a shallow well and using a boron etch-stop technique, a metal layer is deposited on the top surface of the oxide cantilever. The metal layer and the flat silicon on the bottom of the well act as two plates of a variable air-gap capacitor. A lump of gold is formed on the free end of the beam by plating. If the silicon chip is moved suddenly, the inertia of the gold weight causes the beam to flex and change the air gap and hence the capacitance. The output of the sensor is a voltage that is proportional to acceleration. One accelerometer of this type had a sensitivity of 2 mV/g, where g is the acceleration due to gravity. The amplifier is an important part of the circuitry because signal conditioning of some kind must precede the voltage transmission in most small capacitive sensors. Fig. 7-38 illustrates an accelerometer design with capacitive temperature compensation and amplification integrated on the same chip. Refs. 12 through 15 provide additional material on this technology and on other types of micromechanical sensors.

7-9 ELECTROCHEMICAL TIMERS

Electrochemical timing devices are simple, small, low-cost items capable of providing delays that are from seconds to months long (Ref. 16). The operation of electrochemical timers is based on Faraday's first two laws of electrolysis. These two laws can be summarized to state that the mass of an element deposited or liberated during an electrochemical reaction is proportional to the electrochemical equivalent of the element, the current, and the time the current flows. When a solution is electrolyzed, the number of electrons received at the anode must equal the number delivered from the cathode. The ions arriving at the cathode are reduced, i.e., they obtain electrons, and those arriving at the anode are oxidized, i.e., they forfeit electrons. Electrochemical systems that use these principles are called coulombmeters.

7-9.1 ELECTROPLATING TIMER WITH ELECTRICAL OUTPUT

The Bissett and Berman E-Cell has been used in several military applications, including arming and self-destruct delays in the Antipersonnel Mine, BLU-54/B (Ref. 17).

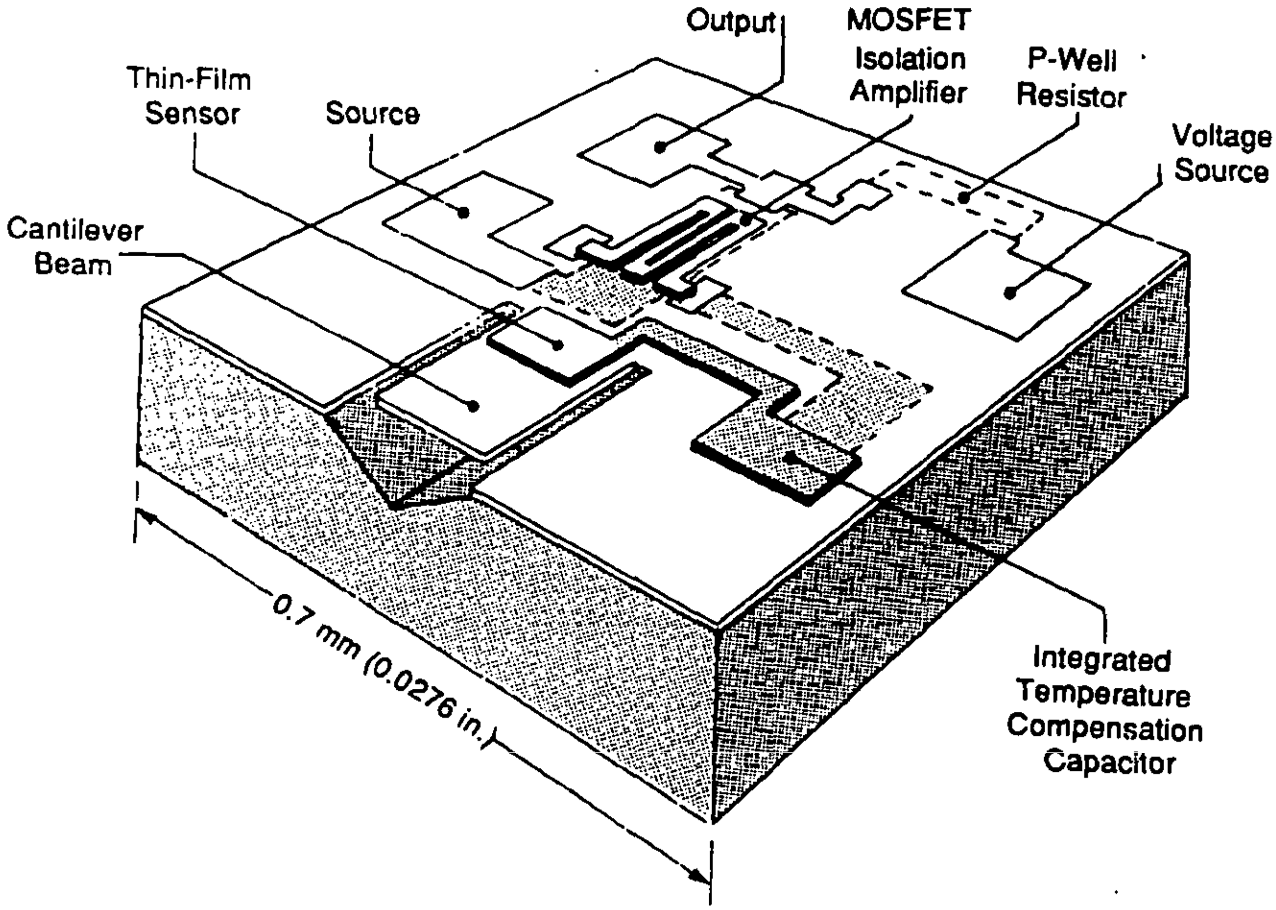


Figure 7-38. Accelerometer Using Micromechanical Technology With Integrated CMOS Circuitry (Ref. 12)

Cell construction is illustrated in Fig. 7-39. The cell consists of a silver case (the reservoir electrode), 6.35 mm (0.25 in.) in diameter and 15.88 mm (0.625 in.) long. The working electrode of gold over base metal is held in place by two plastic disks that function as both seals and electric insulators. The case is filled with electrolyte that contains a silver salt in a weak acid (Ref. 19). Electrical leads complete the cell. Cell mass is about 2.8 g (1.92×10^{-4} slug).

The cell illustrated is a single-anode cell, which permits a single time delay. If more than one delay is desired, several anodes of different sizes may be combined in the same unit (Ref. 20). A dual-anode cell is useful because of the common military requirement for two different time delays. For example, a mine may require an arming delay of a few minutes and a self-sterilization delay of several days.

The system consists of three parts: a source of dc voltage, an electroplating cell in which the constant current causes the metal anode (silver in this design) to be deplated at a known rate, and a detector circuit that senses the progress of the reaction.

During the timing period the voltage across the E-cell is low, as illustrated in Fig. 7-40. Upon completion of anode deplating the voltage rises rapidly and thus indicates the end of the timing interval. One way to detect this voltage rise is to use the simple detector circuit shown in Fig. 7-41. The performance of this circuit can be understood by considering its three phases of operation:

1. While the cell deplates, the run voltage V_R, shown in Fig. 7-40, is below the activation voltage of the transistor. Therefore, since the cell is drawing practically all the current, the equivalent circuit consists of just the cell plus its resistor.

2. During the rapid transition to the high-voltage state, the current level through the cell is reduced as the transistor base starts to take current.

3. While operating at the stop voltage V_s, the cell draws a very small residual current, which in most cases is negligible compared with that drawn by the transistor. Thus the equivalent circuit is essentially the original circuit without the coulombmeter.

Typical voltage-current characteristics at various operating temperatures are shown in Fig. 7-42. Fig. 7-42(A) shows the maximum running (deplating) voltage V_R and current I_R, whereas Fig. 7-42(B) shows the stop voltage V_s

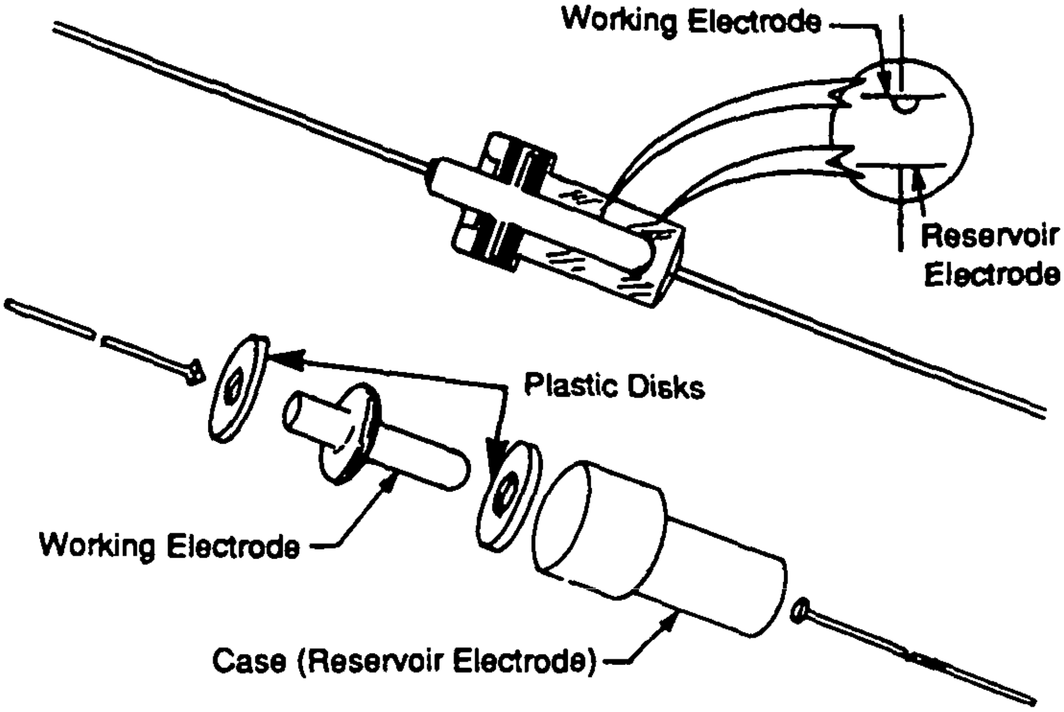


Figure 7-39. Bissett-Berman E-Cell (Ref. 18)

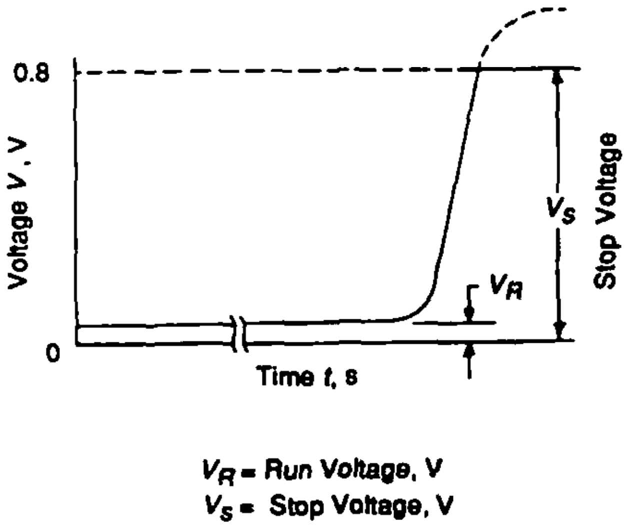


Figure 7-40. Operating Curve of Coulombmeter at Constant Current (Ref. 18)

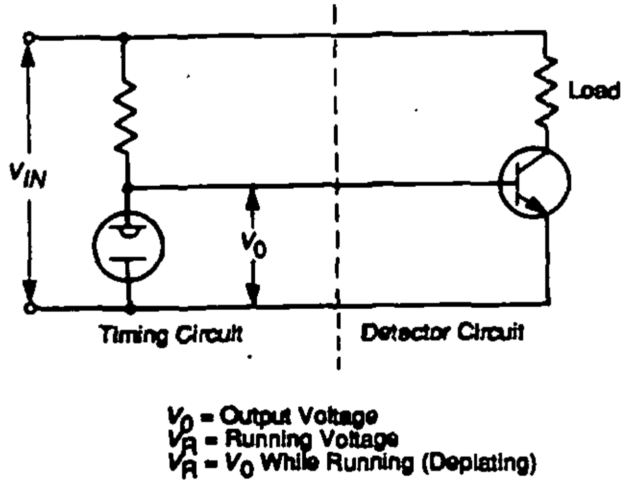


Figure 7-41. Coulombmeter Detector Circuit (Ref. 18)

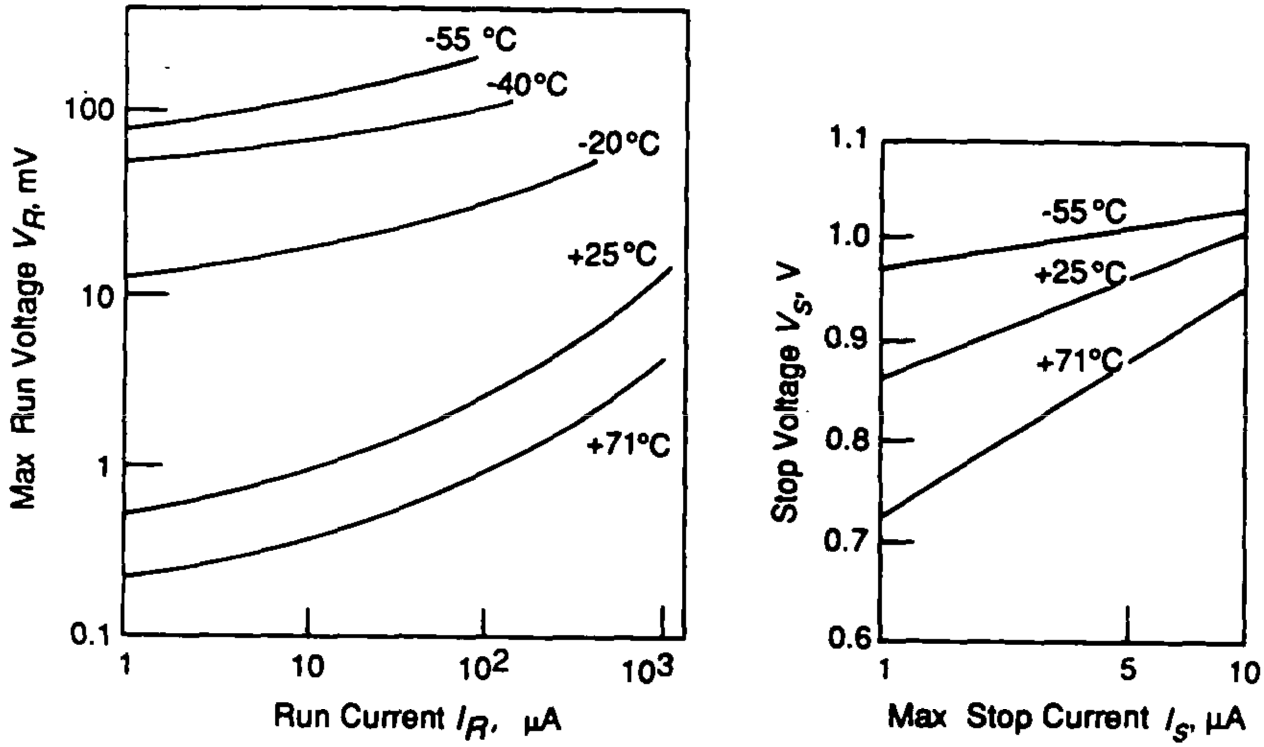
and its associated current. The stop voltage V_s is associated with the activation voltage threshold of the transistor, whereas the stop current I_s is the residual current passing through the cell.

The advantages of an E-cell electrical output coulombmeter are

1. Good accuracy (within ±4%)
2. Good miniaturization
3. Simplicity and inexpensiveness
4. Wide variety of timing intervals
5. Very low power requirements
6. Good shock and vibration resistance
7. Operation over the military temperature range
8. Repeated use (by deplating).

The disadvantages are

1. A power source and detector circuit are required.
2. There is decreased accuracy for short set times after long storage.



(A) During Operation

(B) At Termination

Figure 7-42. Typical E-Cell Coulombmeter Voltage-Current Characteristics (Ref. 18)

7-9.2 ELECTROPLATING TIMER WITH MECHANICAL OUTPUT

The mechanical output timer operates electrochemically in the same manner as the electrical readout E-cell design. At the end of deplating, however, the action is mechanical switching rather than electrical. Fig. 7-43 illustrates the Internal Timer MK 24 Mod 3, which operates on this principle. The timer cell (based on a patented idea (Ref. 21)) consists of a molded polychlorotrifluoroethylene (Kel-F) cup, which holds the anode assembly. After it is filled with an electrolyte of a silver fluoroborate solution, the cup is heat sealed with an end plug, which holds the silver cathode. The anode assembly consists of a silver plunger to which a contact disk is fastened, and the plunger is surrounded by a compression spring and sealed with an O-ring coated with fluorosilicone lubricant. All materials were selected for their chemical compatibility with the electrolyte.

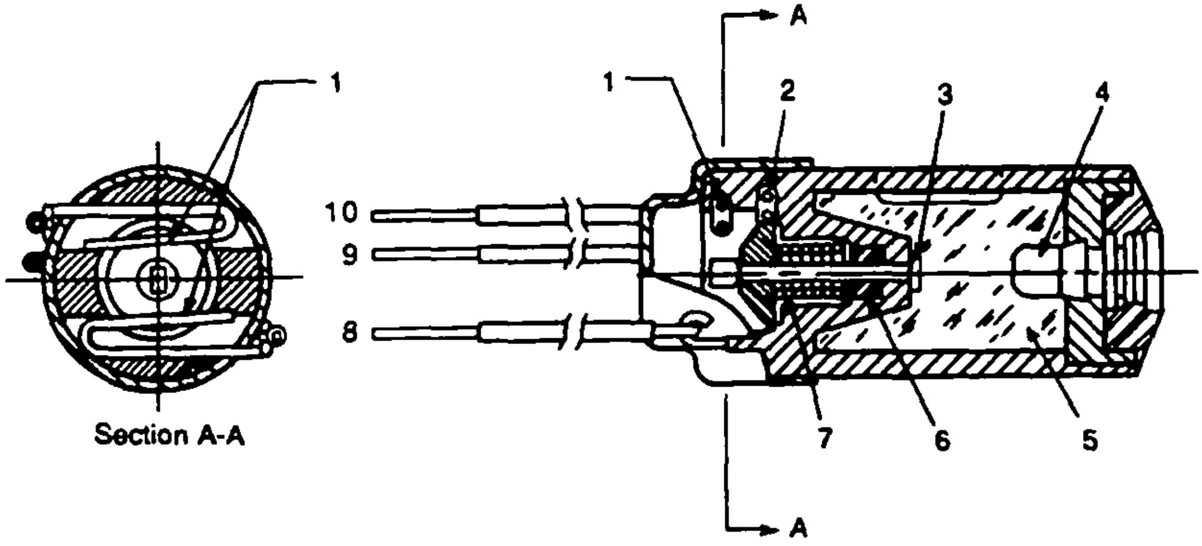
At the end of the timing interval, the anode plunger is pushed to the left. In its new position the contact disk closes a single-pole, single-throw (SPST) switch and opens the anode switch to terminate the deplating action. The contact force at switch closure is 3.6 N (0.800 lb), and contact resistance after switch closure is less than 0.3 Ω.

The timer is 15.88 mm (0.625 in.) in diameter, 41.3 mm (1.625 in.) long, and has a mass of 9 g (6.16×10^{-4} slug). Timer accuracy underwater (the designed-for condition) at −2.22° to 32.22°C (28° to 90°F) is ±5%. Over the entire military temperature range, the accuracy is ±10%. Models have withstood shocks as high as 12,000 g, low- and high-frequency vibrations, cold storage at −62.2°C (−80°F), and temperature-humidity cycling.

7-10 REDUNDANCY AND RELIABILITY TECHNIQUES

Par. 2-3 discussed ways in which reliability can be improved by parallel redundancy and listed a number of standards that address the subject of reliability. To achieve reliability in electronic fuzes, the designer has a number of techniques at his disposal (Ref. 22).

Because of the large number of variables involved, it is not feasible to assess precisely the relative merits of commercial parts versus parts that meet military specifications for any given situation. The designer must select these components based on which are the most technically sound and cost-effective for the design. To achieve this goal, the designer should



1	SPST* Switch Contacts	6	O-Ring Seal
2	Anode Switch	7	Compression Spring
3	Silver Anode	8	Lead From Anode and Second SPST Switch Terminal
4	Silver Cathode	9	Lead From First SPST Switch Terminal
5	Electrolyte	10	Lead From Cathode

* = Single-Pole, Single-Throw

Figure 7-43. Interval Timer MK 24 MOD 3 (Ref. 16)

1. Design for a minimum number of parts without degrading performance.
2. Apply derating techniques.
3. Perform design reliability analyses.
4. Reduce operating temperature by providing heat sinks and good packaging.
5. Eliminate vibration by good isolation and protect against shock, humidity, corrosion, etc.
6. Specify component reliability and burn-in requirements.
7. Specify production quality requirements and system performance tests.
8. Use components whose important properties are known and are reproducible.
9. Use techniques that interrogate fuze operation prior to launch whenever possible.

The quality of the parts used in a system is only one factor in the overall reliability equation, albeit a very significant influence (Ref. 23). The logical starting point in the creation of a reliable system is obviously high-quality parts. There are measures, however, that can compensate, at least partially, when circumstances militate against procurement of parts that fully conform to the most rigorous standards. Such measures include, but are not limited to, more exacting quality assurance provisions at assembly levels during fabrication, and properly designed assembly and end-item level screening and acceptance tests. If these techniques do not sufficiently reduce the component or system failure rate, redundancy, or standby, systems can be used.

The designer of electronic fuzes often must decide whether to use commercial parts or parts that meet military specifications in the electronic design. For example, in high-value weapon systems, the use of higher grade electronic components is mandatory, and the designer must comply or must justify the rationale for his noncompliance. In general, the cost of higher grade discrete components, e.g., resistors, capacitors, and transistors, is not significantly greater than that for commercial grade. The biggest cost differential is in the plastic versus ceramic IC components. For example, a ceramic IC that meets military specifications can cost as much as forty times that of an identical screened plastic IC. Ceramic ICs, however, have the following advantages:

1. The seal is hermetic, so it protects the chip from the deleterious effects of moisture.
2. They are capable of operating at very high temperatures, e.g., 125°C (257°F).
3. They have a lower mean-time-before-failure rate than plastic because of more extensive mechanical and electrical testing.

Disadvantages of military-grade, high-reliability ceramic ICs are

1. The flying leads from chip to lead frame can move and short out under high acceleration.

2. The package material is brittle and can break under high acceleration, potting, and other thermal stresses.

3. The package is costly.

Plastic ICs have the following advantages:

1. The flying leads from chip to lead frame are encapsulated and cannot move and short out under high acceleration.

2. The package material is rigid but not brittle, and it resists breakage under high-shock, potting, and other thermal stresses.

3. The package is inexpensive.

Significant advances in plastic packaging technology and in microcircuit design, directed toward improved reliability without the need for ceramic packs, are constantly being made. It is currently almost impossible to distinguish a difference in reliability between the ceramic-packaged ICs and well-designed plastic-packaged ICs.

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CHAPTER 8
OTHER ARMING DEVICES

Means of obtaining delay arming and/or firing other than the conventional methods of mechanical, electrical, and pyrotechnic are discussed in this chapter. The general characteristics of the systems addressed are simplicity and wide tolerances in timing. A wide tolerance in timing is quite restricting on fuze application. The field covers the use of fluid dynamics, pseudofluids, chemical reactions (other than pyrotechnic), pneumatic dashpots, and plastic deformation.

The fluid field is broken into two categories, fluid flow with moving mechanical parts (pneumatics and hydraulics) and fluid flow with no moving parts other than interacting streams of pressurized gas. A comparison is made between these systems and more conventional mechanical and electrical methods. The limitations are explained, such as difficulty in miniaturizing and the usual necessity of supplying high-pressure gas. Fluid systems differ somewhat from the other nonconventional systems in that more accuracy in timing is possible, but it is at the expense of packaging and cost.

The use of liquid annular-orifice dashpots (LAODs) and pneumatic annular-orifice dashpots (PAODs) for fuze arming and delay functioning is covered.

A unique system of moving a silicone grease from one position to another while sealed in a plastic envelope is described as a delay arming timer currently used in a spinning grenade fuze.

The empirical field of pseudofluids, i.e., tiny glass beads, moving past a restriction is described along with their uses in low-acceleration missiles and rockets. Methods of preventing stickiness from moisture and static charge are discussed.

Two delay systems that saw service and field use in World War (WW) II—a chemical solvent and plastic member system, and a lead shear wire or plastic deformation system—are discussed. Their shortcomings in timing tolerances associated with the military temperature environments are emphasized.

8-0 LIST OF SYMBOLS

B = length of the piston, m (in.)
g = acceleration due to gravity, m/s^2 (ft/s^2)
h = radial clearance, m (in.)
K = orientation factor, dimensionless
L = length of travel, m (in.)
P_1 = pressure beneath piston inside the cylinder, Pa (lb/in.^{2})
P_2 = ambient pressure, Pa (lb/in.^{2})
R_c = radius of cylinder, m (in.)
R_p = radius of piston, m (in.)
t = desired time delay, s
μ = viscosity of air, Pa·s (lb·s/in.^{2})

8-1 INTRODUCTION

Although mechanical and electrical approaches—discussed in Chapters 6 and 7—are the most widely used techniques for fuze arming, other methods can be used. These other methods include fluid, pseudofluid, chemical, pneumatic, and plastic deformation devices. These techniques have been applied to functioning delays as well as to arming delays. However, with the exception of fluid devices, the techniques are useful only where liberal functioning and arming time tolerances are acceptable.

8-2 FLUID DEVICES

In general, fluid-operated devices can be used to transfer motion with an amplified force or displacement, provide arming or functioning delays, and program events for complex devices. The field of fluid mechanics is large and complex but well covered in standard texts (Refs. 1 and 2).

8-2.1 FLUID FLOW

Matter is fluid if the force necessary to deform it approaches zero as the velocity of deformation approaches zero. Both liquids and gases are classified as fluids. Their distinguishing characteristic concerns the difference in cohesive forces. Gases are compressible and expand to fill any volume; liquids are generally incompressible and coalesce into the lower regions of the volume with a free surface as their upper boundary. In addition to true fluids, there are certain materials, such as tiny glass beads or greases and pastes, which although technically not fluids, behave very much like fluids. These pseudofluids are frequently useful in particular circumstances.

8-2.2 FLUERICS

8-2.2.1 Fluidic and Flueric Systems

Two specific terms are employed when the use of fluids in fuzing is discussed:

1. *Fluidics*. The general field of fluid devices and systems with their associated peripheral equipment used to perform sensing, logic, amplification, and control functions
2. *Fluerics*. The area within the field of fluidics in which components and systems perform sensing, logic, amplification, and control functions without the use of any moving parts.

The terminology, symbols, and schematics used with flueric systems are contained in MIL-STD-1306 (Ref. 3).

Flueric technology once was envisioned as a complement to the conventional techniques of arming and sensing. Although the fuze safety and arming (S&A) control and sensing functions now performed by mechanical and electronic techniques also can be performed by flueric systems, interest in these systems has waned because of their cost and size constraints. The basic principles and limitations of flueric technology in fuzing and some of the electronic analogues that can be performed by flueric systems are described in the paragraph that follows.

8-2.2.2 Flueric Components Used for Arming

In a typical electronic fuze timer the fundamental components are an oscillator and a binary counter. A flueric timing system can be built up in the same manner. In a present flueric timer, the oscillator consists of a proportional fluid amplifier with modified sonic feedback loops coupled to a digital fluid amplifier. Fig. 8-1 is a diagram of the amplifiers. The digital amplifier, as with many flueric devices, depends upon entrainment, a situation in which a stream of fluid flowing close to a surface tends to deflect toward that surface and under the proper conditions touches and attaches to that surface. The attachment of the stream to the surface is known as the Coanda effect. The proportional amplifier uses the principle of jet momentum interaction, i.e., one stream is deflected by another.

The digital amplifier illustrated in Fig. 8-1(A) consists of a fluid power supply S, two control ports C_A and C_B, two attachment walls W_A and W_B, and two output ports O_A and O_B. The output ports serve as conduits for directing fluid pulses to the succeeding element in the fluid circuit. In this device a gas supply S of constant pressure is provided to form a jet stream through nozzle N. The jet stream entrains fluid from the space between the stream and the wall, and thereby lowers the pressure. The higher atmospheric pressure forces the stream against the wall. The geometric configuration of the fluid amplifier can be constructed so that the jet stream always attaches itself to one preferred wall. This is accomplished by placing the preferred wall at a smaller angle to the centerline of the flow of the jet stream than the nonpreferred wall.

Fig. 8-1(A) shows a jet stream attached to wall W_B and an output jet stream from output conduit O_B. If an output jet stream from conduit O_A is desired, a jet stream to control conduit C_B will cause the main jet stream to become detached from wall W_B. Entrainment on the opposite side will cause the jet to switch and become attached to wall W_A. The physical relationship that occurs during the switching functions is a momentum interaction between the control jet stream at C_B and the main jet stream at right angles to each other's direction of flow. The fluid amplifier is properly called an amplifier because the switching of the main jet stream having high momentum can be accomplished by a control jet stream having relatively low momentum. The ratio of momenta, or gain, of an amplifier can be as high as 20 or more, depending on design requirements. The higher the gain, the less stable the attachment of the jet stream to the attachment wall.

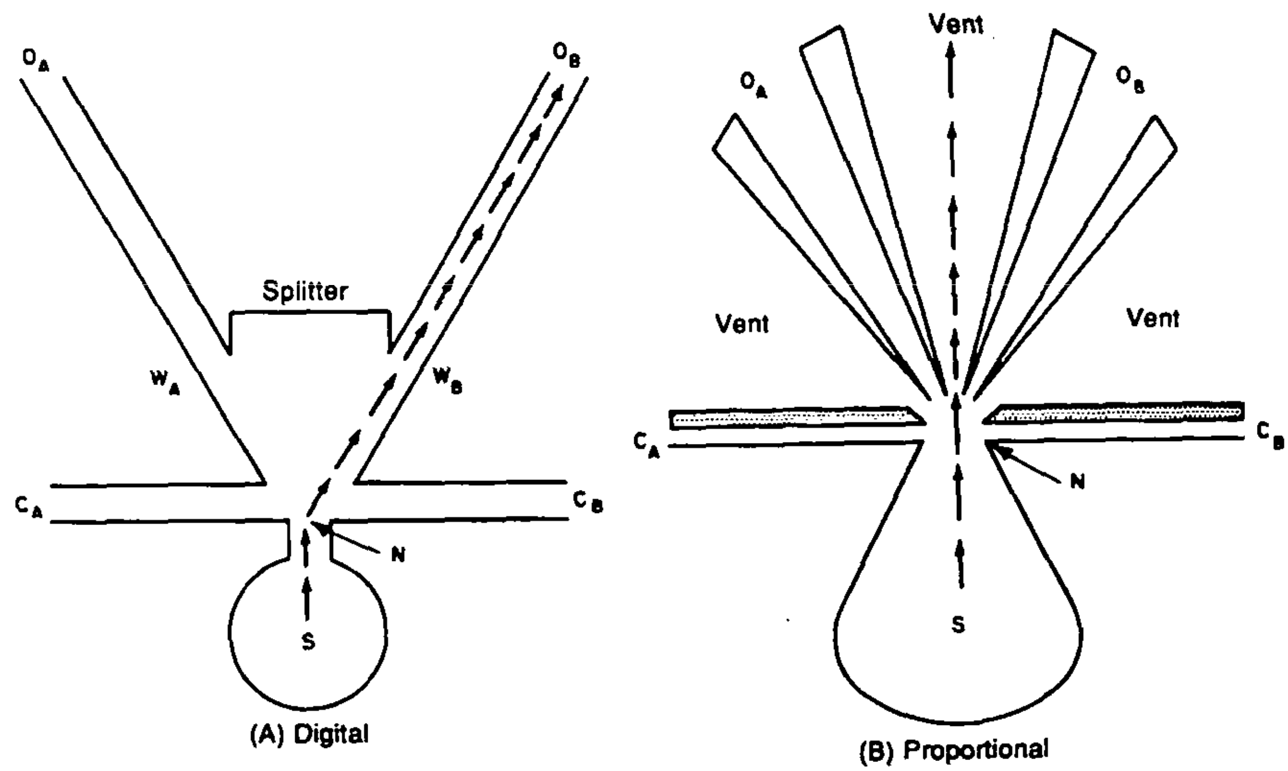

Figure 8-1. Schematic of Flueric Amplifiers (Ref. 4)

The proportional fluid amplifier shown in Fig. 8-1(B) has no attachment walls. The main jet stream flows in a symmetrical pattern through the nozzle to the vent when there is no control jet stream in either conduit C_A or C_B. When a jet stream is applied at C_B, the main jet stream is deflected toward output conduit O_A at an angle proportional to the momentum of the control jet stream C_B. The output jet stream through conduit O_A is proportional to the deflection of the main jet stream. Similarly, an output jet stream in conduit O_B is caused by a control jet stream in conduit C_A.

A fluid oscillator can consist of a fluid circuit using digital and proportional fluid amplifiers to produce an accurate time base to control fuze arming and/or functioning times. This oscillator, which uses a resistance-capacitance-resistance (R-C-R) feedback network, exhibits frequency variations of less than ±1% over the temperature range of −54°C to 71°C (−65° to 160°F) and for pressure variations from 14.27×10^4 to 22.5×10^4 Pa (20.7 to 32.7 psi) (Ref. 4).

The binary counter, or frequency divider, for the timer can be built up from a number of flip-flop stages. A complete counter stage is shown in Fig. 8-2. Ports $P_{A(W)}$ and $P_{B(W)}$ are used after the oscillator. The outputs from the oscillator are connected to control ports $I_{A(B)}$ and $I_{B(B)}$ of the buffer amplifier. This connection causes the main jet stream of the buffer amplifier to switch back and forth between its two attachment walls at the same frequency as the oscillator. One output of the buffer amplifier is vented so that pulses are supplied to input I_W of the Warren loop at half the frequency of the oscillator. Outputs $O_{A(W)}$ and $O_{B(W)}$ of the jet stream of the counter are connected to the two control ports of the buffer amplifier of the second stage in the same manner as the outputs of the oscillator are connected to the first stage. The second stage is connected to the third stage in the same way, and so on, until the last stage.

The counter operates in the following manner: A jet stream supplied by pressurized gas from supply S_W is caused to flow through the orifice and attaches itself to one of the walls. Fig. 8-2 shows the stream attached to wall $W_{A(W)}$ after being switched by the buffer amplifier signal applied at input I_W. When the buffer amplifier signal is removed, a partial vacuum forms at the attachment wall $W_{A(W)}$ according to Bernoulli's principle and causes an entrainment flow of gas from the control port of the wall $W_{A(W)}$ to proceed around the Warren loop in a clockwise direction. When a signal from the buffer amplifier is reapplied at I_W, it follows the preferred direction setup in the Warren loop (clockwise) and causes the main stream to switch to $O_{B(W)}$. When the buffer amplifier signal is removed, the entrainment flow in the Warren loop reverses to a counterclockwise direction. The buffer amplifier signal, when reapplied, is directed around the Warren loop in a counterclockwise direction and switches the main stream back to $O_{A(W)}$, as shown in Fig. 8-2.

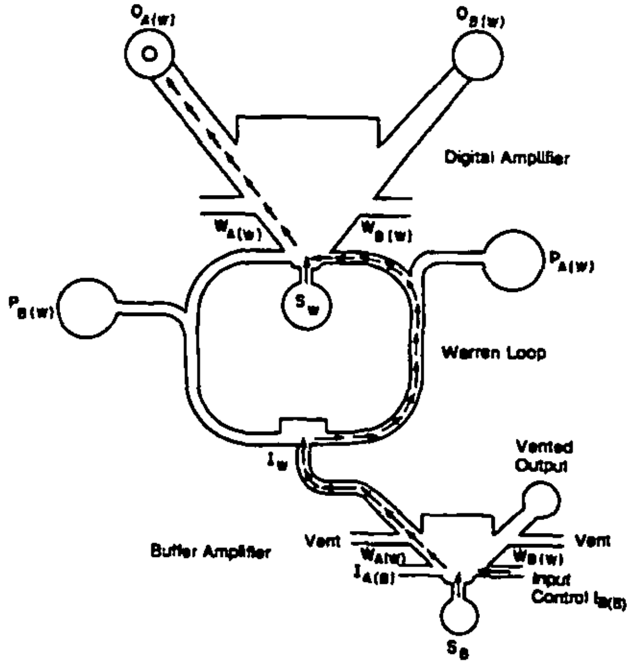

Figure 8-2. Schematic of Flueric Counter Stage (Ref. 4)

Each counter stage receives pulses at a specific frequency, divides that frequency by two, and provides pulses at this reduced frequency to the next counter stage, which in turn repeats the operation. For example, the first counter stage receives an input of 640 pulses per second from the oscillator and divides this frequency by two. The division produces an output of 320 pulses per second, which are provided as input to the second stage of the counter. The second stage similarly provides pulses to the third stage at a frequency of 160 pulses per second, and so on.

8-2.2.3 Flueric System Limitations

The size limitations that fuze arming devices place upon the designer create a problem with supplying power for flueric systems. To drive a flueric system, there must be a fluid reservoir of sufficient size to deliver the proper amount of fluid for the desired period of time. Most of the present thinking has resulted in the use of self-contained, pressurized gas bottles. If times are short and space is not critical, gas bottles are a valid solution. If times are longer and space problems are critical, small volumes must be used with the fluid at high pressure. Since operating pressures for typical miniature flueric devices are 3.45×10^3 to 138×10^3 Pa (0.5 to 20 psi), rather sophisticated pressure-regulating equipment is required.

8-2.3 PNEUMATIC AND FLUID TIMERS

The fuzing functions of safing, arming, initiation, and self-destruct historically have been accomplished by such timing devices as pyrotechnics, chemical reactions, escapements, and electronics. Timers operating on the principles of fluid dynamics have added a new class of timing mechanism that, if tolerances are not critical, can be used for a fraction of the cost of conventional timing devices. Design and application data on several pneumatic and high-viscosity timers are provided in the paragraphs that follow. References are provided for additional devices that have been proposed for fuze applications.

8-2.3.1 Pneumatic Annular-Orifice Dashpot (PAOD)

The PAOD, shown in Fig. 8-3, consists of a piston in a cylinder held to extremely small clearance tolerances and using air as the fluid. These devices are capable of timing in the range of 0.01 s to 3 min with an accuracy of approximately 10% over a temperature range of −54° to 71°C (−65° to 160°F).

The equation for desired time delay t for a PAOD is

$$t = \frac{KR_cLBP_1\mu}{h^3(P_1^2 - P_2^2)}, \text{ s} \qquad (8\text{-}1)$$

where

h = radial clearance, m (in.)
K = orientation factor, dimensionless
μ = viscosity of air, Pa·s (lb·s/in.^{2})
R_c = radius of cylinder, m (in.)
L = length of travel, m (in.)
B = length of the piston, m (in.)
P_1 = pressure beneath piston inside the cylinder, Pa (lb/in.^{2})
P_2 = ambient pressure, Pa (lb/in.^{2}).

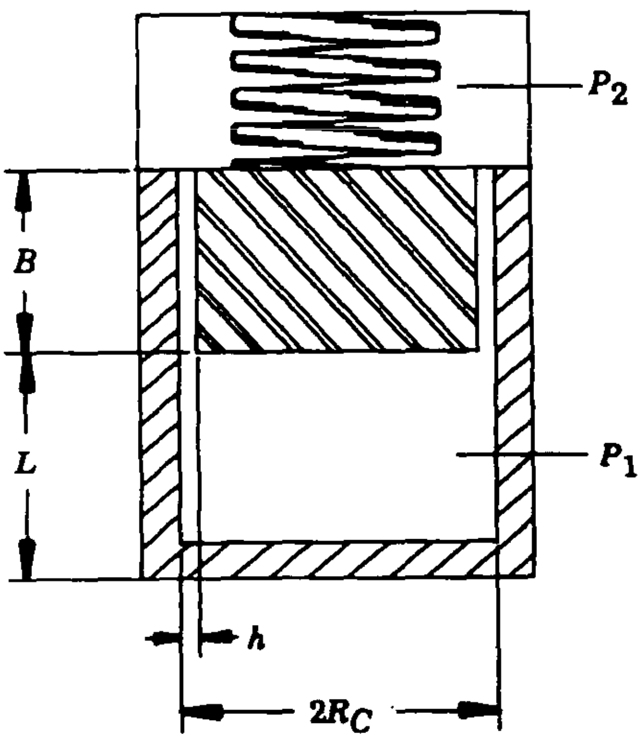

Figure 8-3. Pneumatic Annular-Orifice Dashpot (Ref. 5)

The orientation factor K is a constant that depends on the relative orientation of the piston in the cylinder. K is equal to 4.8 when the piston travels down the side of the cylinder. It is equal to 12 when the piston travels in the center of the cylinder and becomes greater than 12 when the piston is cocked inside the cylinder.

Eq. 8-1 shows that the time delay is a function of the cube of the radial clearance. Therefore, a small change in clearance causes a significant change in the time delay. Fortunately, present manufacturing technology, by using a shrinking technique on a precision mandrel, can produce low-cost glass cylinders with out-of-round conditions of less than 0.635×10^{-3} mm (2.5×10^{-5} in.). Pistons can also be held to this tolerance by centerless grinding and microstoning. For tighter timing tolerances selective assembly of mating parts is required. Timing variations due to the changes in the air viscosity (increases 45% when temperature goes from −54° to 71°C (−65° to 160°F) can be compensated for by using different glass compositions having different coefficients of thermal expansion, which cause the clearance between the piston and cylinder to increase with increasing temperature.

Fig. 8-4 shows a PAOD used in the XM431 rocket fuze. Prior to launch, the piston assembly 1 (Fig. 8-4(A)) maintains the slider assembly 2 with a detonator 3 in an out-of-line position. On launch, setback forces cause the setback weight 9 to move rearward and compress the setback weight spring 10 (Fig. 8-4(B)). This action permits the piston spring 7 to act against the piston assembly to initiate a timed rearward traverse of the piston. The rate of traverse of the piston through the cylinder 8 depends on the clearance between the piston and cylinder as air entrapped behind the piston bleeds through the annular orifice (Fig. 8-4(B)). As the piston moves rearward, the piston plug is gradually withdrawn from the hole in the detonator slider assembly. After a predetermined time interval, the end of the piston plug clears the hole in the slider and allows the slider spring 4 to force the detonator slider assembly 3 in line with the firing train lead 6. The fuze is now in an armed condition (Fig. 8-4(C)). On impact the nose of the fuze is crushed against the firing pin 5; the pin is driven into the detonator and initiates the firing train, which consists of the detonator, the lead, and the booster 11.

This particular PAOD, used as an approximate double integrator of acceleration, yielded an arming distance that was constant within 6.1 m (20 ft) over an acceleration range of 25 to 50 g.

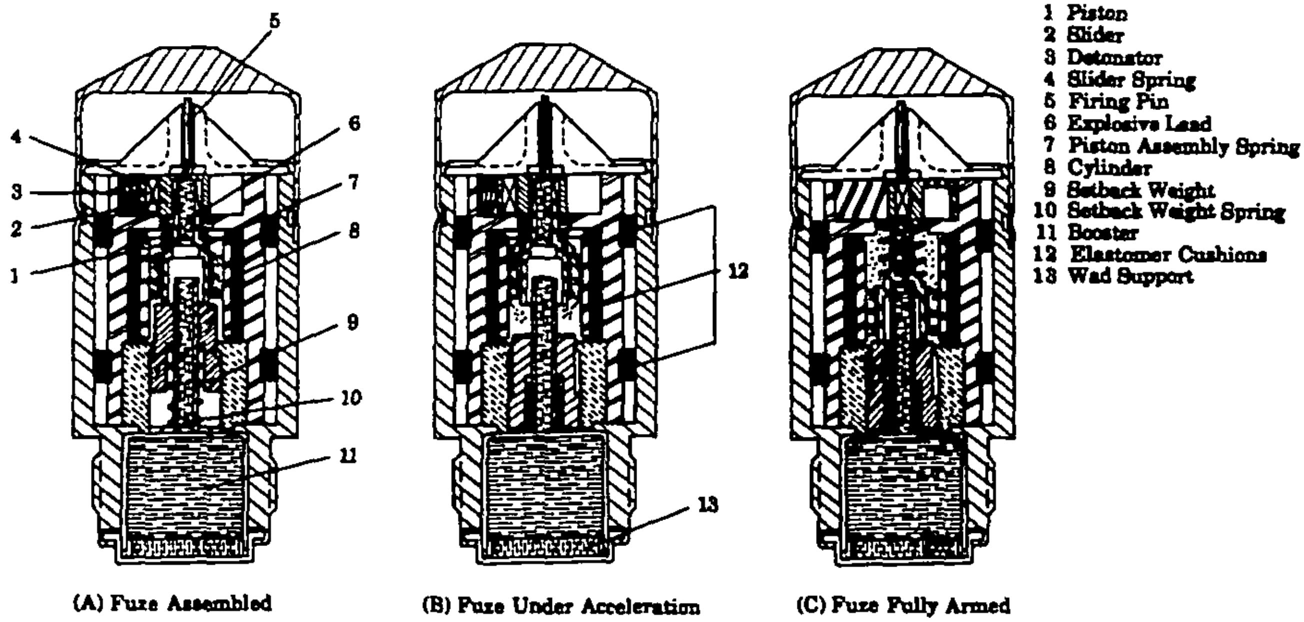

Figure 8-4. Fuze, Rocket, XM431 With Pneumatic Annular-Orifice Dashpot (Ref. 5)

Additional reference material on PAOD designs can be found in Refs. 6, 7, and 8.

8-2.3.2 Internal Bleed Dashpot

Par. 1-8.1 discussed the operation of the M758 fuze used with the 25-mm (1-in.) automatic cannon BUSHMASTER gun. Delayed arming in this fuze is achieved by an internal bleed dashpot shown in Fig. 8-5. Before firing, air is entrapped in Volume A below the out-of-line disk rotor (Fig. 8-5(A)). During setback the rotor and firing pin assemblies are displaced rearward forcing the air from Volume A to Volume B (Fig. 8-5(B)). Centrifugal force acting on the O-ring presses the plastic cup against the surface at C and creates a seal between Volume B and the rest of the internal volume. Motion of the conical, spring-driven seal and firing pin assembly is now governed by the rate of air metered through a porous sintered metal disk D. Fuze arming occurs when the firing pin is fully extracted from the rotor, and the rotor, under centrifugal force, assumes a position of dynamic equilibrium and aligns the explosive train (Fig. 8-5(C)). A delayed arming distance of 10 to 100 m (32.8 to 328 ft) is achieved by this technique and represents the tolerance for the system.

8-2.3.3 External Bleed Dashpot

Pneumatic delays can be accomplished through the use of an air-bleed dashpot device that restricts the flow of air from the outside atmosphere. One such design is illustrated in Fig. 8-6. In the M717 mortar fuze the slider is held in the out-of-line position by a bore rider pin, which is locked in place by a setback pin. On launch the setback pin moves rearward and releases the bore rider pin, which is ejected at muzzle exit, and frees the slider. Motion of the spring-driven slider is restricted by the vacuum behind the slider and by the rate of the flow of air through a porous sintered Monel alloy restrictor. An O-ring is mounted on the slider to maintain the vacuum. The vacuum is relieved gradually by the restrictor. A plastic disc covered with pressure-sensitive tape protects the restrictor during transportation and storage. A delay from 1.5 to 6 s was achieved by this external bleed dashpot (Ref. 10).

8-2.3.4 Liquid Annular-Orifice Dashpot

Liquid annular-orifice dashpots (LAOD) have been used in fuzes as inexpensive, miniature, mass-producible, and rugged timing devices for arming, firing, and self-destruct functions. Specific designs have been developed with timing cycles of 30 min to 1.5 months for applications in which precise timing is not required.

A two-stage LAOD timer that features a housing with two discrete diameters is illustrated in Fig. 8-7. The device functions as follows: A piston, driven by an external force, i.e., setback, spin, or spring, penetrates the rupture film and contacts the surface of the ball. Continued force causes the ball to move through the fluid at a rate governed by the fluid viscosity, applied force on the piston, and annular clearances between the ball and the cylinder. Initial ball travel through the larger diameter can satisfy short-time parameters, such as an arming cycle. Subsequent motion of the ball is slower, and longer duration functions, such as self-destruct, can be achieved. Fig. 8-8 illustrates interrelationships between fluid dynamic viscosity and annular clear-

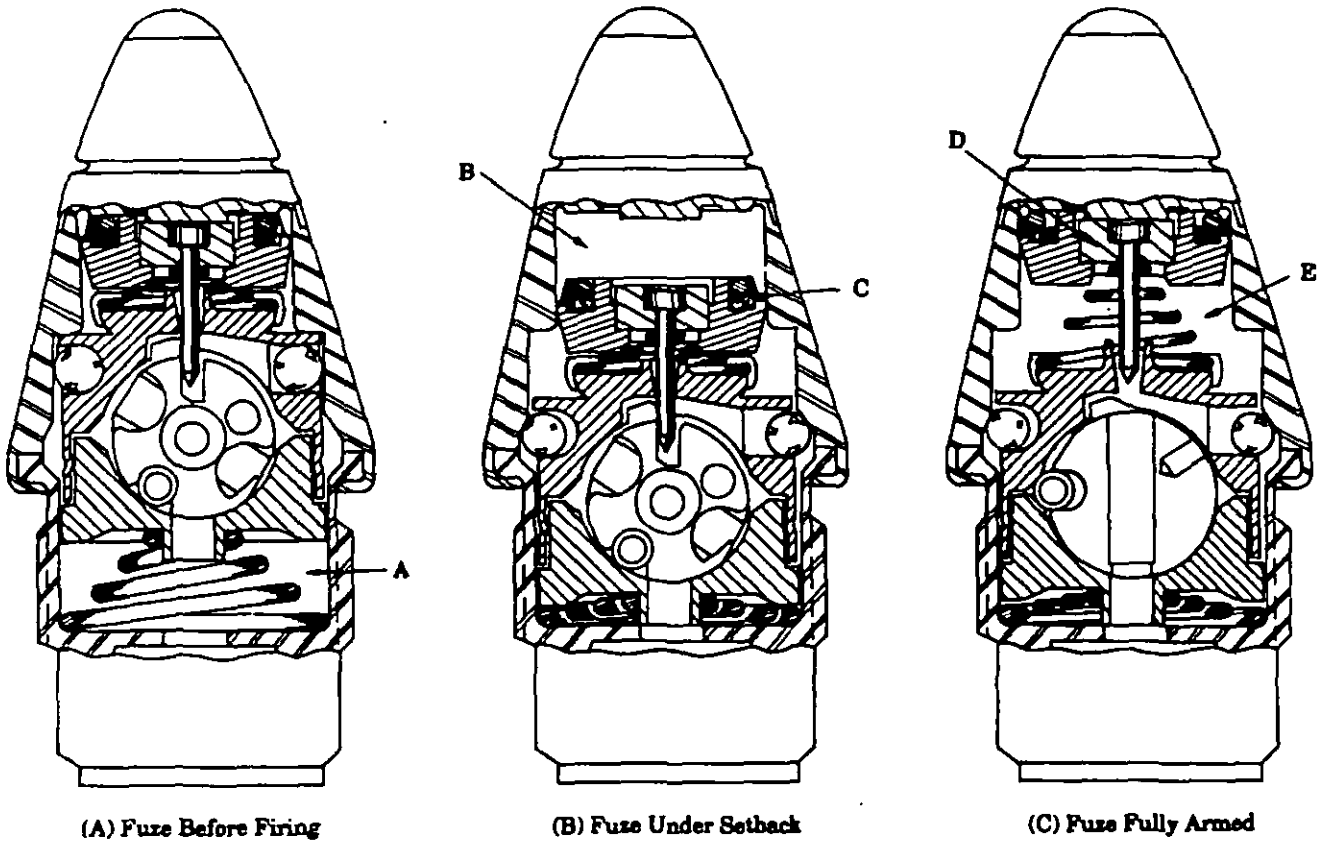

Figure 8-5. Internal Bleed Dashpot Design, Fuze M758 (Ref. 9)

ance for dashpots in the minute range. Fig. 8-9 presents guidelines for higher viscosity fluids used in the hour time range. Fig. 8-10 illustrates the effects of temperature variations on a family of dashpots that has a 10.0-Pa·s fluid and clearances ranging from 4.83×10^{-3} to 6.35×10^{-3} mm (1.90×10^{-4} to 2.50×10^{-4} in.).

The basic equation for computing the desired time delay for an LAOD with a given mean radial clearance for a cylindrical piston is (Ref. 12)

$$t = \frac{KR_pLB\mu}{h^3(P_1 - P_2)}, \text{s} \qquad (8\text{-}2)$$

where

R_p = radius of piston, m (in.).

The orientation factor K is a constant that depends on the relative orientation of the piston in the cylinder. K is equal to 4.8 when the piston travels down the side of the cylinder. It is equal to 12 when the piston travels in the center of the cylinder and becomes greater than 12 when the piston is cocked inside the cylinder.

The material used in the piston of a LAOD must have a significantly higher coefficient of expansion than the cylinder. For this reason, a metallic piston must be used in many applications. Because the viscosity of most liquids changes greatly over the temperature range of −54° to 71°C (−65° to 160°F), it is more difficult to compensate for this viscosity change in a LAOD. Silicone fluids are generally used because their viscosities vary less than most other fluids. However, even with these fluids and with ideal choice of materials, the time delay will still vary approximately 10 to 20% over the temperature range. Refs. 5, 13, and 14 contain additional information on LAOD and PAOD devices.

8-2.4 DELAY BY FLUIDS OF HIGH VISCOSITY

8-2.4.1 Silicone Grease

The viscosity of silicone greases and gums offers resistance to motion. The temperature viscosity curve of silicone grease is flatter than the curves of other oils and greases. Use of this substance was attempted to provide time delay; however, the leakage problem was severe, and the grease gummed up the arming mechanism and rendered it useless. This problem was overcome in the M218 and M224 grenade fuzes by sealing a silicone gum in a plastic sack made of heat-sealable Mylar® tape. These fuzes provide safing, arming, and functioning for a number of grenades and bomblets. Arming occurs when a specified spin rate is

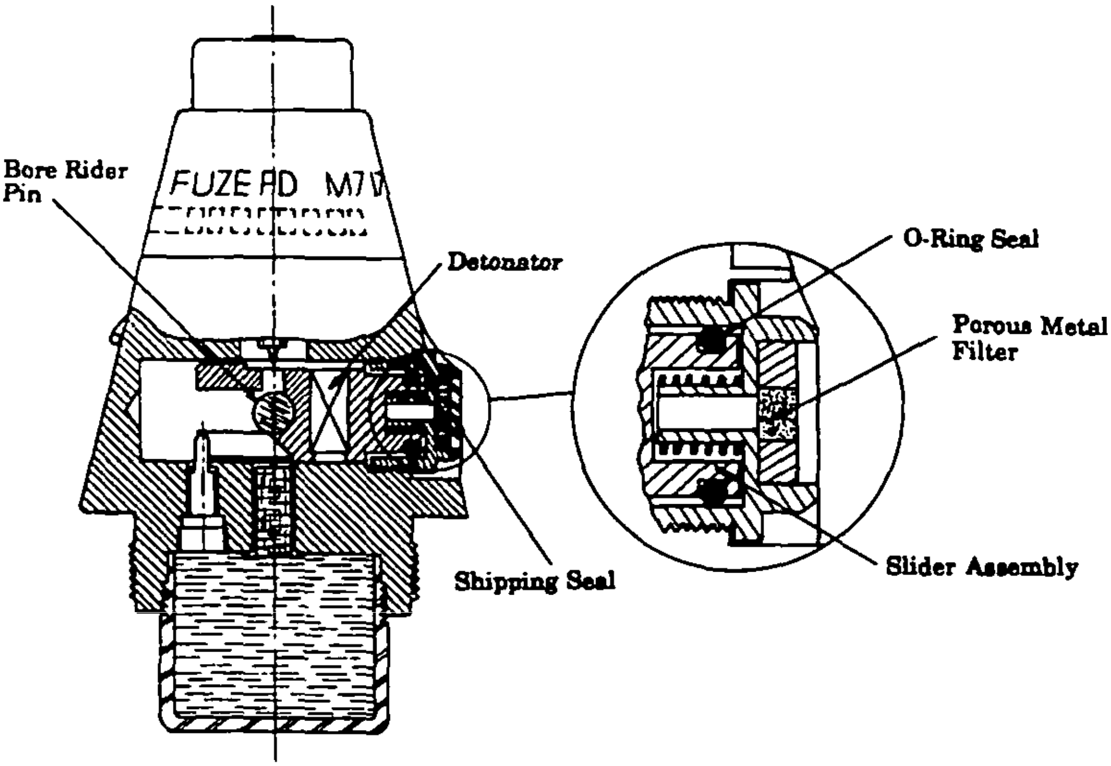

Figure 8-6. External Bleed Dashpot Used in Fuze M717 (Ref. 9)

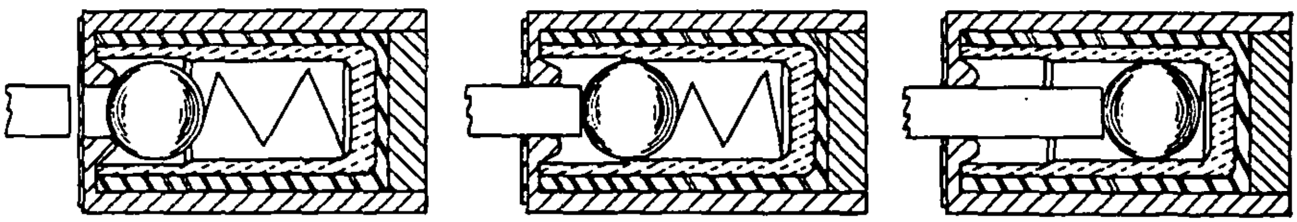

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Figure 8-7. Two-Stage Liquid Annular-Orifice Dashpot (LAOD) Timer (Ref. 11)

achieved by the descending grenade. At the point of arming, centrifugal forces disengage four lock weights to permit a spring-powered detonator rotor to turn 90 deg to the armed position in order to release the delay assembly.

Fig. 8-11 shows the sack and rotor delay mechanism of the M218 grenade fuze (Ref. 15). The sack assembly consists of a metal backing disk and a plastic capsule, about 19 mm (0.75 in.) in diameter and 3.18 mm (0.125 in.) thick, containing silicone grease. The periphery and a segment of the plastic disk are heat sealed to the metal disk to form a pocket for the delay fluid. The sack assembly is placed against the delay rotor assembly. (The space between the two assemblies in Fig. 8-11 was introduced solely to show the sack assembly clearly.) In operation the delay is obtained when the four blades of the delay rotor slide over the surface of the fluid sack by virtue of a torsion spring, and thus displace and meter the fluid from one side of each blade to the other. After rotation of the delay rotor, a firing pin is released to initiate the explosive train. The design described was obtained by empirical means. The analysis is complex because the flow in the fluid sack passages varies as a function of rotor radius. Analytical techniques relating to the interactions of timer geometry, silicone fluid properties, and friction levels are not available.

8-2.4.2 Pseudofluids

Because small glass beads flow similarly to a fluid, their use has been investigated for arming delays and safety

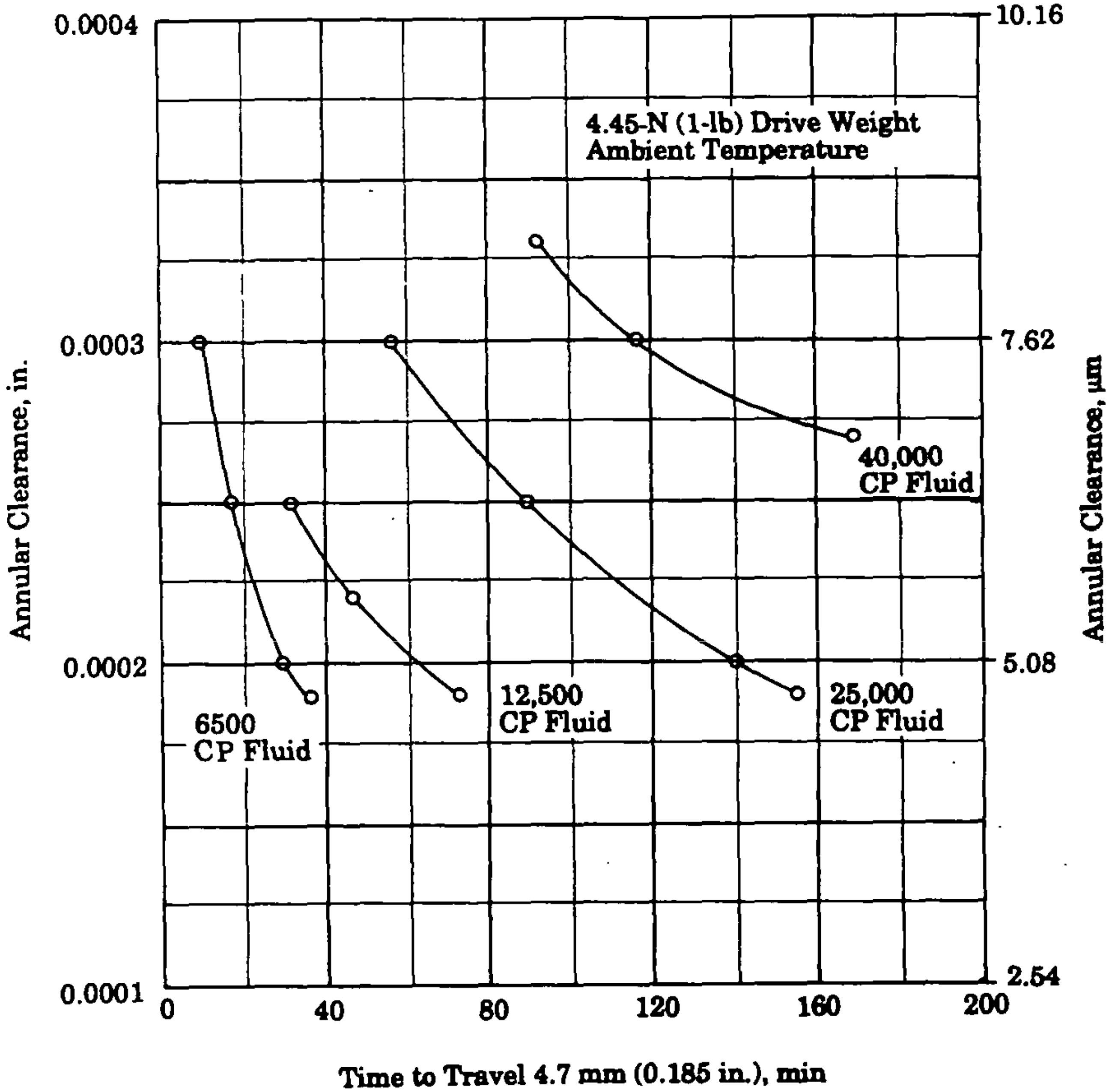


Figure 8-8. LAOD Performance as a Function of Low Viscosity-Clearance Relationship (Ref. 11)

detents in fuzes and safety and arming devices (SADs) (Refs. 16 through 19). Motion of a piston caused by acceleration is regulated by the flow of beads through an orifice. Either a central hole or the annular space surrounding the piston can serve as that orifice.

Glass beads have the advantage of being much less temperature dependent in operation than true fluids. Glass bead delay mechanisms have been successfully tested in mortar fuzes with launch accelerations from 500 to 10,000 *g*. Other glass bead safety switches have been used in missiles and rockets under accelerations from 10 to 50 *g*.

Factors that affect the performance of glass bead accelerometers include

1. Orifice, piston, and container configurations
2. Bead size and material
3. Bead shape
4. Moisture content
5. Surface lubrication
6. Electrostatic charge.

No design parameters have been established for the size relation of orifice, piston, and container; past designs have been empirical. Beads approximately 0.127 mm (0.005 in.)

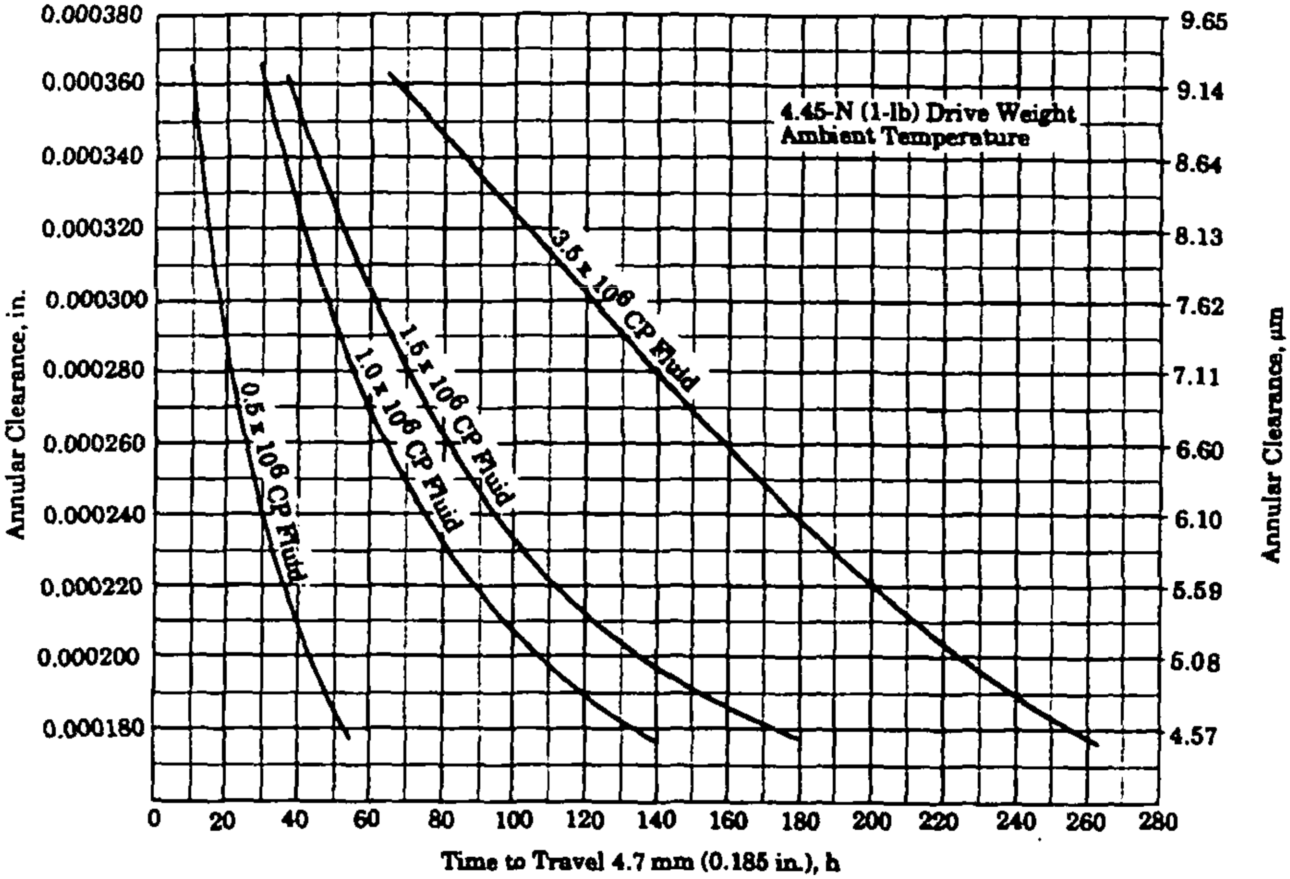


Figure 8-9. LAOD Performance as a Function of Viscosity-Clearance Relationship (Ref. 11)

in diameter formed from crown-barium glass have been used in these devices. It is critical that beads are near-perfect spheres. If they are not, they tend to interlock. Preconditioning of parts and controlled-atmosphere assembly areas are required to exclude moisture, which causes sticking. Properly applied dry surface lubricants, such as molybdenum disulphide, improve performance. At low *g* values static electricity causes problems. Static electricity generated by the beads rubbing together tends to make the beads stick and impede flow. Silver plating the glass beads materially improves the dissipation of static charges.

8-3 CHEMICAL ARMING DEVICES

Chemical reactions are used to provide heat, to dissolve obstructors, or to activate electrical batteries.

Some bombs used during World War II used a chemical long-delay fuze. One form contained a liquid that dissolved a soluble washer in order to release a firing pin. The liquid was kept in a glass vial that broke on bomb impact to activate the system. Fig. 8-12 illustrates a system in which a plastic collar is dissolved by acetone so that the firing pin will slip through and strike the detonator.

This delay is relatively simple to build, but the time interval is not consistent because the rate of reaction is so heavily dependent upon ambient temperature. Further, if the solution is stirred or agitated, the reaction rate increases, and if the original concentration varies, the reaction rates vary accordingly.

8-4 DELAY BY SHEARING A LEAD ALLOY

The soft metal alloys of lead, such as tin and lead solders, have been used as a low-cost nonprecision delay by employing a shearing or cutting action from spring loading.

Two applications are (1) an arming delay in a boobytrap or land mine that allows personnel to leave the area after installation and prior to the arming of the charges, as shown in Fig. 8-13(A), and (2) a firing delay in a bomb tail fuze, illustrated in Fig. 8-13(B), to delay firing over a range of one-third of an hour to 7 days to provide area denial for such periods.

Any arrangement that causes the alloy to flow or displace slowly will suffice. The most convenient is the shearing of a wire of round cross section. The cutting of a bar or wire by a knife edge is equally satisfactory and nearly as simple.

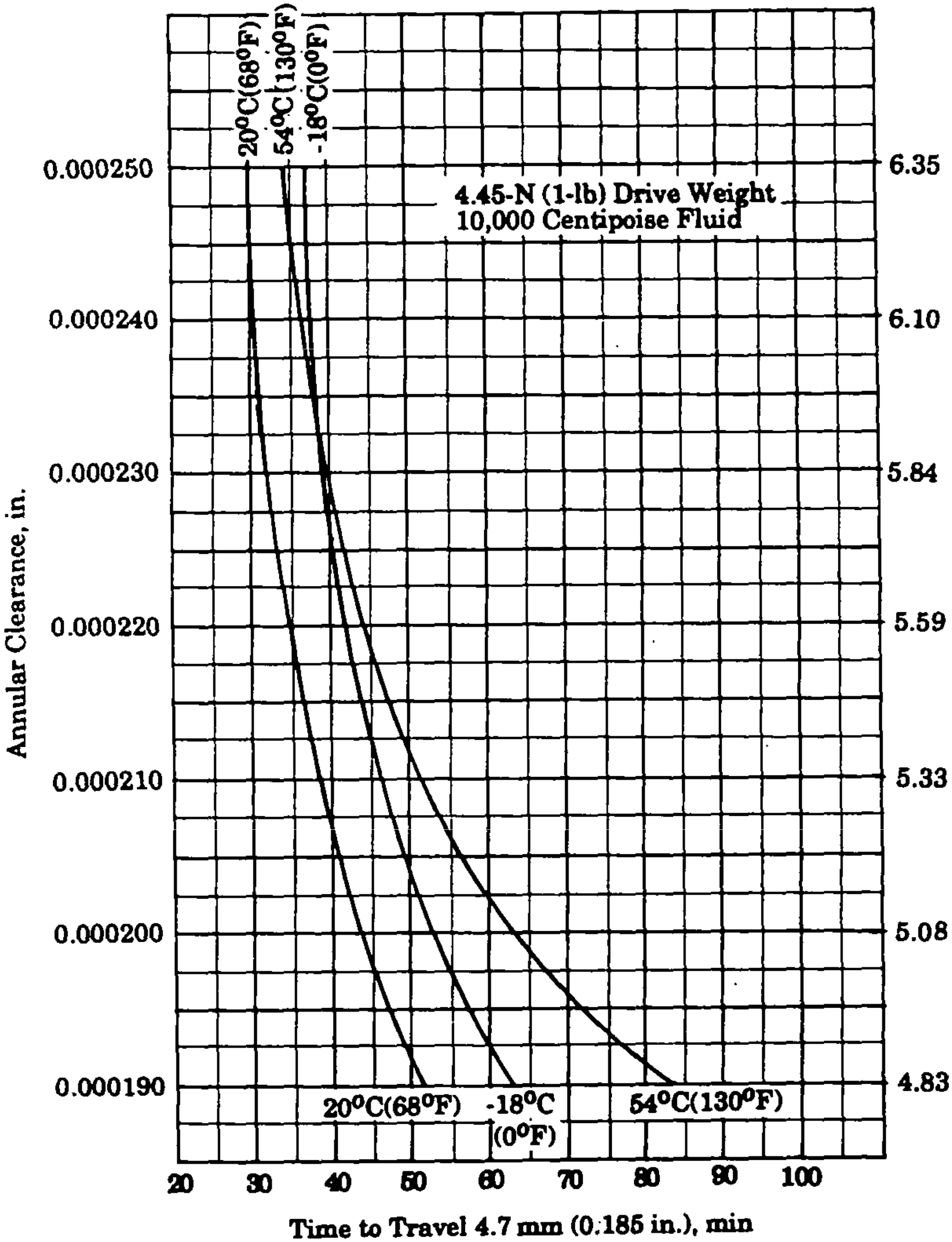


Figure 8-10. Effect of Temperature on LAOD Performances (Ref. 11)

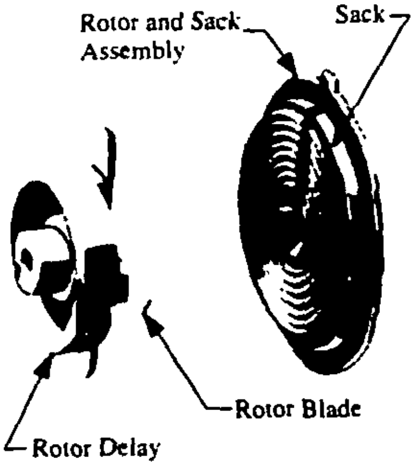


Figure 8-11. Delay Assembly of Fuze M218 (Ref. 15)

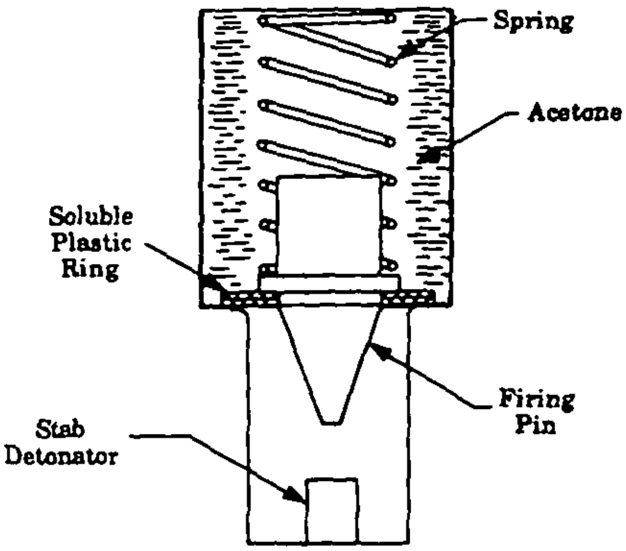


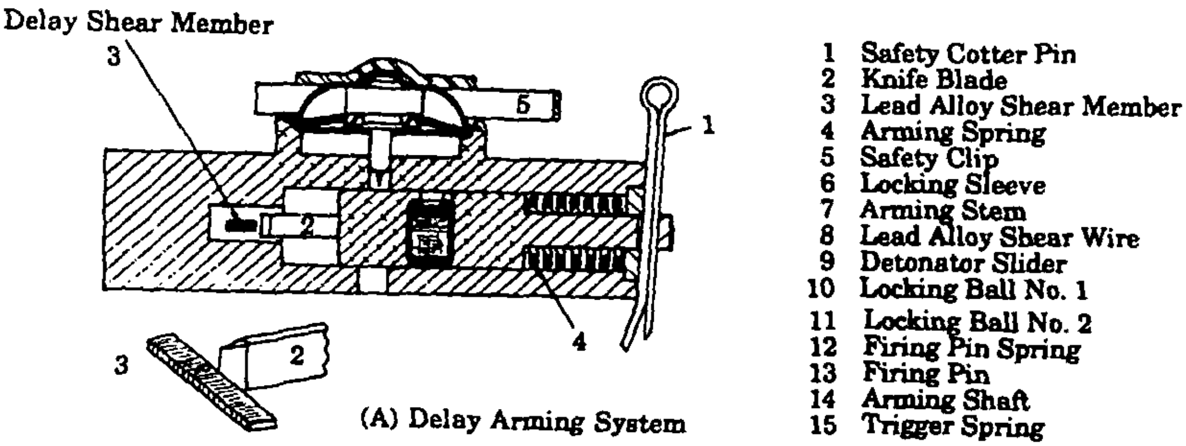
Figure 8-12. Chemical Long-Delay System

As presented in Fig. 8-13(A), the arming delay is activated by removing the cotter pin 1 after the charge is in place. This action allows the knife edge 2 to start cutting the alloy 3 under pressure of the arming spring 4.

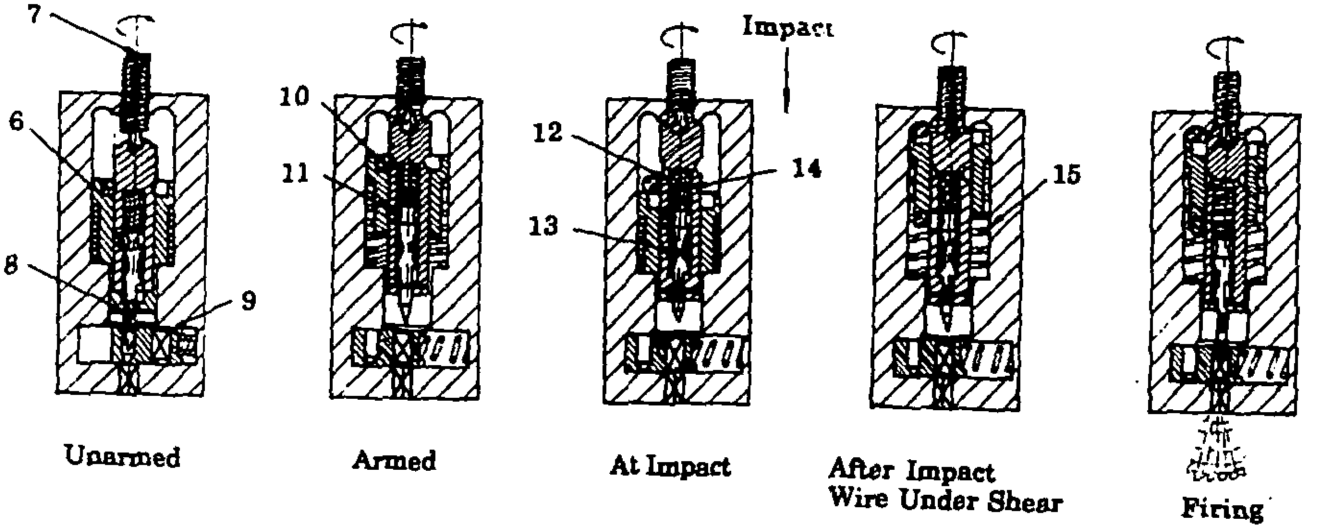
As shown in Fig. 8-13(B), the firing delay is secured by means of two ball locks; the first 10 is armed by the flight environment and releases the arming shaft 14 at impact. The second 11 prevents loading the lead alloy shear wire delay 8 until after impact deceleration has ceased when the trigger spring 15 releases this second ball lock. The spring 12 loads the alloy in shear.

The firing delay principle, as depicted, was used in the Bomb Tail Fuzes MK 237 Mod 0 and MK 238 Mod 0, the MK 237 for 500-lb general-purpose (GP) bombs and the MK 238 for 1000- and 2000-lb GP bombs. The functioning times of both fuzes are given in Table 8-1. The most convenient method of changing delay time was to use one alloy of different wire diameters (Wires No. 1, No. 2, and No. 3).

The delay is not a precise one and must be used in applications that do not require precision. Two methods of improving the precision are (1) automatic temperature adjustment of the energizing spring load and (2) annealing of the lead alloy to stabilize the crystalline structure.



(A) Delay Arming System



(B) Delay Firing System

Figure 8-13. Delays by Shearing Lead Alloy

TABLE 8-1. FUNCTIONING TIMES OF MK237 AND MK238 FUZES

TEMPERATURE	WIRE NO. 1, h	WIRE NO. 2, h	WIRE NO. 3, h
−6.7°C (20°F)	10	51	170
20°C (68°F)	2	10	30
43.3°C (110°F)	0.32	1.9	5.8

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PART THREE
FUZE DESIGN

Part Three describes the considerations that must be addressed in designing a fuze. There are a large number of weapon systems in existence, and new ones are continuously being developed. These weapons require a great variety of fuzes ranging from simple, low-cost, high-volume production submunition fuzes to highly sophisticated missile fuzes. Each fuze design has its own unique requirements with regard to size, complexity, cost, and launch requirements. Although the launch environments and target sensing requirements vary, all fuzes must survive a rigorous set of standard environmental tests before they can be certified for service use.

Chapter 9 presents the environmental and safety requirements for fuzes and the basic steps in designing a fuze. Chapters 10, 11, and 12 discuss the unique environments and design considerations for fuzes launched with high acceleration, low acceleration, and stationary weapons, such as land mines and boobytraps. Chapter 13 provides guidance on design practices that have proven successful in designing modern fuzes. Chapter 14 stresses the importance of test and evaluation in the acquisition process. A detailed discussion of tests requiring specialized test equipment and typical test programs is provided.

CHAPTER 9
CONSIDERATIONS IN FUZE DESIGN

This chapter discusses considerations in fuze design and provides a procedure that can be used as a guide for fuze design.

Fuze development begins with the preparation of a requirement document, which includes objectives for performance, safety, and reliability as well as environmental, physical, and cost requirements.

Once all requirements have been completely defined and documented, design options are explored. Design concepts evolve from the researching of existing designs and literature, discussions with experts, and innovative ideas. The formulation of concepts into a preliminary set of drawings that comprises the design and fabrication of models for test and evaluation is discussed.

After testing and iterative design modifications have determined that all requirements have been satisfied, more comprehensive testing is conducted with emphasis on field testing in realistic environments. The purpose and objective of this testing are to provide final evaluation of the suitability of the design for type classification.

The entire design process, including testing and evaluation, can be futile unless the design is described and documented properly in the technical data package (TDP). The TDP defines the results of the myriad analyses, investigations, iterations, and refinements that have been accomplished. Formal standards for the preparation of drawings and specifications are presented with an example of how the principles of tolerancing and dimensioning must be applied to control and delineate shape, form, fit, function, and interchangeability. Illustrations and calculations are provided to show how the fuze envelope and internal space are apportioned and how components are designed to achieve the required detonator safety, arming, and functioning.

The chapter also addresses the setting of fuzes. Design considerations and human engineering factors are provided to aid in designing hand-settable fuzes. Newer technologies that use inductive and radio frequency (RF) techniques to set fuzes are also presented.

9-1 INTRODUCTION

There are few, if any, mechanical or electrical devices for either commercial or military use that must satisfy as many stringent requirements as a fuze for ammunition. It must not only withstand the rigors of transportation, field storage in any part of the world, and launching under a multitude of conditions, but it must also function as designed upon the first application of the proper stimulus. From the assembly line at the loading plant to battlefield launch, the fuze must be safe to handle and use.

The fuze designer's problem is twofold. He must design a fuze (1) that will amplify a small stimulus in order to detonate a high-explosive charge, as described in Part One of this handbook, and (2) that will contain safety mechanisms to prevent premature functioning, as described in Part Two. In Part Three considerations for fuze design are discussed and then applied to a simple but representative fuze. Subsequent chapters are devoted to sample designs of specific fuze features and to fuze testing.

A designer's ability to develop a fuze depends upon his understanding of exactly what the fuze must do and upon his knowledge of all of the environments to which it will be exposed. The purposes of this chapter are to discuss the basic safety and environmental requirements, to present a general plan for the major phases of development from the first pencil sketch to final acceptance for production, and to illustrate the sequence of design and the application of the principles developed in Parts One and Two. The procedures for testing the fuze after the preliminary design will also be addressed in order to illustrate the iterative process necessary to achieve a successful fuze design.

9-2 REQUIREMENTS FOR A FUZE

Fuzes are designed for different situations: instantaneous actuation, delay actuation after impact, influence actuation near target, and time actuation after launch. They are used with various types of munition and delivery systems: artillery projectiles, mortars, tank main armament projectiles, aircraft bombs, mines, grenades, rockets, and guided missiles. Each type has its own set of requirements and launching conditions that govern the final design of the fuze. Within a type of ammunition item, e.g., artillery projectiles, a fuze may be designed for a specific round that is used with one particular weapon, or it may be designed for assembly to any one of a given type of projectile, e.g., all high-explosive (HE) projectiles used for guns and howitzers ranging from 75 mm to 8 in. The first fuze satisfies a set of specific requirements, whereas the second must be operable over a range of launching conditions. Therefore, before undertaking the development of a fuze, a designer must be thoroughly familiar with the requirements of the fuze and the conditions in the specific weapon(s).

All fuzes, regardless of use, must satisfy precise basic environmental criteria and safety requirements.

9-2.1 ENVIRONMENTAL REQUIREMENTS

Requirements vary for specific fuzes, but every fuze will be subjected to a number of environmental conditions during its lifetime. Although all fuzes do not experience the same environmental conditions, a number of requirements have been standardized and broadly applied to fuzes. Accordingly, the specifications, i.e., design objectives and operational requirements document (ORD), for new fuzes can be, in part, written by reference. The environmental conditions influence choice of materials, method of sealing, protective finishes, ruggedness of design, and method of packaging. Some of the standardized requirements that have been adopted by all services are

1. *Safety*. The fuze must meet the safety requirements of MIL-STD-1316 (Ref. 1).

2. *Storage Temperature*. The fuze must be capable of withstanding storage temperatures from –62° to 71°C (–80° to 160°F) and must be operable thereafter.

3. *Operating Temperature*. The fuze must withstand and be operable in temperatures ranging from –54° to 49°C (–65° to 120°F). Temperatures can drop to –62°C (–80°F) in bomb bays of high-flying aircraft, and aerodynamic heating in high-velocity-launched munitions can produce surface temperatures greater than 316°C (600°F) (Ref. 2).

4. *Rough Handling*. The fuze must withstand the rigors of transportation and rough handling without compromising its safety or functioning reliability.

5. *Electromagnetic Hazards*. The fuze electronics and electroexplosive devices must be capable of performing safely and reliably in the electromagnetic fields experienced during its life. These include radio and radar fields, electronic countermeasures, lightning, electromagnetic pulse, and electrostatic discharge (Ref. 3).

6. *Life*. The fuze must remain safe and operable during and after storage in all the climatic conditions of the world for at least 10 yr (preferably 20 yr).

Specific requirements for environmental and performance testing of development and production fuzes are provided in MIL-STD-331 and MIL-STD-810 (Refs. 4 and 5). Fig. 9-1, taken from MIL-STD-810, illustrates some of the induced and natural environments that fuzes and military hardware are likely to encounter during their lifetime.

9-2.2 GENERAL SAFETY REQUIREMENTS

The basic mission of a fuze is to function reliably and to receive and amplify a stimulus when subjected to the proper target conditions. The tactical situation often requires the use of a very sensitive explosive train—one that responds to small impact forces, to heat, or to electrical energy. Another of the designer's important considerations is safety—safety during manufacture, loading, transportation, storage, and assembly to the munition. In some cases the forces against which the fuze must be protected may be greater than the target stimulus. Safety, then, is a substantial challenge for the designer.

MIL-STD-1316 (Ref. 1) defines the specific safety design criteria for fuzes for all services. This standard is applicable to all fuzes and safety and arming devices (SADs) except nuclear devices, hand grenades, manually emplaced munitions, and flares. Some of the more important requirements of MIL-STD-1316 are

1. *Safety Redundancy*. It is a basic requirement that fuzes have at least two independent safety features, each of which is capable of preventing unintentional arming. The forces enabling the safety features must be derived from different environments. This philosophy is based on the low probability of both features failing simultaneously.

2. *Arming Delay*. The fuze must provide an arming delay and thus assure that a safe separation distance can be achieved for all defined operational conditions.

3. *Explosive Sensitivity*. Only those explosives listed in Table 1 of MIL-STD-1316 (Ref. 1) or others approved by the Fuze Safety Review Board of the services are permitted beyond the interrupter of the fuze.

4. *Explosive Train Interruption*. At least one interrupter shall separate the primary explosives from the explosive lead and booster. The interrupter(s) shall be directly

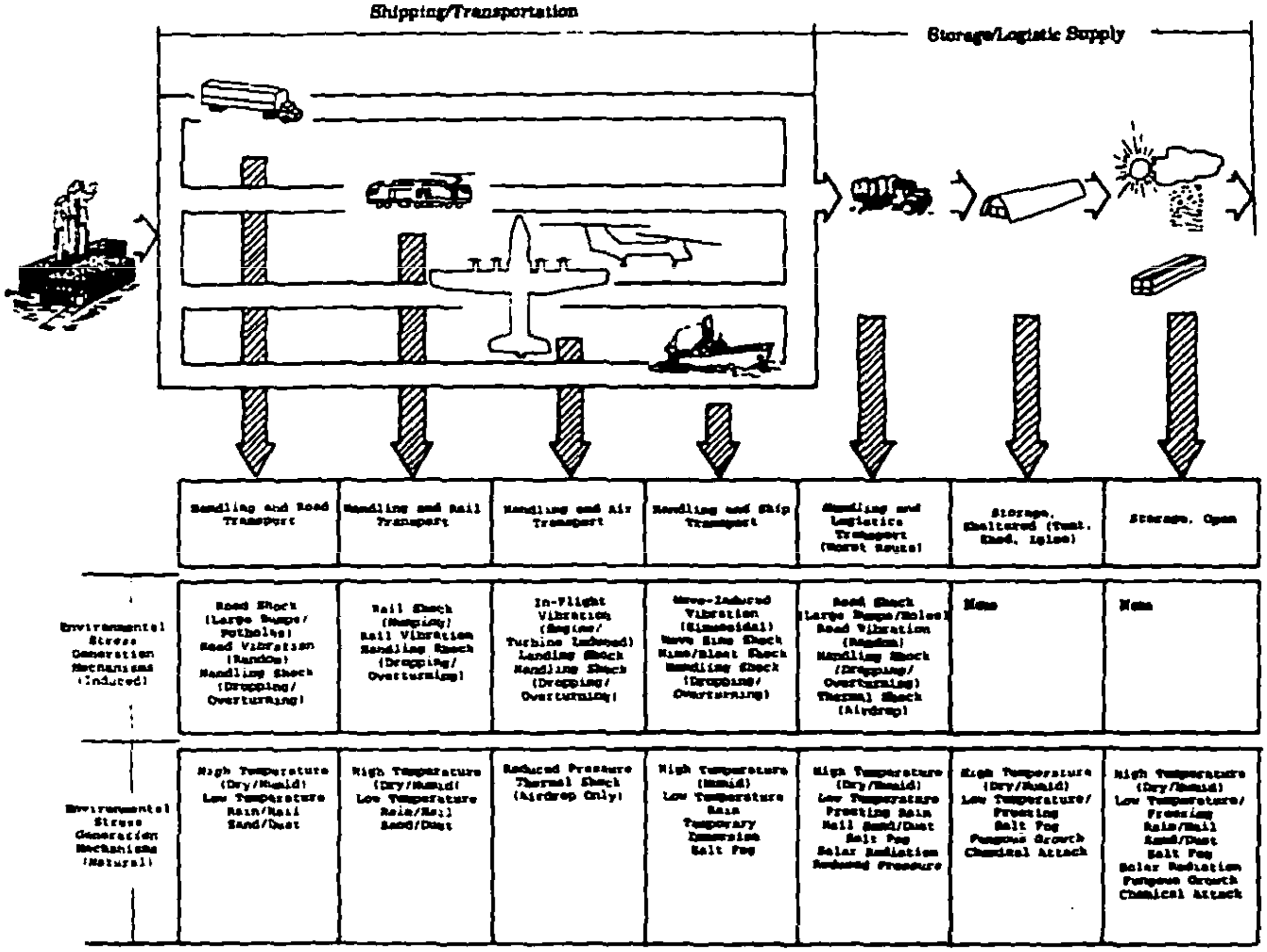


Figure 9-1. Generalized Life Cycle Histories for Military Hardware (Ref. 5)

locked in the safe position mechanically by at least two *independent* safety features.

5. *Noninterrupted Explosive Train Control*. When the explosive train contains only those secondary explosives listed in Table 1 of MIL-STD-1316, no explosive train interruption is required. The standard describes three methods to preclude arming before the safe separation distance is attained for this condition, and one of these must be used.

6. *Safe or Armed Condition Detection*. One or more of the following options shall be combined in the fuze design:

a. A feature that assures a positive means of determining the safe condition at the time of fuze installation into the munition

b. A feature that prevents installation of an armed fuze into the munition

c. A feature that prevents assembling the fuze in the armed or partially armed condition.

In addition, MIL-STD-1316 provides design objectives and design guides that include features, procedures, controls, and good design practices to aid the designer in obtaining optimum safety.

Fig. 9-2 illustrates schematically the implementation of the requirements of MIL-STD-1316 described as follows:

1. *Safety Redundancy*. The two independent safety features are the centrifugal locks and the setback lockpin, both of which secure the out-of-line SAD. Each depends on a separate and different environment to enable it.

2. *Arming Delay*. The arming delay is represented by the runaway escapement controlling the rotor motion.

3. *Explosive Sensitivity*. The rotor detonator consists of a primary explosive whereas both the lead and booster are approved secondary explosives.

4. *Explosive Train Interruption*. Interruption consists of a detonator that is displaced from the armed position by a rotor that is secured in the safe position by centrifugal and setback operated locks.

5. *Safe or Armed Condition Detection*. The antimalassembly feature prevents assembling an armed SAD into the fuze.

The importance of safety cannot be overemphasized. The survivability of our military personnel and materiel is highly dependent upon the fuze designer's ability to provide controls that effectively prevent mishaps.

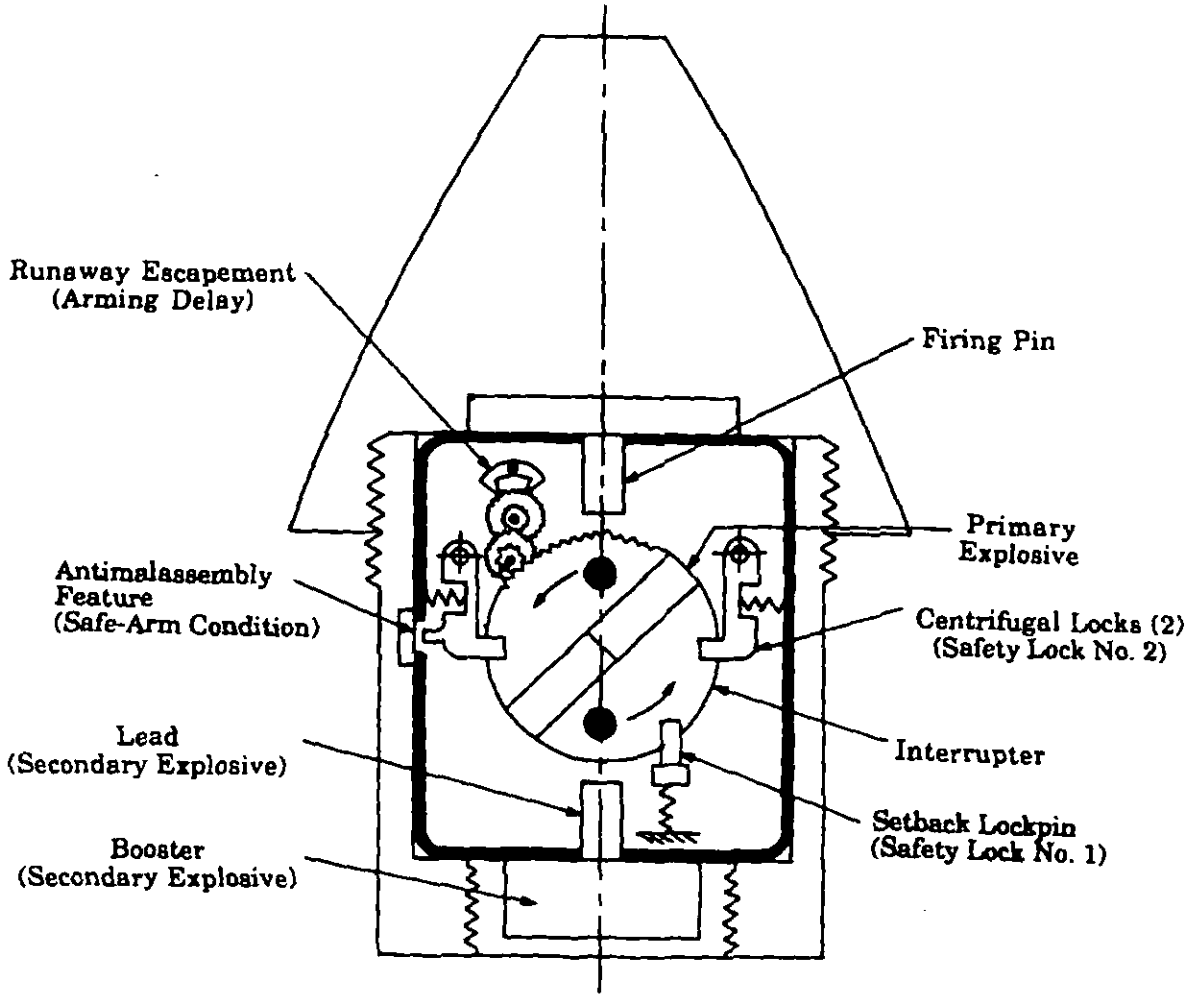


Figure 9-2. Application of MIL-STD-1316 to a Typical Artillery Fuze

9-2.3 OVERHEAD SAFETY REQUIREMENTS

Overhead safety is a mandatory requirement for Army fuzes on projectiles carrying submunitions. This requirement is necessary to provide safety against an early burst over friendly troops and/or equipment forward of the munition launch platform. An early burst is defined as a malfunction by which the fuze functions after the arming delay but before it should properly function. A minimum quantitative requirement for overhead safety is generally specified in the operational requirements document (ORD). The minimum requirement failure rate varies from 1×10^{-3} to 1×10^{-6}, depending upon the particular weapon and its use. Obviously, the cost to verify this requirement by field firing in all types of environments would be prohibitive. Statistical analyses, such as fault trees and hazard analyses, are usually employed to estimate the fuze system failure rate.

To reduce the probability of an early burst, some time fuzes permit arming only when the fuze is almost ready to function. Electric and proximity fuzes incorporate circuitry to delay charging of the detonator firing capacitors or to delay activation of the proximity sensing element until the munition is near the target.

9-3 STEPS IN DEVELOPMENT OF A FUZE

Development of a fuze is considered successful only when the design has passed all tests, has been certified by the US Army Test and Evaluation Command (TECOM) and the Army Fuze Safety Review Board, and has been type classified. Many steps are involved between concept and type classification:

1. Definition of the requirements and objectives
2. Conceptual design, calculations, and layout
3. Model tests and revisions
4. Development and operational testing
5. Technical data package (TDP) preparation.

9-3.1 DEFINITION OF THE REQUIREMENTS AND OBJECTIVES

The first step in development of a fuze is the requirements definition. The designer defines the requirements and objectives of the fuze without regard to how to meet and achieve them. The fuze designer should maintain close liaison with the weapon designer and other cognizant combat development agencies to ensure that all the required details and interfaces are covered. Unfortunately, important requirements, changes, and interfaces often have been overlooked or have gone unnoticed until late in a program and consequently have resulted in program delays, increased costs, and in some instances less than optimum performance.

The output of this effort is a clearly stated, comprehensive set of requirements and objectives that completely covers the performance of the fuze design. This document can state both a minimum acceptable level of performance and a desired level of performance. At a minimum, this document should typically include

1. *Performance*. Performance includes such things as definition of target(s), fuze obliquity and sensitivity requirements, timing accuracy, functioning and arming delays, setting modes, munition(s) used, and impact survivability.
2. *Safety*. Adherence to MIL-STD-1316 (Ref. 1) is mandatory for fuzes developed by all services. In addition, special safety requirements are sometimes invoked, e.g., fuze must not be able to receive its electrical input if it is armed, to enhance the safety requirements of a particular weapon system.
3. *Reliability*. Reliability is usually expressed as a numerical goal of the acceptable probability of performance of the intended function for a specified interval under stated conditions. Usually two numbers are stated: one is an acceptable minimum, e.g., 95%, and the other is the desired minimum, e.g., 98%. Sometimes confidence levels are stated to define the number of tests required to demonstrate the reliability goal.
4. *Size and Weight*. Restrictions on the size and weight of a fuze are determined by such things as how it is to be launched, with what munition it will be used, and its effect on the center of gravity and ballistic characteristics of the munition. Within these restrictions the size and weight of subsystems and components must be fixed by reasonable apportionment. This can have a significant effect on design considerations.
5. *Environments*. Environments the munition will experience are listed. Included are standard tests specified in MIL-STD-331 and MIL-STD-810 (Refs. 4 and 5), as well as any unique environmental tests peculiar to the operational and logistic usage of the weapon system. These conditions have an important impact on choice of materials, structural design, finishes, insulation, and sealing.
6. *Cost*. Cost has an important effect on design approaches. Fuzes should be designed to be produced at the minimum cost consistent with safety, reliability, size, and production quantity considerations. In general, reliability and production quantity have the greatest impact on fuze cost. For example, the cost of a fuze for a small submunition requiring reliability of about 90% and built at a rate of about 50 million units per year is only about $0.40 each. Conversely, the cost of a dual channel SAD for an air defense missile requiring reliability greater than 99% and built at a rate of only several hundred units per year is several thousand dollars per unit. The cost of a fuze must be in proportion to the ultimate value of the weapon. The cost of a fuze is, therefore, a big factor in determining how it must be designed.

9-3.2 CONCEPTUAL DESIGN, CALCULATIONS, AND LAYOUT

Once the design requirements and objectives have been established, it is appropriate to explore design options. Before beginning the design, however, the designer should research existing designs and literature because it is almost certain that work that is applicable has already been done. Some sources of material that should be considered are

1. MIL-HDBK-145, MIL-HDBK-146, and MIL-HDBK-777 (Refs. 6, 7, and 8) identify all procurement-standard fuzes; obsolescent, obsolete, terminated, and canceled fuzes; and procurement-standard explosive components.
2. Library search of applicable reports
3. Textbooks
4. Institute of Electrical and Electronics Engineers (IEEE) proceedings
5. American Defense Preparedness Association (ADPA) proceedings
6. Manufacturers' data books
7. Independent research and development (IR&D) projects in private industry
8. Discussions with experts in fuze and explosive research.

Having gathered available information, the designer can consider design options, component tradeoff analyses, and system compatibility studies. In general, design options should be considered in the following order of preference: to use an existing design, to modify an existing design, or to develop a new design.

The next step is selecting the design alternatives that are best suited to meeting the design objectives. At this point, there may be more than one promising concept. If so, the designer should evaluate each alternative by listing its advantages and disadvantages. A good fuze design includes the following features:

1. Reliability of action
2. Safety during manufacture, handling, and use
3. Resistance to damage during handling and use
4. Simplicity of construction

5. Design margin of strength during use
6. Compactness
7. Ease and economy of manufacture.

These factors can be used as evaluation criteria for selection of the best design approach.

The designer can now proceed to the task of preparing preliminary detailed drawings of the selected components that comprise the design. During this phase, calculations of the stresses involved in transportation and use are performed and materials, sizes, shapes, tolerances, and finishes are selected. External forces to which a fuze may be subjected are the shock and vibration that occur when a fuze is transported, accidentally dropped, or launched. Acceleration forces on different fuze parts occur during launch (setback forces), forces during flight (centrifugal and creep forces), and on target contact (impact forces). The fuze must be able to withstand all of these forces without compromising its operational characteristics. The choices of materials and dimensions for the parts depend on elastic moduli, strength, friction characteristics, corrosion resistance, compatibility, machinability, availability in times of emergency, and cost.

All fuze parts must be properly toleranced while following good design practice. Every length, diameter, angle, and location dimension must be given and defined in tolerances as broad as practicable within the requirements for functioning and within the capability of the selected manufacturing process because costs rise rapidly as tolerances are made tighter. Tolerance stack up (accumulation) calculations are made to determine whether parts can be assembled properly and whether an assembly will operate as expected. Expected user environments, temperature extremes, and the effects of both upon critical interference and clearance fits must be considered. Tolerancing affects the interchangeability of parts, and complete interchangeability is desirable whenever feasible. In complex mechanisms, such as mechanical timers, in which components are small and tolerances are critical, however, complete interchangeability is often impractical. Selective assembly or built-in provision for adjustment after assembly may be required in these cases. In rare cases some machining operations can be performed after assembly.

Seals and corrosion-protective finishes are important considerations at this stage because the fuze is expected to survive storage in all of the climatic regions of the world for up to 20 yr. O-ring seals and organic sealants are the most commonly used to seal a fuze; however, when hermetic seals are required, such techniques as soldering, ultrasonic welding, metal injection, or storage in hermetically sealed cans are used. One of the most difficult sealing problems is to seal against the intrusion of moisture-laden air that is driven by the effects of extreme temperature cycling.

New material technology is constantly increasing, and plastics are being used more extensively in modern fuzes. However, requirements for ruggedness in fuze parts to resist setback and acceleration and to survive impact dictate the characteristics and properties that a material must have. Each material can be used only with a limited number of manufacturing processes, and each of these processes is valid only for certain design requirements of tolerance, finish, configuration, and quality. Material selection therefore requires an intimate knowledge of the interrelationships of design and the manufacturing process, chemical and environmental compatibility, consideration of the manufacturing process and its availability, and an understanding of the need to consider alternate materials and manufacturing processes (Ref. 9).

9-3.3 MODEL TESTS AND REVISIONS

Once the preliminary drawings have been prepared, model fabrication can begin. Usually, the number of fuzes fabricated for the first series of tests is kept to a minimum. After one or two prototype models, twenty-five fuzes are a good number for the first lot. This lot size may vary, however, depending on the type of fuze, severity of requirements, and available time and funds. Models of partial subassemblies could also be fabricated in order to check properties such as arming characteristics, explosive train reliability, or in the case of electronic fuzes, breadboard testing. It is important to plan the test schedule because planning permits maximum use from the small sample size, and sequential and combined tests can be planned to conserve test hardware. The test plan for the first lot should include the standard fuze tests specified in MIL-STD-331 (Ref. 4), i.e., jolt, jumble, transportation vibration, and temperature and humidity, as well as any specialized tests imposed by the requirements. It is good practice to exercise the fuzes for simulated arming, i.e., centrifuge, wind tunnel, and other nondestructive tests, prior to actual testing to ensure that they are, in fact, operable. It is also good practice not to use live booster explosives in these fuzes since the safety of the design has not been verified at this stage. Simulated booster pellets of compressed soap powder, sulfur, or wood can be used to provide the desired weight or support.

Following these tests, those fuzes required to be operable after conditioning, e.g., transportation vibration, temperature, and humidity, are subjected to simulated arming tests to verify their operability. These fuzes, as well as those not required to be operable after testing, are then disassembled and critically examined for damage, corrosion, broken parts, explosive initiation, moisture intrusion, and other conditions that could result in potential safety or reliability problems. Once this examination has been made, the fuzes can be used to conduct destructive tests such as firing train reliability and static detonator safety. Usually, no field tests with live, loaded rounds are conducted on the first lot of fuzes. The principal reason is that fuze safety has not been sufficiently established at this point in the development.

Undoubtedly, there will be design changes required as a result of the testing of the first lot. How well the design performs in the future is based on the designer's ability to identify design weaknesses and devise proper solutions.

Design changes are incorporated into the drawings, and a second lot of fuzes is fabricated for further testing. The number of fuzes in this lot may be increased because the designer now has more confidence in his design. Three lots are usually sufficient to demonstrate that technical risks have been identified and that solutions are in hand. Limited field testing can also be performed during this time to demonstrate system and interface compatibility and reliability.

In creating the design and recording test results, documentation is critically important. A notebook of detailed records that trace the evolution of the design must be kept. Design iterations, calculations, experimental and standard test results, and failures and successes are all appropriate material for permanent record. This tangible record of the evolution of the design serves several purposes:

1. It is the legal basis for a patent application if the design is patentable.
2. It traces the thinking that went into the design as it evolved; this thought process is important if a designer leaves the project and a new person is to finish the work.
3. It provides valuable historic data for other designs and for problems and their solutions.

9-3.4 DEVELOPMENT AND OPERATIONAL TESTING

The Production Proveout Test (PPT) provides the final technical data necessary to determine readiness of the fuze and weapon system for transition into production. During this phase, fuzes are manufactured in larger lots, consistent with the program requirements, and are subjected to a comprehensive test and evaluation program. Fuzes evaluated during this phase should be manufactured by the same processes and techniques proposed for full-scale production. This would include die castings, stampings, extrusions, and sintered and molded plastic parts. PPT measures the technical performance, safety, reliability, compatibility, interoperability, and supportability considerations of the fuze, weapon system, and associated support equipment. It also includes tests of both the technical and human engineering aspects of associated training devices and methods, and it demonstrates whether the engineering of the fuze is reasonably complete and solutions to all significant design problems are available.

The final test of the development is Initial Operational Testing (IOT). IOT is conducted by the designated user and is performed in as realistic an operational environment as possible. For a system, IOT determines (Ref. 10)

1. Military potential, utility, operational effectiveness, and operational suitability
2. Whether the new system is desirable from the user's viewpoint, considering systems already available and the benefits and burdens associated with the new system
3. The need for any modifications
4. The adequacy of organization, doctrine, operating techniques, and tactics for employment of the system, as well as the adequacy of the system for maintenance support.

9-3.5 TECHNICAL DATA PACKAGE (TDP)

Perhaps the most important aspect of a fuze development effort is the design disclosure, which controls the manufacture and determines the quality of the fuze design. Considerable extra cost and delay in fielding a fuze can result if the design disclosures do not adequately define the design and specify the quality of the end product.

Drawings control and delineate the shape, form, fit, function, and interchangeability requirements of a fuze. Military design drawings are prepared in accordance with DOD-D-1000 (Ref. 11). In addition to drawings, there are specifications that are basic documents containing general criteria, performance requisites, workmanship, and inspection and acceptance criteria not covered on the drawings. Both drawings and specifications constitute a part of the fuze documentation and often are called the technical data package (TDP). Department of Defense Instruction (DOD-I) 5010.12 (Ref. 10) states that end-product documentation must be sufficiently defined to permit a competent manufacturer to reproduce an item without referring to the design activity. The engineering drawings for a fuze, when supplemented by the applicable specifications and standards, should describe completely the characteristics and quality assurance provisions of the product.

To accomplish this task, government and industry have established an organized system of geometric dimensioning and tolerancing for drawings. American National Standards Institute (ANSI) Y14.5M, *Dimensioning and Tolerancing*, (Ref. 12) contains guidance for this procedure. Some of the advantages of geometric dimensioning and tolerancing are (Ref. 13)

1. They save money directly by providing for maximum producibility of the part, insofar as tooling and gaging are concerned, through maximum machining tolerances. They provide "bonus", or extra, tolerance in many cases.
2. They ensure that design dimensional and tolerance requirements, as they relate to actual function, are specifically stated and carried out.
3. They ensure interchangeability of mating parts at assembly.
4. They provide uniformity and convenience of drawing delineation and interpretation and thereby reduce controversy and guesswork.

To illustrate the concept of geometric tolerancing and dimensioning, Fig. 9-3 is a reasonably complete drawing. All dimensions are toleranced, surface roughness requirements are noted, and material finishes are specified. The drawing appears complete, but some controls are missing. Fig. 9-4 shows two production possibilities. If the piece is

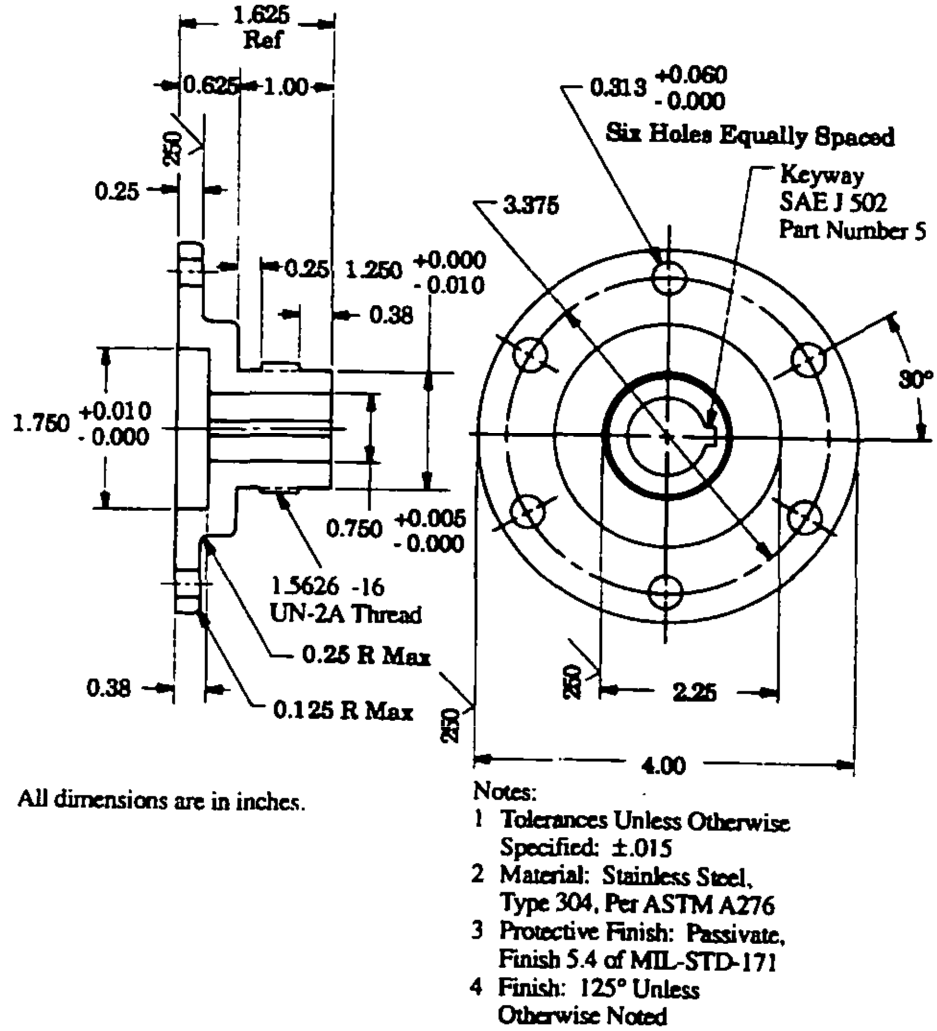


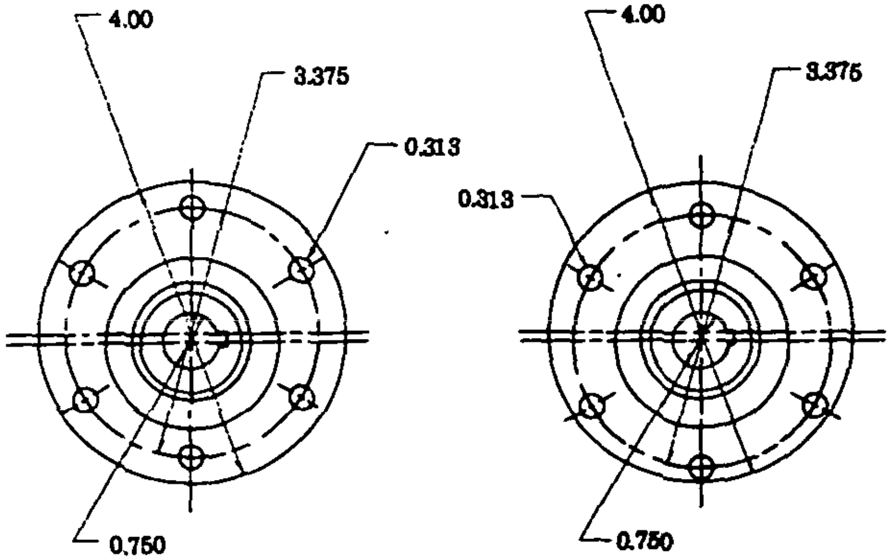
Figure 9-3. Drawing Without Positioning Controls (Ref. 9)

chucked on the 101.6-mm (4.00-in.) outer diameter (Fig. 9-4(A)). the six 7.95-mm (0.313-in.) diameter holes may be concentric with the 101.6-mm (4.00-in.) outer diameter. However, the other bores, the diametral bosses, and the keyway may be off-center, depending on the process used. If the piece is held in an expanding arbor, everything may be concentric and symmetrical, but the six 7.95-mm (0.313-in.) diameter holes may be located off-center, as shown in Fig. 9-4(B). Fig. 9-5, which depicts a similar part, gives information that will eliminate the previously discussed, incorrect production possibilities by specifying controls using geometric dimensioning and tolerancing. In Fig. 9-5 data are established, geometric requirements are specified, quality assurance is invoked, and all items produced and accepted will meet the form, fit, function, and interchangeability requirements. As a result, parts from any producer will fit.

To ensure that the fuze will perform as designed and that quality is maintained during its production, the designer must also prepare a fuze specification. The fuze specification delineates the amount of inspection, the attributes to be inspected, the method of inspection, and the acceptable quality. A typical electronic fuze specification may contain requirements and test criteria for arming and nonarming, timing event accuracy, electronic module operation, insulation and contact resistance, inertia switch operation, potting integrity, and explosive functioning and output.

The fuze specification also specifies the type of test equipment and its required accuracy in the performance of the tests. Another important function of the fuze specification is to provide a comprehensive test plan for preproduction and periodic inspections.

Preproduction and periodic production testing are usually done by a designated government activity, although they can be performed by the contractor under the cognizance of government inspectors. MIL-STD-331 tests, normal specification performance tests, and service operation tests generally are included. The purpose of these tests is to ensure that



(A) 0.313-in. Holes Processed With Respect to 4.00-in. Diameter

(B) 0.313-in. Holes Processed With Respect to 0.750-in. Hole

All dimensions are in inches.

Figure 9-4. Possible Results of Failing to Provide Positioning Controls (Ref. 9)

the product is manufactured in accordance with the drawings and specifications. Government acceptance of the preproduction sample is required prior to the contractor's starting full production. Periodic sample inspection is usually required on the first three lots; if no failures are observed, skip-lot testing of one lot randomly selected in five is sometimes permitted.

Acceptance criteria for passing the specified preproduction and periodic production tests are established by the fuze designer in accordance with the sampling plans and procedures in MIL-STD-105 (Ref. 14). To select a sampling plan, the designer should ask, "What would be the result of passing a defect?". If the defect could cause a safety hazard or incur equipment loss, 100% inspection might be used in place of a sampling inspection. There are certain risks inherent with inspection. For example, with sampling inspection there is, in addition to the possibility of human error, always the chance that good lots may be rejected and bad lots accepted. In general, the smaller the sample, the greater the risk. The curve shown in Fig. 9-6 illustrates the probability of accepting lots of varying quality for a single sampling plan with an inspection sample of 50 units and an acceptance criterion of accept on two defects and reject on three. For example, if the desired quality were to reject all lots with greater than 5% defectives, the curve indicates that 20% of the time lots could have as many as 7% defectives.

It is desirable to perform the specification tests on the highest level of fuze assembly as practicable. Many subassembly tests are required, however, to verify component reliability and safety prior to the next level of assembly.

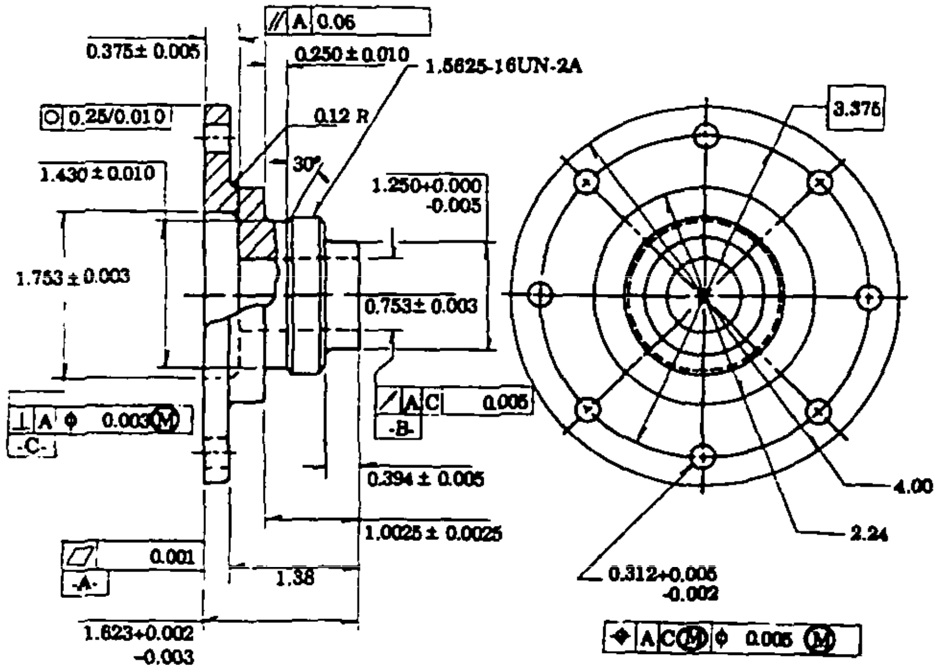
9-4 APPLICATION OF FUZE DESIGN PRINCIPLES

This paragraph develops and illustrates the rudiments of a step-by-step procedure that can be followed in designing a fuze for a new weapon system. The mechanical fuze design selected as an example was chosen for its simplicity. It does not necessarily meet all the current fuze requirements, such as sufficient delayed arming and a setback lock on the rotor, nor does it embody the latest technologies.

9-4.1 REQUIREMENTS FOR THE FUZE

A new weapon system can evolve in several ways. A combat element may determine a need to meet certain tactical situations or to counter a particular threat. An advance in a technology, perhaps resulting from independent research by Government or industry, may provide the breakthrough for an improved weapon system. In either case, the tactical requirements provide the input data for ballistic studies, effectiveness analyses, fuzing requirements, and other parameters.

Assume that a fuze for a projectile is required. Input data from ballistic studies will determine the size, weight, and shape of the projectile. These data are used to develop a caliber drawing of the projectile, which defines the contour, volume, and interface requirements for the fuze, as shown in Fig. 9-7. In the case of projectiles, some of these parameters, e.g., fuze threads, contour, and projectile cavities, have been standardized for 75 mm and larger calibers in MIL-STD-333 (Ref. 15). Additional data are available from the



All dimensions are in inches.

Figure 9-5. Illustration of Proper Positioning Controls (Ref. 9)

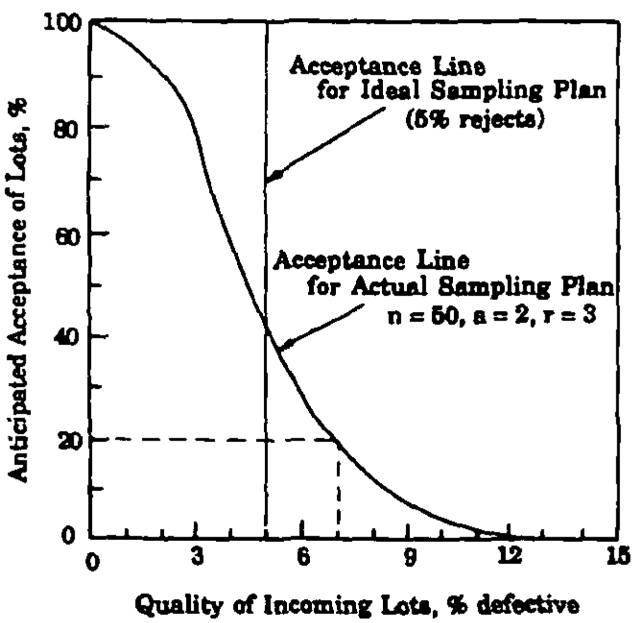


Figure 9-6. Comparison of a Theoretical Ideal Sampling Plan With an Actual Sampling Plan (Ref. 9)

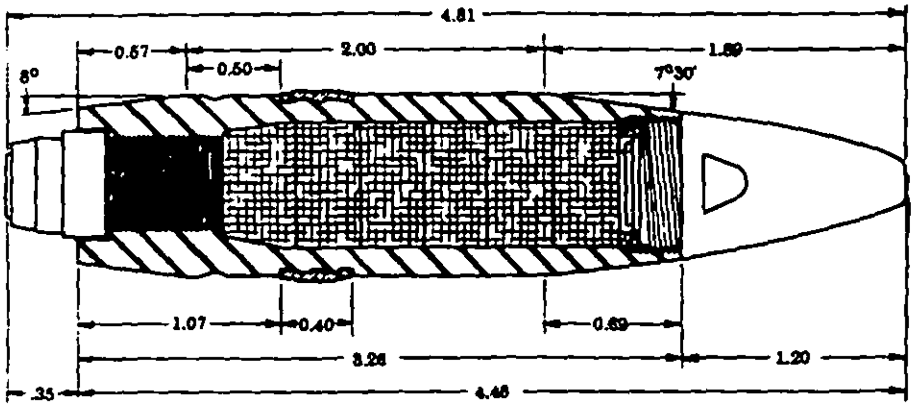
ballistic curves of the weapon, as shown in Fig. 9-8. From these curves, the fuze designer can determine the internal and external ballistic forces that may be used for safety and arming functions and must be withstood by the structural design. The tactical use will define other parameters such as minimum arming distance, target sensitivity, and functioning delay. These and other requirements and design data that affect fuze design, as discussed in par. 9-3.1, are summarized in Table 9-1.

When all the requirements are defined, the fuze designer can start to consider the parts, explosive components, materials, and configuration that will most likely achieve the specified safety and performance objectives.

9-4.2 DESIGN CONSIDERATIONS

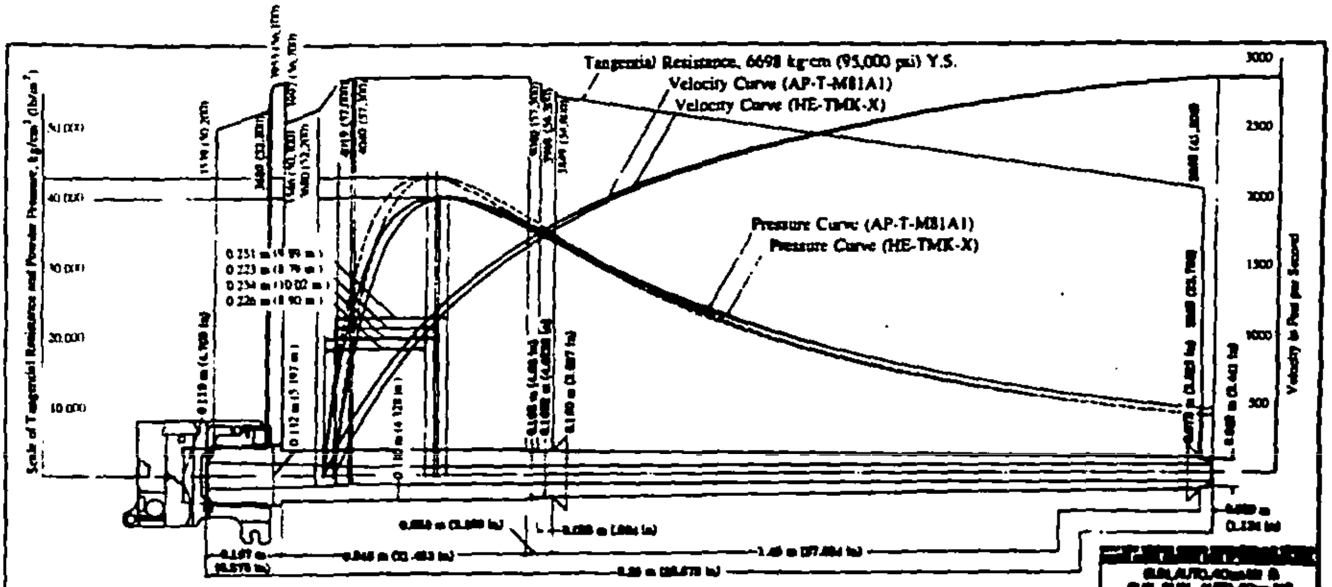
The first step in designing this simple mechanical fuze is to make a series of sketches, of which Fig. 9-9 might be the first. This sketch defines the external shape and the fuze and projectile interface. Within the restrictions of this envelope, the designer must fit the safety and arming mechanisms and the explosive output charge.

Next, it is necessary to apportion the available space for the essential components: (1) an explosive booster assembly, (2) a detonator, and (3) an initiating element, as shown in Fig. 9-10. These components will establish the three basic subassemblies of the design, each of which must be fitted into its allotted space. This space can be machined ini-



All dimensions in calibers

Figure 9-7. Caliber Drawing of 40-mm Projectile



Characteristics of Gun

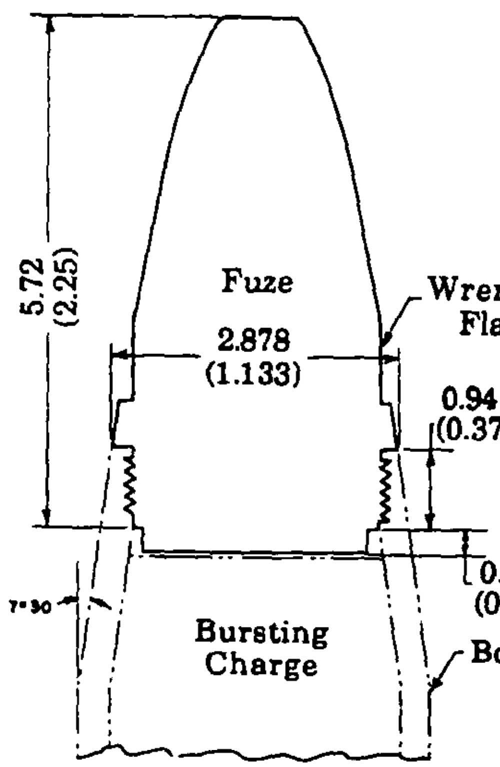
Projectile	AP-T-M81A1	HE-TMK-X
Length of Bore in Calibers	56.31	56.31
Muzzle Velocity	875 mps (2870 fps)	875 mps (2870 fps)
Volume of Chamber	0.0478 cu. m (29.14 cu. in.)	0.0504 cu. m (30.73 cu. in.)
Weight of Projectile	0.891 kg (1.96 lb)	0.865 kg (1.905 lb)
Weight of Charge	0.311 kg (0.685 lb)	0.333 kg (0.7075 lb)
Travel of Projectile	1.97 m (77.366 in.)	1.989 m (78.323 in.)
Density of Loading	0.622 g/cm³ (0.0224 lb/in.³)	0.637 g/cm³ (0.0229 lb/in.³)
Computed Maximum Powder Pressure	2820 kg/cm² (40,000 psi)	2820 kg/cm² (40,000 psi)
Rated Maximum Powder Pressure	3032 kg/cm² (43,000 psi)	3032 kg/cm² (43,000 psi)
Muzzle Energy	31.01 m·ton (111.91 ft·ton)	31.40 m·ton (113.34 ft·ton)
Weight of Gun 40 mm M1	461.4 kg (1015 lb)	461.4 kg (1015 lb)

Figure 9-8. Ballistic Drawing for 40-mm Gun

TABLE 9-1. REQUIREMENTS AND DESIGN DATA FOR SAMPLE FUZE

Maximum Gas Pressure:	27.6 × 10^7 Pa (40,000 psi)
Gas Pressure at Muzzle:	62.0 × 10^6 Pa (9000 psi)
Muzzle Velocity:	875 m/s (2870 ft/s)
Rifling Twist:	1 turn in 30 cal
Bore Diameter:	40 mm (1.575 in.)
Projectile Weight:	8.86 N (1.99 lb)
Safety:	MIL-STD-1316
Arming Distance:	Bore safe only
Type of Initiation:	PDSQ* (<100 μs after contact)
Impact Angle:	0 to 85 deg (normal to target)
Sensitivity:	10.2 mm (0.40 in.) 2024T3 Al
Explosives:	MIL-STD-1316 approved
Shelf Life:	20 yr desired
Environmental:	MIL-STD-331

*PDSQ = point-detonating superquick



All dimensions are in centimeters (inches).

Figure 9-9. Outline of Fuze Contour

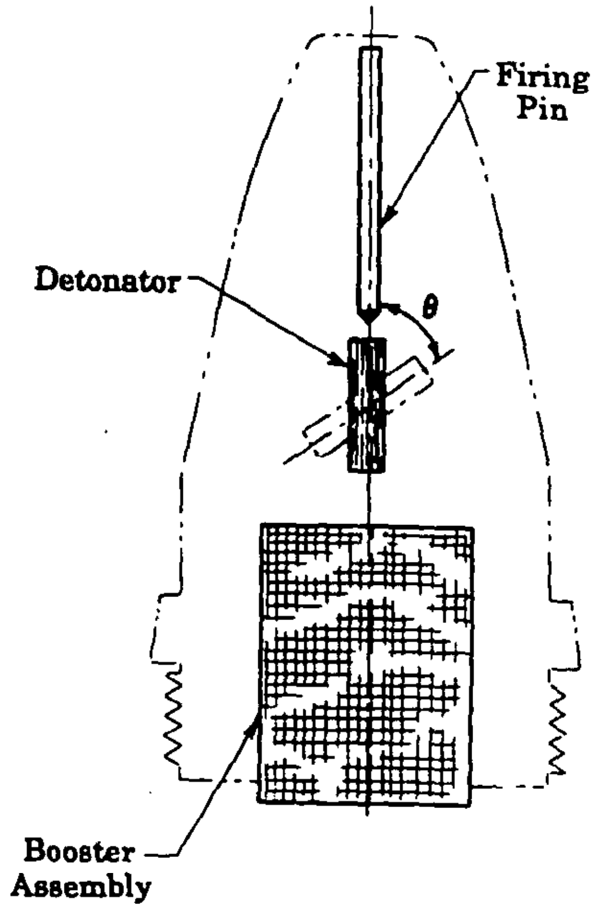


Figure 9-10. Preliminary Space Sketch

tially from solid stock for engineering prototypes. If ballistic forces permit, the part could be die-cast later in the development, and the three subassemblies could be encased in their own housing for safety and ease of handling and loading. These assemblies are described in the paragraphs that follow.

9-4.2.1 Booster Assembly

The booster assembly includes the booster pellet, the booster cup, the lead, and a closing disk. In addition to the fuze functioning and operating requirements, the designer must always consider the manufacturing and loading techniques that are in common use. It may be decided that 5.4 g (0.19 oz) of CH-6 at a density of 1578 kg/m^3 (0.057 lbm/$in.^3$) are required to initiate the bursting charge. For best output the length-to-diameter ratio should be less than 3. (See par. 4-4.4 for further discussion.) Two standard CH-6 pellets, each 2.8 g (0.10 oz), 14.2 mm (0.56 in.) in diameter, and 10.7 mm (0.42 in.) long, could be used. These dimensions will leave enough space for a stab detonator between the firing pin and booster.

The figures cited in the previous paragraph are based on the assumption that the pellet is allowed to extend into the projectile cavity to increase its reliability of initiating the bursting charge. Enough space must be provided for metal side walls on the booster in order to confine the explosion properly. Since the booster should be held in a housing as previously described, Fig. 9-11 shows the fuze with the booster pellet encased in a cup that is screwed into the fuze body. Because the cup is placed open end out, a closing disk is placed over the output end of the booster to retain the CH-6 explosive filler.

A lead of the same explosive as the booster is inserted in a small cavity on the centerline of the fuze, in line with the booster pellet, as shown in Fig. 9-11. The purpose of the lead in this design is to augment the output of the detonator and thus provide the necessary explosive amplification to initiate the booster reliably.

9-4.2.2 Detonator Assembly

In this simple fuze the detonator converts the kinetic energy of the firing pin into a detonation wave. Thus a stab detonator is required that will be sensitive to the results of the expected target impact and yet will have an output that will reliably initiate the CH-6 lead charge.

In accordance with the desire that standard components be used whenever possible, a stab detonator is selected from MIL-HDBK-777 (Ref. 8) that will fulfill the requirements for sensitivity and output. For example, the MARK 18 MOD 0 Stab Detonator has an input sensitivity of 6.4 N·m (9 oz·in.), and its output gives an indentation of 3.0 mm (0.117 in.) in a lead disc. MIL-HDBK-777 indicates that this detonator was used in a similar explosive train for a 40-mm fuze and therefore provides reasonable assurance that it will perform reliably in this fuze. Dimensions are also supplied, which provide the controlling dimensions for the detonator housing (rotor).

In order to provide detonator safety, the detonator must be moved out of line from the lead. A simple device for doing this is a disk rotor that carries the detonator. In the unarmed position the explosive train is completely interrupted because the firing pin is blocked from the detonator, and the detonator output end is not close to the lead. In the armed position the disk will be rotated so that both of these safety features will be removed. Fig. 9-11 shows these features.

The rotor diameter must be slightly larger than the length of the detonator, and the rotor thickness must surround the detonator with enough material to provide adequate confinement. (See par. 4-3.3 for further discussion.) These considerations fix the dimensions of the rotor at 11.10 mm (0.437 in.) diameter and 3.96 mm (0.156 in.) thickness. Rotor material is selected on the bases of density, confinement, and safety. Possible materials in order of preference are wrought aluminum, stainless steel, or die-cast zinc alloy.

Next, the designer determines the arming limits. In theory a fuze arms at a certain instant; in practice, however, allow-

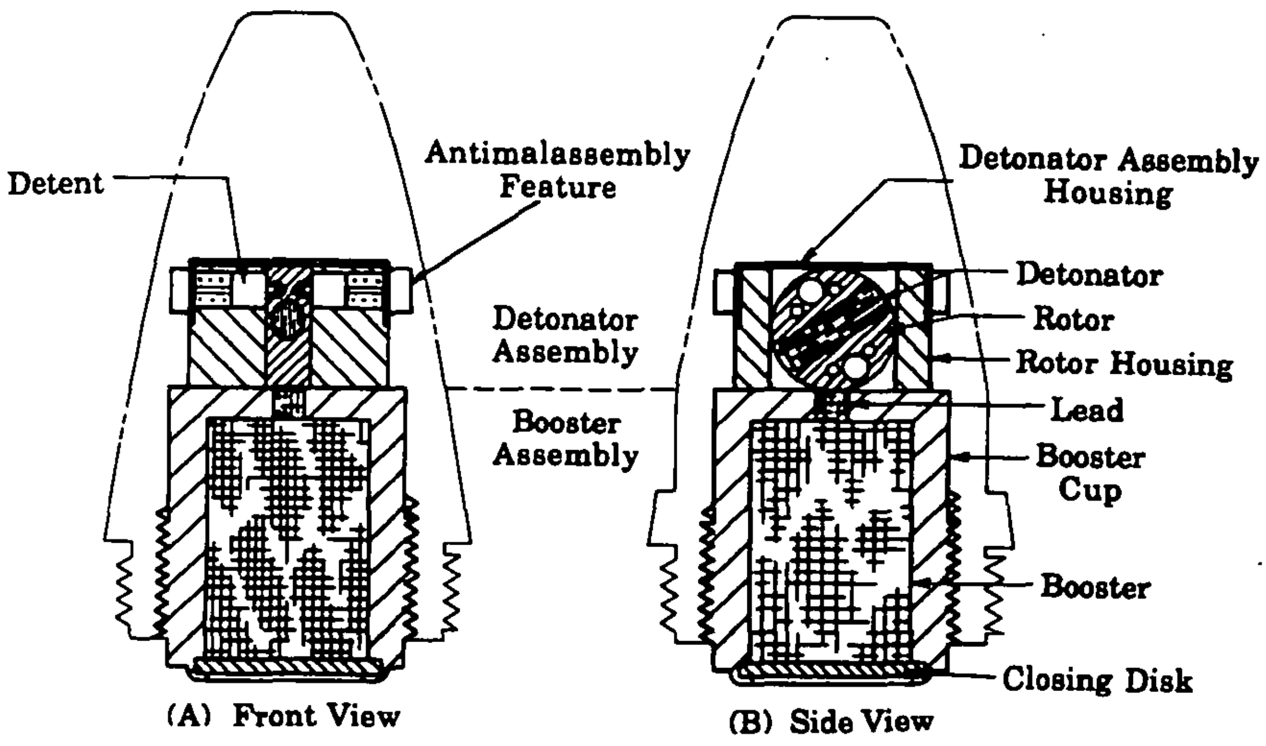


Figure 9-11. Booster and Detonator Assemblies

ances must be made for dimensional tolerances and variations in friction. Hence both minimum and maximum arming limits must be determined. The minimum arming level (must-not-arm value) must be sufficiently high to assure safety during handling and testing, whereas the maximum arming level (must-arm value) must be well within the capability of the available forces. The spread between these two values must be reasonable from the viewpoint of manufacturing tolerances, and experience dictates which of the many values that meet these broad limits are optimum. For the sample projectile the spin at the muzzle is 730 rps, or 44,000 rpm. Reasonable arming limits based on the given considerations would be 12,000 and 20,000 rpm.

From the equations in par. 6-5.1, the time to arm, the time for the rotor to turn into the aligned position, is calculated. For a first approximation Eq. 6-44 may be solved for time by neglecting friction. This value should be the minimum arming time. Note from Eq. 6-44 that the time to arm depends in part upon the ratio of the moments of inertia of the disk.

Table 9-2 lists the various moments of inertia for the rotor and its parts. By using Eq. 6-44

$$t = \frac{1}{\omega}\sqrt{\frac{I_z}{I_p - I_D}}\int_{\phi_1}^{\phi_2}\frac{d\phi}{\sqrt{1 - K_\theta^2 \sin^2\phi}}, \text{ s}$$

with θ_0 = 55 deg and θ' = 0 deg, the time to arm at the spin for the muzzle velocity is about 3 ms. Since the friction present always decreases the velocity, the time to arm will be greater than 3 ms. The lead weights decrease the arming time. They also increase the stability of the rotor in the armed position, which increases the reliability of the fuze to initiate the bursting charge.

The time would provide a minimum arming of only 2.4 m (8.0 ft). This distance would be unsatisfactory for current fuzes, so the designer would have to consider other means of achieving a longer delay. An escapement, pyrotechnic delay, pneumatic annular orifice dashpot (discussed in par. 8-2.3.1), spiral unwinder (discussed in par. 6-4.5), or internal bleed dashpot (discussed in par. 8-2.3.2) are design considerations for achieving an arming delay in a small caliber fuze of this type.

To restrain the disk in the unarmed position, detents are inserted that are held by springs. If friction between the detent and rotor hole is considered negligible, these springs are set with an initial compression equivalent to the centrifugal force produced by the detents at the minimum spin to arm. At this minimum spin rate, the detents will be in equilibrium, but at any higher spin rate they will move radially outward to release the rotor. Eq. 6-13 defines the motion for the detents. Two items are important: (1) the spring force increases as the spring is compressed, but the centrifugal force increases at the same rate, and therefore, once the part moves it will continue to move radially outward and (2) the frictional forces that arise from the torque induced in the rotor. The driving torque on the rotor, which is resisted by the detents, is represented by the second term on the right-hand side of Eq. 6-43. From the value for the disk assembly in Table 9-2, the torque is found to be 5.04 N·m (44.64 × 10^{-3} lb·in.) at 12,000 rpm, and the friction force on each of the two detents is 0.67 N (0.15 lb) (for μ = 0.5 and an offset distance of the rotor of 1.9 mm (0.075 in.)). The centrifugal force on a detent, which weighs 25.9 × 10^{-2} g (5.7 × 10^{-4} lb) and has a center of gravity 3.8 mm (0.150 in.) from the spin axis, is calculated as 1.56 N (0.35 lb) at 12,000 rpm. The initial spring load, according to Eq. 6-13, must be at least 0.98 N (0.22 lb) to prevent arming below the spin of 12,000 rpm. The spring design is explained in par. 10-2.1.

To comply with the requirements of MIL-STD-1316 (Ref. 1), either an antimalassembly feature or a visual indication of the safe or armed status is required. In this design this function is achieved by adding an annular groove in the fuze housing, as shown in Fig. 9-11. If the rotor is not in the safe position with the detents engaged, the detents will extend beyond the rotor housing and the rotor housing cannot be assembled into the cavity in the fuze body. The

TABLE 9-2. COMPUTATIONS OF MOMENT OF INERTIA

	$I_z \times 10^{-8}$		$I_p \times 10^{-8}$		$I_D \times 10^{-8}$		$(I_p - I_D) \times 10^{-8}$	
	kg·m²	lb·s²·in.	kg·m²	lb·s²·in.	kg·m²	lb·s²·in.	kg·m²	lb·s²·in.
Solid Disk	1.592	14.088	1.413	12.504	1.413	12.504	0.000	0.000
Hole for Lead	0.106	0.936	0.111	0.984	0.012	0.110	0.099	0.874
Hole for Detonator	0.205	1.812	0.019	0.168	0.205	1.812	−0.186	−1.644
Hole for Detent	0.006	0.052	0.004	0.038	0.003	0.023	0.001	0.015
Disk	1.166	10.320	1.133	10.032	1.163	10.296	−0.030	−0.264
Detonator	0.129	1.145	0.014	0.127	0.129	1.145	−0.115	−1.018
Lead Weight	0.437	3.864	0.461	4.080	0.052	0.456	0.409	3.624
Disk Assembly	2.127	18.828	2.070	18.324	1.395	12.348	0.675	5.976

groove in the fuze housing provides an opening into which the detents move during the normal arming sequence.

9-4.2.3 Initiating Assembly

This assembly, shown in Fig. 9-12, contains the firing pin, the firing pin extension, two detents, a firing pin housing, and a spiral spring. The firing pin will be subjected to rearward motion on setback if unrestrained, and this would damage the point. Therefore, some means must be provided to prevent rearward motion. Fig. 9-12 shows two hourglass-shaped detents that restrain motion of the firing pin during normal transportation and handling. During setback the hourglass shape provides a more positive lock than a cylinder because the detents cock and produce a wedging action, which prevents their motion. This arrangement assures that the firing pin cannot move while the projectile is in the bore of the gun. Once the setback acceleration is removed, the detents are free to move radially outward.

For this geometry a spiral (wraparound) spring is used to hold the firing pin detents inward. (See par. 10-3.2 for the calculations appropriate for such a spring.) To ensure that the spring cannot return the detents and relock the firing pin during flight, the designer must check the spin decay rate to be certain the selected operational spin rate is maintained to the maximum time of flight. A reliable alternative is to place a small compression spring around the firing pin extension so that it is pushing rearward on the firing pin and to incorporate a light shear pin through the firing pin and firing pin housing. The size of the hole in the firing pin housing is sufficient to allow the spring-biased firing pin to advance far enough to lock the detents in the outward position but is not so large that it allows the firing pin to advance far enough to engage the rotor. The forces required to shear the pin are added to those required to deform or shear the nose bulkhead.

A plastic material is selected for the firing pin extension to reduce the inertial effects on the firing pin during impact and thus enhance sensitivity.

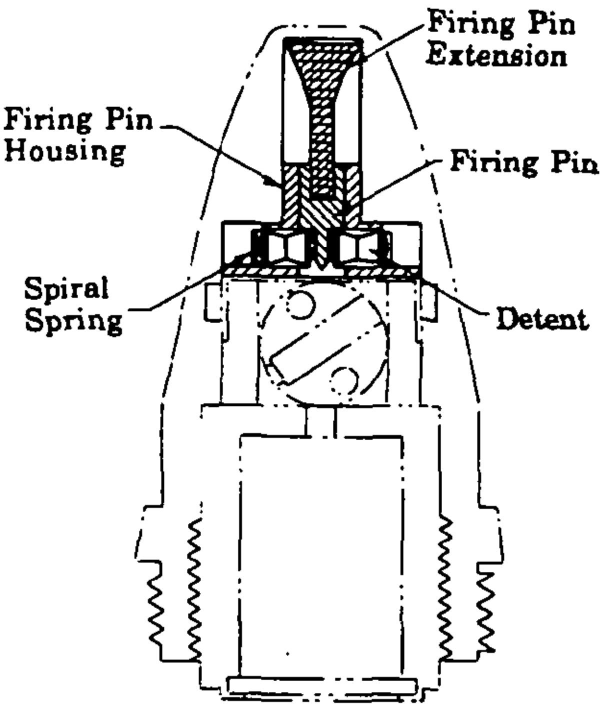


Figure 9-12. Initiating Assembly

9-4.3 TESTS AND REVISIONS

Upon completion of the preliminary design, as illustrated in Fig. 9-13, sample fuzes will be built and subjected to the testing phase described in par. 9-3.3. Design changes will be made to correct deficiencies and improve performance. Depending upon the type of program, the design status will be reviewed several times prior to entering the PPT and IOT II phases to ensure that all or most of the design requirements have been satisfied. If satisfactory test results have been achieved, larger quantities are produced and subjected to the testing described in par. 9-3.4. When the fuze passes this series of tests and becomes type classified, the design and development team has achieved its goal.

9-5 SETTING OF A FUZE

To meet a diversity of tactical requirements and to reduce inventories, many fuzes are designed to perform more than one function. The paragraphs that follow discuss some of the methods employed for setting functions such as superquick, delay, proximity, and time into fuzes. Tactical use

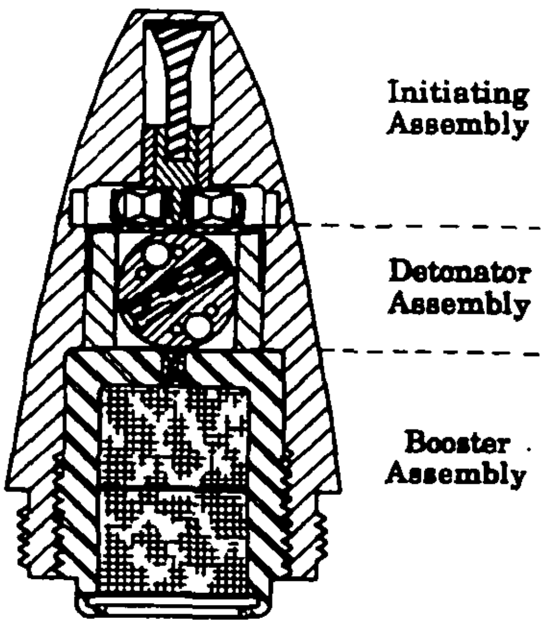


Figure 9-13. Complete Fuze Assembly

establishes the operational requirements and hence the need for flexibility in setting fuze functions made to achieve maximum effectiveness against a variety of targets.

The designer must include manpower and personnel integration MANPRINT inputs to ensure that a fuze can be quickly and easily set in the field. A number of design considerations for designing the fuze-setting system are (Ref. 16)

1. The fuze must be easy to set under all environmental extremes. Also it should require little training for use by average weapon crew members.

2. The numerals must be easy to read and the settings easily made under all ambient light and weather conditions. These must include night operations under lighting security, the night-lights used on armored weapon platforms, and the possibility that operators will be wearing protective masks and gloves.

3. The technique should be low cost. It must be capable of being mass-produced without the use of critical materials.

4. The setting mechanism must be compact. Future fuzes will likely have multifunction capabilities requiring high-density packaging of components.

5. The mechanism must be rugged. It must survive all expected shipping, storage, and handling environments, and the setting must not change during loading and firing.

Par. 2-6.2 discusses some of the human factors engineering aspects of setting fuzes.

9-5.1 HAND SETTING

Most of the settable fuzes in the Army inventory are of the hand- or tool-set type. Settings for superquick or delay function, proximity or near-surface-burst, and time can be hand set by the user in a variety of artillery and mortar fuzes. Par. 1-5.1 discusses the M739 point-detonating (PD) fuze, which can be set for superquick (SQ) or delay by rotating a setting device on the side of the fuze. The setting device performs the function of controlling the path of the output of a flash detonator located in the nose of the fuze. That is, when the delay mode is selected, the path to the instantaneous detonator is blocked and delay is achieved through an inertial firing pin and delay detonator, as shown in Fig. 1-31.

The M734 60-mm mortar fuze described in par. 1-6.3 has four hand-settable options: proximity, near-surface-burst, superquick, and delay. Before firing, the fuze is set to the desired mode by rotating the nose to align an arrow with the desired setting option on the fuze base.

The M577 Mechanical Time Fuze (MTF), as illustrated in Fig. 9-14 and described in par. 1-5.2, uses an odometer or a mechanical counter to display the setting, which is made through a screwdriver slot in the nose of the fuze. Although this design is less susceptible to human error in setting than the vernier type used in most of the other MTFs, it occupies a large volume and is mechanically complex.

The M732 proximity fuze, described in par. 1-5.4 and illustrated in Fig. 1-35, is set by rotating the fuze ogive relative to the base, and the time is read out on a scale engraved on the fuze base. Variable time is achieved by aligning a mechanical wiper along a variable resistor. The turning capsule joint is fairly complex and expensive, and earlier models exhibited a change in setting during firing. The problem was reduced by increasing the friction torque, but a large wrench was required to set the fuze. The latest design,

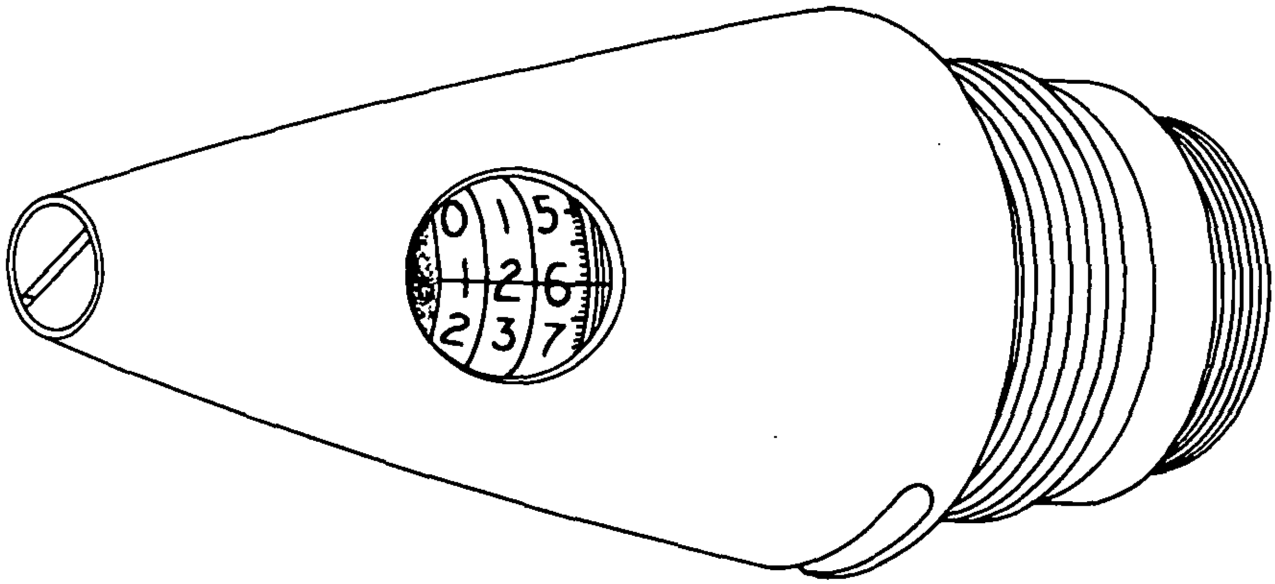


Figure 9-14. M577 MTSQ Artillery Fuze (Ref. 16)

M732E2, eliminates the slipping problem and the need to use a wrench by employing two lock buttons that must be depressed to rotate the turning capsule. Ref. 16 provides an evaluation of hand-setting techniques for proximity fuzes.

As presented in par. 2-6.2, present Army doctrine requires a rapid setting reaction time to engage multiple targets and set fuzes accurately under all battlefield conditions. This requirement is being addressed in future generations of fuzes through inductive and other electronic setting techniques, but some fuzes will also have a manual backup method of setting.

9-5.2 INDUCTIVE SETTING

Some fuzing systems will require a method of remote setting to provide a capability for quick response to multiple threats and/or to change gun fire quickly from an offensive to a defensive posture. An inductively set, multioption fuze and communication link meet this requirement.

Basically, this system will operate as shown in the block diagram of Fig. 9-15. The setter coil and the internal fuze coil form an air-coupled transformer, i.e., the voltage applied across the primary (setter coil) is reflected on the secondary (fuze coil). Fuze setting is divided into three phases: power-up, message transmission, and message read back.

In the power-up phase a short-duration energy pulse is transmitted to the fuze through the inductive coil. This energy is stored on a capacitor until power from the reserve power supply is available after launch.

During message transmission a number of bits of binary digital data are transmitted to the fuze by pulse-width modulation of the carrier frequency on the setter coil. The first series of bits program the mode—i.e., time, proximity, PD, delay—and the remaining bits program functioning or proximity turn-on time. The fuze receives and decodes the message and stores it in a register. Upon reception of the last message bit, the fuze transmits the message just received to the setter coil by alternately shorting and opening the fuze receiver coil. This effects a change in the impedance reflected to the setter coil, which is decoded and compared to the transmitted message.

A military standard is being prepared to establish standardized design criteria for signal-level parameters and message format for artillery and rocket fuzes. Additional information on inductive setters and inductively set fuzes can be found in Refs. 17 and 18.

9-5.3 HARDWIRE SETTER

The XM36E1 Fuze Setter, illustrated in Fig. 9-16, is designed to set the electronic time fuzes M587E2 and M724 to a desired function time that ranges from 0.2 to 199.9 s in 0.1-s increments (Ref. 19). The fuze setter also has the capability to set a fuze to a point-detonating function or to interrogate a previously set fuze to recall its time. Switches on the fuze setter, which may be illuminated for night operation, allow the operator to select the desired function time. The operator accomplishes setting by placing the fuze setter on the nose of the fuze. The setter has five contacts that

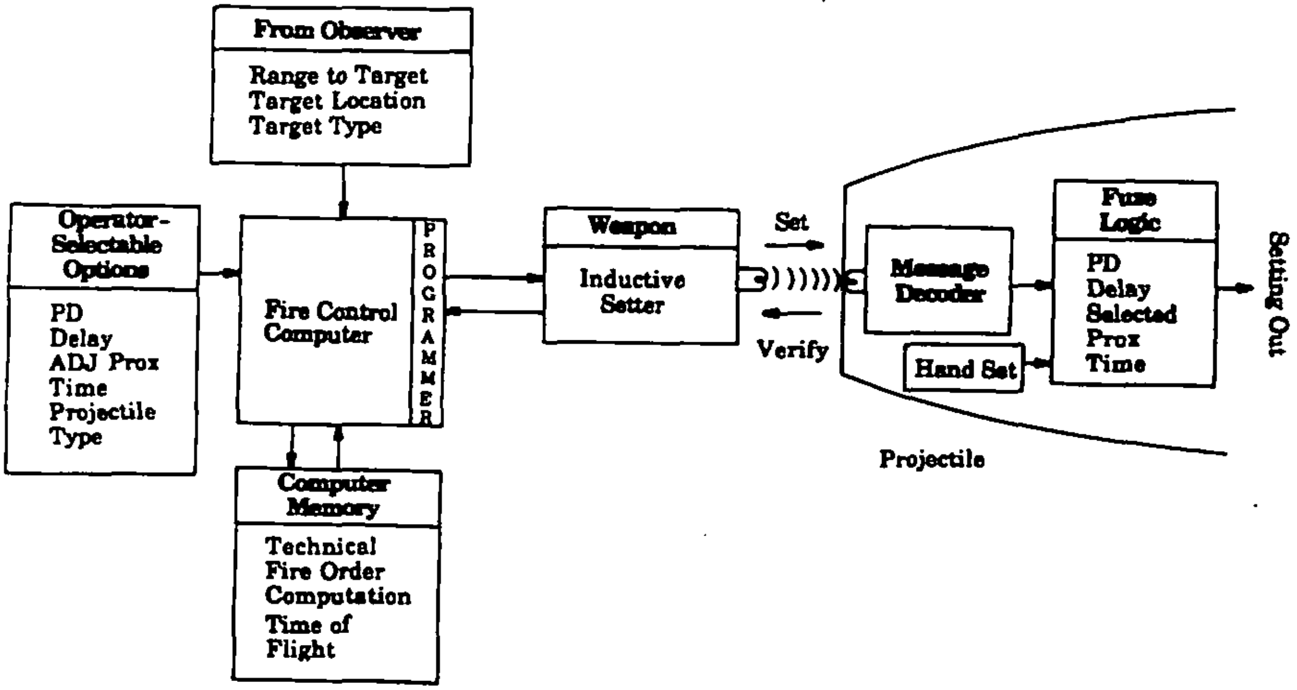


Figure 9-15. XM773 Multioption Fuze/Artillery Future Weapon Interface

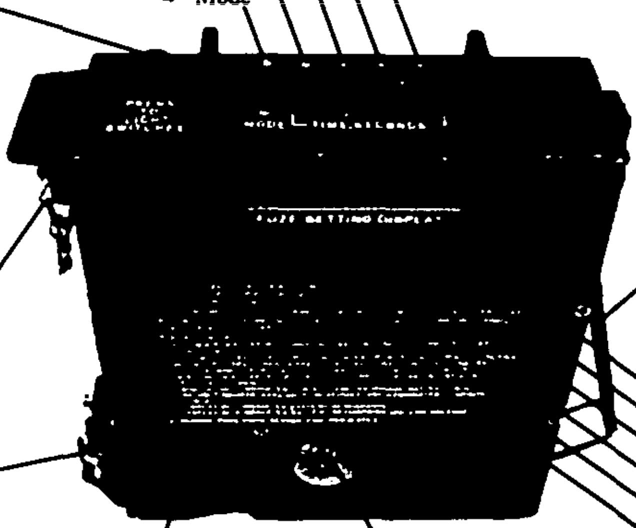


Figure 9-16. M36E1 Fuze Setter Operational Features (Ref. 19)

interface with a central contact and two concentric setting rings on the fuze. Within 1 s after the electrical contacts of the self-aligning guide of the fuze setter are connected, the correct operation of the fuze is verified and the actual time set into the fuze is displayed by the light-emitting diodes of the setter.

The fuze setter is completely self-contained and requires no field maintenance, except for recharging its internal battery. Other capabilities include low-battery indication, self-checking test features, remote setting of fuzes, operation over wide operating and storage temperatures, and ruggedness to survive field environments.

9-5.4 RADIO FREQUENCY (RF) REMOTE SETTING

This system uses a radio frequency link to communicate with gun-fired munitions immediately after launch. A microwave transmitter is located within the launch vehicle and interfaces with the fire control system. A small, rugged antenna is the only addition required to the exterior of the vehicle. To complete the RF link, the munition contains a fuze that accepts the transmitted signal. The fuze consists of an antenna, receiver, digital circuitry, power supply, and the necessary SAD for the particular munition. Communication between the transmitter and fuze receiver occurs within 3.7 m (12 ft) of the muzzle after the munition has been fired. Data communicated can be a time fuze setting, a mode selection (PD, PD delay, etc.), or any other useful information. The feasibility of this system was demonstrated in an exploratory development program for a tank artillery round, but it has not been fielded because some communication difficulties were encountered at full charge due to excessive ionized gases at the muzzle. This problem was corrected by putting an ionization suppressant in the propellant.

There is additional information on RF remotely set data links in Refs. 20 and 21.

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CHAPTER 10
FUZES LAUNCHED WITH HIGH ACCELERATION

Fuzes used in gun-fired munitions experience high acceleration and severe environmental forces. This chapter covers methods of designing fuzes to withstand these forces to ensure bore safety and methods of achieving two independent safety features that will respond to the launch environment.

The use of spin and setback are discussed as the most commonly used environments for achieving safety and arming (S&A) in gun-launched munitions. Ram air and drag are discussed as alternate environments that can be used for nonspin fin-stabilized munitions.

Mechanical and electromechanical fuzes are presented with their respective advantages and disadvantages. The functions of the components of these fuzes, such as detents, springs, rotors, strikers, sliders, lockpins, and sequential leaf mechanisms, are described in detail. Sample design calculations for the actions of these components are included. Specific fuzes are cited as examples, e.g., the M223, M565, M577, M732, and M758.

Five acceleration-responsive safety mechanisms are described: linear setback pin, zigzag pin, nut and helix, rolamite, and sequential leaf system.

Special considerations in designing fuzes for the rocket-assisted projectile (RAP) are included together with a suggested electronic solution to the safety and ineffectiveness problems inherent in rocket motor malfunctions.

Means of obtaining improved setting accuracy, timing accuracy, and overhead safety for time fuzes are explained.

The improved conventional munition (ICM) (or cargo round) is described and illustrated in a specific configuration. The submunition payload and fuze are also described.

10-0 LIST OF SYMBOLS

a = acceleration, g-units
a' = creep, g-units
C_d = drag coefficient, dimensionless
D = mean diameter of spring, mm (ft)
D_H = diameter of hole for spring, mm (ft)
D_t = projectile striker diameter, mm (ft)
d_w = wire diameter, mm (ft)
F_d = drag force, N (lb)
F_s = force exerted by spring, N (lb)
F_{sp} = frictional force associated with safety pin, N (lb)
f = frictional force caused by slider shutter pressing on pin, N (lb)
G = torque caused by projectile spin, N·m (lb·ft)
G_f = frictional torque, N·m (lb·ft)
G_s = shear modulus of wire, Pa (lb·ft^2)
g = acceleration due to gravity, 9.80 m/s^2 (32.2 ft/s^2)
L_f = free length of a spring, mm (ft)
K_w = Wahl stress correction factor for round wire helical spring, dimensionless
k = spring constant, N/mm (lb/ft)
L_1 = length of spring in initial position, mm (ft)
L_2 = length of spring in final position, mm (ft)
m = mass of safety pin, kg (slug)
m_g = mass of gear segment, kg (slug)
m_s = slider mass, kg (slug)
N = number of coils, dimensionless
N_a = number of active coils, dimensionless
N_T = total number of coils, dimensionless
OD = outside diameter, mm (ft)
P_1 = load on spring in initial position, N (lb)
P_2 = load on spring in final position, N (lb)
r_p = radius to CG of sector, mm (ft)
= distance from the center of the pivot pinhole to the center of mass of the shutter, m (ft) (See Fig. 6-26.)
r_s = distance from the projectile axis to the center of the pivot pinhole, m (ft) (See Fig. 6-26.)
r_0 = radius of center of mass of slider from spin axis measured along the x-axis or measured along the direction of motion, mm (ft)
S_s = stress of maximum spring compression, MPa (lb/ft^2)
S_y = yield strength of spring material, MPa (lb/ft^2)
S_{yp} = maximum permissible stress at yield point, MPa (lb/ft^2)
s = distance, mm (ft)
t = arming time, s
= time to move a distance S, s
v = velocity of projectile, m/s (ft/s)
W_p = weight of part, N (lb)
W_s = slider weight, N (lb)
x_0 = initial compression, mm (ft)
$\ddot{x}$ = acceleration, m/s^2 (ft/s^2)
μ = coefficient of friction, dimensionless
ρ = density of air, kg/m^3 (lbm/ft^3)
ϕ = angle between slider and spin axis, rad
ϕ_0 = initial angular shutter position, rad
$\phi - \phi_0$ = angular displacement, rad
$\ddot{\phi}$ = angular acceleration, rad/s^2
ω = angular spin on velocity, rad/s

10-1 INTRODUCTION

Munitions normally are called projectiles when fired from guns, howitzers, or recoilless rifles. The projectile parts must withstand great setback forces and still retain their operability. While the projectile is in the gun tube, setback pushes all parts rearward along the munition axis. Motion in a radial direction for both arming and functioning can begin when the setback acceleration is sufficiently reduced, usually after the projectile leaves the muzzle but under some conditions just inside the muzzle.

In spin-stabilized projectiles the radial force (centrifugal) can overcome the frictional forces induced by setback and cause arming near the muzzle while the munition is still in the bore. Special measures must be used to overcome this problem.

The simplest fuze designs use mechanical arming with percussion (contact) initiation. Electronic fuzes are more complex because they have mechanical arming and such features as remote setting, safety logic, and proximity triggering by radio frequency (RF) or infrared (IR) techniques.

This chapter contains design examples for typical projectile fuze parts, i.e., springs, rotors, sliders, lockpins, and sequential leaves.

10-2 FUZE COMPONENTS FOR FIN-STABILIZED PROJECTILES

Fin-stabilized projectiles either do not experience spin or spin at a rate below that required to stabilize them. If centrifugal forces exist, they cannot be used for arming because they are not sufficiently different from the forces of normal handling. The second arming signature is usually accomplished by using ram air and/or drag forces. As with spin projectiles, initiation of fin-stabilized projectiles can be effected by a preset timer, target impact, or the proximity of the target. When more than one mode of initiation is used in a single fuze, the designation "multioption" is used.

10-2.1 COIL SPRING DESIGN

One common problem for the fuze designer is to design a spring that will support a certain load. Usually the designer calculates the load and then fits a spring that will support the load into the available space. The designer determines wire size and material, number of coils, and free height necessary to fulfill the spring requirements. An approximate design is made that may be modified later, if necessary. The paragraphs that follow illustrate this procedure.

10-2.1.1 Restraining Motion

As an illustrative example, design a striker spring for a fuze head assembly such as the one shown in Fig. 10-1. The spring is required to prevent ram air forces, i.e., exterior ballistic forces experienced in flight, from driving the firing pin into the detonator until the target is struck. The material chosen for the spring is ASTM A228 music wire. The given data are

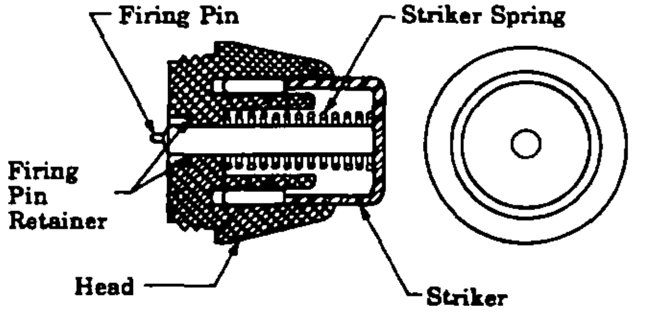


Figure 10-1. Fuze Head Assembly

Projectile striker diameter, D_s = 20.8 mm (0.068 ft*)
Allowable space for spring diameter, D_H = 12.7 mm (0.042 ft)
Length of spring under initial load, L_1 = 31.8 mm (0.104 ft)
Length of spring at full striker displacement, L_2 = 19.0 mm (0.063 ft)
Drag coefficient, C_d = 0.35 dimensionless
Air density, ρ = 1.29 kg/m^3 (0.0806 lbm/ft^3)
Shear modulus of wire, G_s = 79,000 MPa (16.5 × 10^8 lb/ft^2)
Projectile velocity, v = 213 m/s (700 ft/s).

The objective is to determine d_w, D, and N such that S_s will be less than S_y where

d_w = diameter of wire, mm (ft)
D = mean diameter of spring, mm (ft)
N = number of coils, dimensionless
S_s = stress at solid height or maximum compression, MPa (lb/ft^2)
S_y = yield strength of spring material, MPa (lb/ft^2).

The drag force F_d on the striker is determined by Eq. 5-2. In the International System of Units (SI)

$$F_d = \rho v^2 D_s C_d, \text{ N} \quad (10\text{-}1a)$$
$$= 1.29\,(213)^2\,(20.8\times10^{-3})^2\,0.35$$
$$= 8.86 \text{ N}$$

*Although inch is a more convenient unit to use with fuzes, foot is used to simplify the equations.

or in the English system of units

$$F_d = \frac{\rho v^2 D_s^2 C_d}{32.17}, \text{lb} \quad (10\text{-}1b)$$

$$= \frac{0.0806\,(700)^2\,(0.068)^2\,0.35}{32.17}$$

$$= 2.0 \text{ lb.}$$

A safety factor of 1.5 is chosen to ensure that the ram air forces cannot compress the striker. Therefore, the load P_1 on the spring at L_1 is equal to

$$P_1 = 1.5F_d$$
$$= 1.5 \times 8.86$$
$$= 13.3 \text{ N } (3.0 \text{ lb})$$

where

P_1 = load on spring in initial position, N(lb).

If it is assumed that the spring must exert a load of 50% greater at the fully compressed length of 19 mm (0.0625 ft), the spring constant k can be obtained from

$$k = \frac{P_2 - P_1}{L_1 - L_2} = \frac{20 - 13.3}{31.8 - 19} = 0.52 \text{ N/mm (36 lb/ft).} \quad (10\text{-}2)$$

10-2.1.2 Wire Diameter

An initial estimate of the wire diameter d_w may be obtained from the following equation:

$$d_w = \sqrt[3]{\frac{2.55P_2D_H}{S_s}}, \text{mm (ft)} \quad (10\text{-}3)$$

where the stress correction factor for direct and torsional shear is assumed to be 1.

For a first approximation assume S_s = 689 MPa (99,931 lb/in.^{2}) and $D = D_H$

$$d_w = \sqrt[3]{\frac{2.55 \times 20 \times 12.7}{689}}, \text{mm (ft)}$$
$$= 0.98 \text{ mm.}$$

The outside diameter OD of the spring to allow for clearance may be obtained by

$$OD = 0.95\,D_H \text{ for } D_H \geq 12.7 \text{ mm (0.042 ft)} \quad (10\text{-}4)$$

$$OD = 0.95 \times 12.7 = 12.1 \text{ mm (0.040 ft)}$$

therefore, D = 12.1 − 0.98 = 11.1 mm (0.036 ft)

10-2.1.3 Number of Coils

The number of active coils N_a may be obtained from

$$N_a = \frac{G_s d_w^4}{8D^3k} \quad (10\text{-}5)$$

$$= \frac{79{,}000 \times (0.98)^4}{8\,(11.1)^3 \times 0.52}$$

$$= 12.8 \text{ or } 13 \text{ coils.}$$

If the ends are to be square, the total number of coils N_T will be

$$N_T = N_a + 2 = 13 + 2 = 15 \text{ coils.} \quad (10\text{-}6)$$

The free length L_f of the spring can now be calculated from

$$L_f = \frac{P_1}{k} + L_1 = \frac{13.3}{0.52} + 31.8 = 57.4 \text{ mm (0.187 ft).} \quad (10\text{-}7)$$

The stress at maximum compression S_s may now be determined from

$$S_s = \frac{2.55P_2DK_w}{d_w^3}, \text{MPa (lb/ft}^2) \quad (10\text{-}8)$$

where

K_w = Wahl stress corrective factor for round wire helical springs, dimensionless.

K_w can be obtained from

$$K_w = \frac{4\left(\frac{D}{d_w}\right) - 1}{4\left(\frac{D}{d_w}\right) - 4} + \frac{0.615}{\frac{D}{d_w}}, \text{dimensionless.}$$

This equation for K_w can be simplified to the following if only the stress correction for direct shear is considered:

$$K_w = 1 + \frac{0.5}{\frac{D}{d_w}}, \text{dimensionless.}$$

Using the simplified equation for K_w,

$$K_w = 1 + [0.5/(11.1/0.98)] = 1.04.$$

$$\text{Therefore, } S_s = \frac{2.55 \times 20 \times 11.1 \times 10^{-3} \times 1.04}{(0.98 \times 10^{-3})^3}$$

$$= 626 \text{ MPa } (13.1 \times 10^6 \text{ lb/ft}^2).$$

From Fig. 10-2 the minimum ultimate tensile strength for ASTM A228 music wire with a diameter of 0.98 mm is 2171 MPa (45.3×10^6 lb/ft^2). Table 3 in Ref. 1 indicates that the torsional yield point for ferrous materials as a percent of tensile strength should not be greater than 45% for zero residual stress. Therefore, the maximum permissible stress at yield point S_{yp} is

$$S_{yp} = 2171 \times 0.45 = 977 \text{ MPa } (20.4 \times 10^6 \text{ lb/ft}^2).$$

Since the value of actual torsional stress of 626 MPa (13.1×10^6 lb/ft^2) is less than the maximum permissible yield point for music wire, the spring design is acceptable.

10-2.1.4 Controlling Motion

Helical springs also may be used to control the motion of a mass. The locking action of a setback pin on another pin is an example. A suggested interlock is shown in Fig. 10-3.

During launching, setback forces drive the setback pin rearward. This action releases the safety pin so that the safety pin spring can move the pin outward. Because the setback pin is free to return following launch, the designer must be certain that the safety pin moves far enough during or just after launch to prevent the setback pin from reentering the locking hole after setback forces cease.

The motion of the safety pin is controlled by the frictional force F_{sp}

$$F_{sp} = \mu W_p a, \text{ N (lb)} \qquad (10\text{-}9)$$

where

μ = coefficient of friction, dimensionless
W_p = weight of part, N (lb)
a = acceleration, g-units.

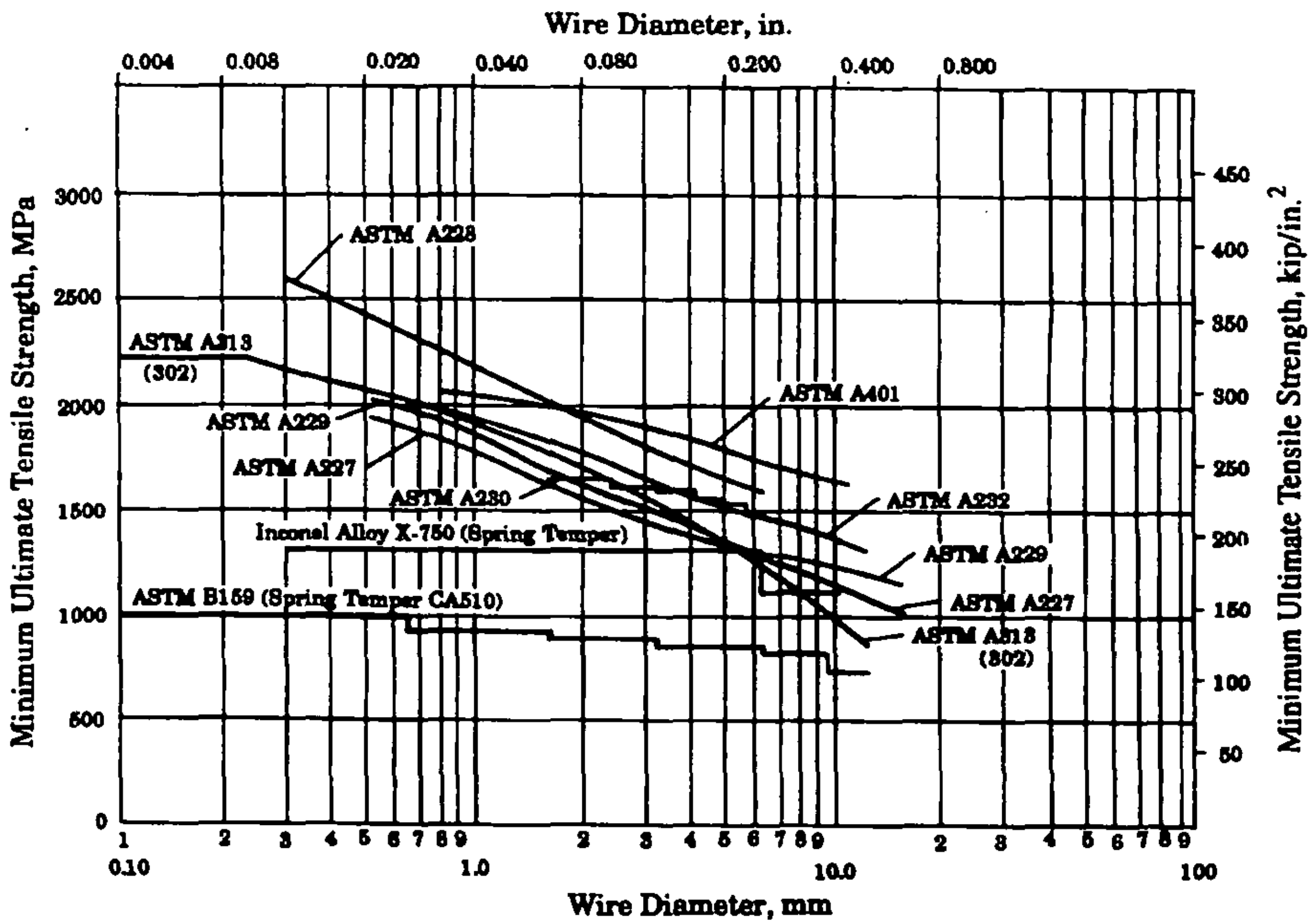


Figure 10-2. Minimum Tensile Strengths of Spring Wire (Ref. 1)

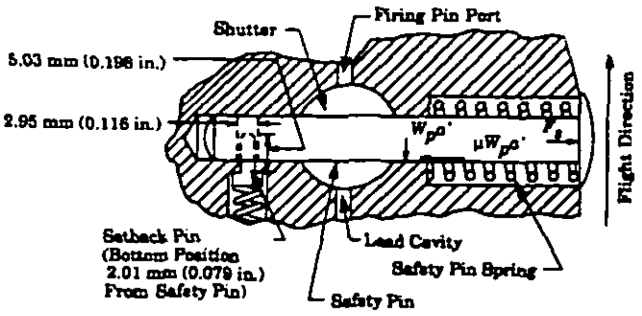


Figure 10-3. Interlocking Pin

During setback, the acceleration a is so great that F_{ip} exceeds the force F_s exerted by the spring, which predicts that the safety pin will not move during launch. The safety pin must move fast enough, however, to keep the setback pin from reentering the locking hole. (This is a marginal condition.)

Let the designer set the condition so that the safety pin will move a distance greater than 1/4 the diameter of the setback pin before this pin returns to lock the safety pin. The mass of the safety pin m is 6.64×10^{-4} kg (0.455×10^{-4} slug), its spring constant k is 0.23 N/mm (15.72 lb/ft), and the coefficient of friction μ is assumed to be 0.20. This safety pin is acted upon by the spring, the friction force resulting from creep $\mu W_p a$, and the frictional force f caused by the slider shutter pressing on the pin. The equation of motion for the safety pin is similar to Eq. 6-12:

$$t = \sqrt{\frac{m}{k}} \mathrm{Cos}^{-1}\left(\frac{kS + f + \mu W_p a'}{kx_0 + f + \mu W_p a'}\right), \text{s} \quad (10\text{-}10)$$

where

t = time to move a distance S, s
m = mass of safety pin, kg (slug)
S = distance, mm (in.)
f = frictional force caused by the slider shutter pressing on pin, N (lb) = 1.11 N (0.25 lb)
x_0 = initial compression, mm (ft)
a' = creep, g-units = 10 g.

To solve for the time t to move the distance S, the initial compression x_0 of the spring must be known. This is typical of design problems—assumptions are made, computations are performed, and then the original dimensions are corrected if necessary.

Hence, if x_0 = 38 mm (0.125 ft) and if the pin must move 0.74 mm (2.42×10^{-3} ft), which is one-fourth the diameter of the setback pin, the time interval by Eq. 10-10 will be 1.1×10^{-3} s. How far will the setback pin move in this time? Fig. 10-3 shows the pertinent dimensions for the setback pin. Let the spring constant k be 0.23 N/mm (15.72 lb/ft) and the pin weight 9.79×10^{-3} N (0.0022 lb). To obtain the greatest distance the pin will move, the effects of friction are neglected. If we assume that x_0 for the setback pin is approximately 11.4 mm (3.75×10^{-2} ft), then from Eq. 6.5 x = 9.9 mm (3.25×10^{-2} ft), which means that the pin will move 1.5 mm (5×10^{-3} ft). Therefore, the setback pin must be bottomed at least 1.5 mm away from the safety pin to prevent reentry within the time frame.

The setback pin will strike the safety pin sometime later than 1.1 ms, and the pin will not be able to reenter the hole. Hence the fuze will continue to arm.

10-2.2 SEQUENTIAL LEAF ARMING

For projectiles that do not rotate, one of the arming signatures is usually provided by setback forces. The design feature sensing setback, however, must be able to discriminate against firing setback and impact forces due to drops or rough handling.

Perhaps the easiest way to discriminate between the two is to build a device that is actuated only by the accelerations present under firing. An approximation of this acceleration can be obtained with a sequential leaf mechanism (Ref. 2). Its main design feature is the requirement of an extended acceleration, i.e., one much longer than that present in a drop impact into any medium usually encountered. With a provision for return to the unarmed position, this device can withstand many drop impacts without becoming committed to arm.

Sequential leaf mechanisms are designed to respond to a threshold acceleration sustained for some period of time. The product of time and acceleration must be greater than that resulting from a drop but less than that produced by a properly fired projectile.

The three-leaf mechanism used as the safety device in the 81-mm Mortar Fuze, M532, is similar to that shown in Fig. 6-24. Operation is as follows: Upon setback, the first leaf turns against its spring; when it rotates far enough, it permits the second leaf to rotate, and that in succession releases the last leaf; the last leaf moves out of the way to release the arming rotor.

This mechanism uses a large portion of the area under the acceleration curve because successive leaves are assigned to successive portions of the curve, as shown in Fig. 6-25. Each leaf is designed to operate at a slightly different minimum acceleration level by using identical springs with geometrically similar leaves of different thicknesses. Each leaf operates when it experiences approximately half of the average acceleration occurring in the interval to which it is assigned. The total design velocity change for the three-leaf system shown in Fig. 6-24 is approximately 33.5 m/s (110 ft/s).

This mechanism has been shown to be safe when subjected to 12-m (40-ft) drops because the impact velocity in a 12-m (40-ft) drop—about 15 m/s (50 ft/s)—is less than half the design velocity change for the mechanism. A parachute drop, however, imposes the most stringent requirements on this mechanism (Ref. 3). Ref. 3 specifies that the fuze must withstand the ground impact forces that result when it is delivered by parachute. The mechanism prevents arming when the ammunition is delivered by a properly functioning parachute because the impact velocity is less than that for a 12-m (40-ft) free-fall drop. If the parachute malfunctions during delivery, however, the velocity change at impact is greater than the design velocity change. Accordingly, it is possible that a fouled parachute delivery could produce the minimum design acceleration for a length of time sufficient to arm the mechanism.

10-2.3 OTHER COMPONENTS

Several other arming mechanisms used to differentiate between setback and handling shocks are shown in Figs. 10-4, 10-5, and 10-6.

The first, the nut and helix sensor arming mechanism shown in Fig. 10-4, is essentially a spring-biased nut running on a long lead screw. Although it offers advantages over the linear setback pin, it does not have the start-stop-start cycle of the zigzag sensor; it is, however, cheaper to manufacture. The equation of motion for the nut and helix is the same as that for a single stage of a zigzag system, which is described in par. 6-4.6. The one-stage drive curve of Fig. 6-14 applies to this system.

The negator extension spring used as a one-piece setback sensor (Fig. 10-5) offers several improvements compared to the simple linear setback pin of Fig. 10-3. In operation, the negator acts as both the spring and sensing mass, wherein the ratio of the spring force to the mass of the inert coils determines the bias levels. The coil engages an inclined ramp on the rotor and moves in a guide channel in the housing, which provides lateral control and locks the rotor in the

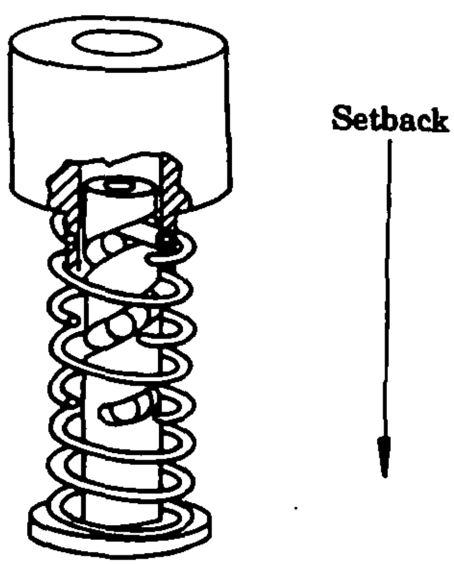


Figure 10-4. Nut and Helix Setback Sensor

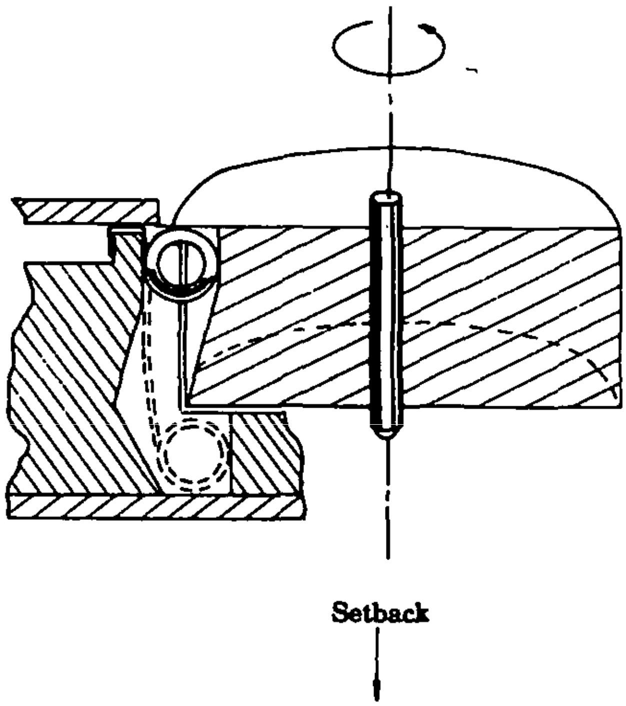


Figure 10-5. Negator Spring Setback Sensor

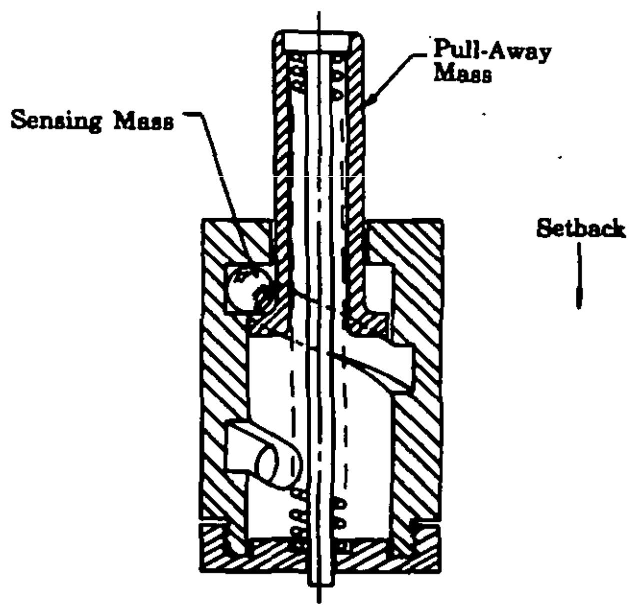


Figure 10-6. Pull-Away Mass/Unbiased Setback Sensor

unarmed position. After completion of movement under setback, the coil disengages from the rotor and locks in a cutout; this ensures no further interference to rotor movement. The significant advantages of the negator extension spring over the linear setback pin are

1. The constant force characteristics of the negator maximize the velocity change (kinetic energy) required for a given force and stroke.

2. The device has a very long operating stroke for a given vertical space, which maximizes the required velocity change.

3. The fact that the coil must unroll enables the device to act as an integrating accelerometer with a scale factor of one-half to two-thirds, which increases the velocity change requirement by at least 50% over that for the purely linear system.

Another system that is superior to the linear setback pin in safety quality is the ball and helix setback sensor. This mechanism consists of a spring-biased linear setback weight that controls a sensing ball located in a helical track, as shown in Fig. 10-6. The ball prevents the setback weight (or pin) from disengaging from the safety and arming device (SAD) by the length of its diameter. Upon setback the weight moves back and allows the ball to roll back around the helical track. If the setback endures for a normal launch time, the ball can escape through a radial port and thus permit the pin to withdraw from the SAD at cessation of setback. The time required for the ball to travel around the helix is the factor that differentiates this device from the linear setback pin. For accelerations produced by accidental drops, the setback weight resets to the safe position prior to the escape of the ball from the exit port. More detail on this system is given in Ref. 4.

10-3 FUZING FOR SPIN-STABILIZED PROJECTILES

The spin environment of spin-stabilized projectiles is of major importance in fuze arming operations. The spin rates imparted by zone-firing weapons and larger caliber (155-mm and 8-in.) weapons must be examined in light of an accidental roll of the munition down an incline during handling, which could produce spin rates near or equal to those imparted by the guns. The possibility of this situation demonstrates the soundness of the requirement that the fuze must be responsive to two independent arming environments.

Sliders or interrupters can be moved by centrifugal force, rotors can be repositioned by turning, and detents can be withdrawn against spring pressure. Pars. 6-2.2.2, 6-3, 6-4.1, 6-4.3, 6-4.6, and 6-5 describe the details of the use of centrifugal spin forces.

10-3.1 SLIDERS

Sliders are a convenient way to hold the detonator out of line. The designer is interested in the time after firing during which the fuze is safe or the slider has not moved. The designer calculates this time from the estimated dimensions of the slider. The time interval requirement is based on three considerations, which are

1. Because the fuze must be bore safe, the time interval for sliders must not begin until after the projectile leaves the gun. (The separate time delay, required while the fuze is in the bore, is usually achieved by setback friction.)

2. The fuze must not arm below a certain spin velocity. (The centrifugal field is too weak to cause arming.)

3. The fuze definitely must arm above a certain spin velocity.

These concepts are discussed more fully in par. 9-2.2.

If the sliders are placed at an angle of less than 90 deg to the spin axis, setback forces have a component that opposes the radial outward motion of the slider. This provision can satisfy Consideration 1. For a nose fuze a convenient angle is one that makes the slider perpendicular to the ogive. An angle of 75 deg serves as a first approximation. The final angle depends on the ratio of setback to centrifugal forces.

A retainer spring can satisfy Consideration 2 as well as the safety requirements for rough handling. The spring constant and the position of the slider mass center with respect to the spin axis must be properly adjusted. Consideration 3 is also satisfied with this measure.

Since the slider generally will continue to move once it starts, the designer needs to know the conditions under which the slider will move. This can be determined by the following equation (See Fig. 10-7.), which expresses the behavior of the system at its initial position:

$$m_s\ddot{x} = -kx_0 - W_s a'(\sin\phi + \mu\cos\phi) \quad (10\text{-}11)$$
$$+ m_s\omega^2 r_0(\cos\phi - \mu\sin\phi), \text{ N (lb)}$$

where

m_s = slider mass, kg (slug)
W_s = slider weight, N (lb)
r_0 = radius of center of mass of slider from spin axis measured along the x-axis or measured along the direction of motion, m (ft)
ω = angular spin velocity, rad/s
ϕ = angle between slider and spin axis, rad
$\ddot{x}$ = acceleration, m/s² (ft/s²).

For Consideration 1, $\ddot{x} < 0$ for all possible combinations of values of ω and a'; for Consideration 2, $\ddot{x} < 0$ for $a' = 0$ and where ω is the lower spin specification; and for Consideration 3, $\ddot{x} > 0$ where a' is the creep deceleration and ω is the upper spin specification.

For example, it is desired to find the angular spin velocity necessary to arm a fuze having the slider shown in Fig. 10-7. The data are ϕ = 15 deg, x_0 = 7.6 mm (2.49×10^{-2} ft), r_0 = 1.6 mm (5.25×10^{-4} ft), μ = 0.2, spring constant k = 0.175 N/mm (12.0 lb/ft), W_s = 0.093 N (0.021 lb), and

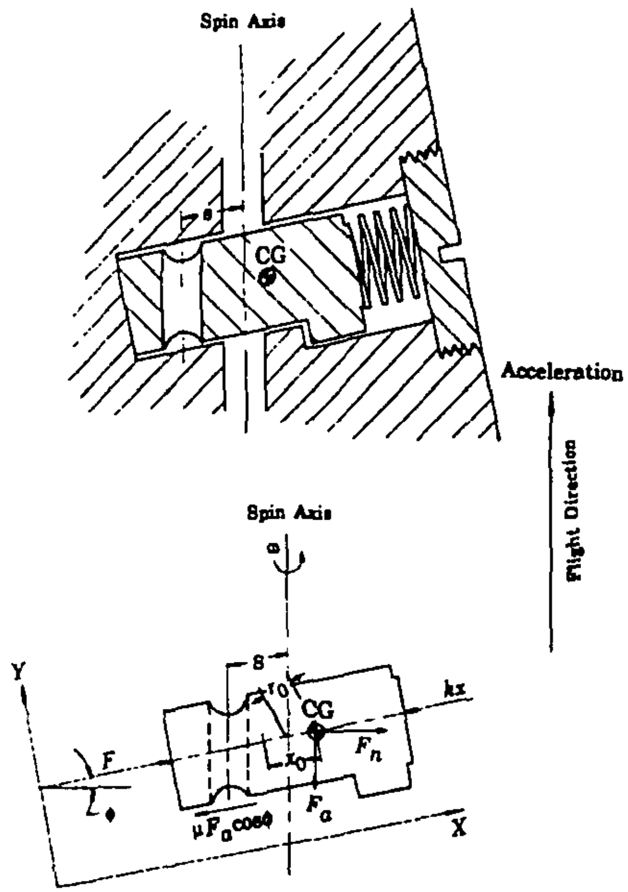


Figure 10-7. Transverse Motion of Centrifugally Driven Slider

$m_s = 0.95 \times 10^{-2}$ kg (6.52×10^{-4} slug). Table 10-1 shows a summary of the conditions and calculations. For $\ddot{x} < 0$, $kx_0 + W_s a' (\sin\phi + \mu\cos\phi) > m_s\omega^2 r_0 (\cos\phi - \mu\sin\phi)$, which implies that

$$\omega^2 \le \frac{kx_0 + W_s a' (\sin\phi + \mu\cos\phi)}{m_s r_0 (\cos\phi - \mu\sin\phi)}, \frac{\text{rad}^2}{\text{s}^2}. \quad (10\text{-}12)$$

The specifications state that this fuze must not arm at 2400 rpm but must arm at 3600 rpm. The data given in Table 10-1 satisfy this specification.

10-3.2 ROTOR DETENTS

Fig. 10-8 shows another detent system used in fuzes M724 and M732 that secures a dynamically and statically unbalanced disk rotor in the unarmed position. The rationale of using two opposing detents is to ensure that one is moved toward the lock position to resist those handling shocks that would move the other out of lock. This feature is easily attained with conventional cylindrical detents; however, with the "latch"-type detent the lines of force for impacts occurring at Points I and II must be parallel and run through the centers of gravity (CGs) and the centers of the pivots of the detents to avoid arming torques simultaneously on both detents during handling. Of equal importance is the angle of contact between the engaging tips of the detents and the notches in the rotor. Ideally, the normal to those surfaces should pass through the pivot points of the detents to avoid arming torques from the rotor simultaneously on both detents under handling shocks. Some bias is necessary, as shown in lines of force A_1 and B_1 in Fig. 10-8, to avert rotor bind on the detents, which could result in a lockup. Both detents must be identical for ease of assembly. The equation of motion for this type of detent is similar to that for the rotary shutter given in par. 10-3.3. In this case the frictional torque also includes the interaction between the shutter and the detent. Because of manufacturing tolerances, however, it is conceivable with this type of detent that some handling shocks could cause arming of the system. This design is a clear illustration of the necessity for a separate and independent lock controlled by another environment, e.g., setback.

Fig. 10-9 shows a linear detent used as a setback-actuated pin. Although not as effective as the zigzag pin, which is discussed in par. 6-4.6, it offers significant safety in applications for which space is limited. The problem of reentry of the withdrawn pin prior to arming (as in gun launch) is solved in the case shown by a tilt/lock action under spin force.

TABLE 10-1. SUMMARY OF CONDITIONS AND CALCULATIONS FOR DETERMINING ANGULAR SPIN VELOCITY TO ARM A FUZE

CONDITION	$\ddot{x}$	a'	ω	ARM	SPRING IN USE	a', g-units	kx_0, N (lb)	ω TO ARM, rev/min
1	< 0	Very large setback	Reasonable value	No	No	13,600	0	62,000
	< 0	Muzzle value setback	Muzzle spin	No	No	2,500	0	26,000
2	< 0	0	Muzzle spin	No	Yes	0	1.33 (0.300)	2,980
3	> 0	< 0 (creep)	Muzzle spin	Yes	Yes	–10	1.33 (0.300)	2,460

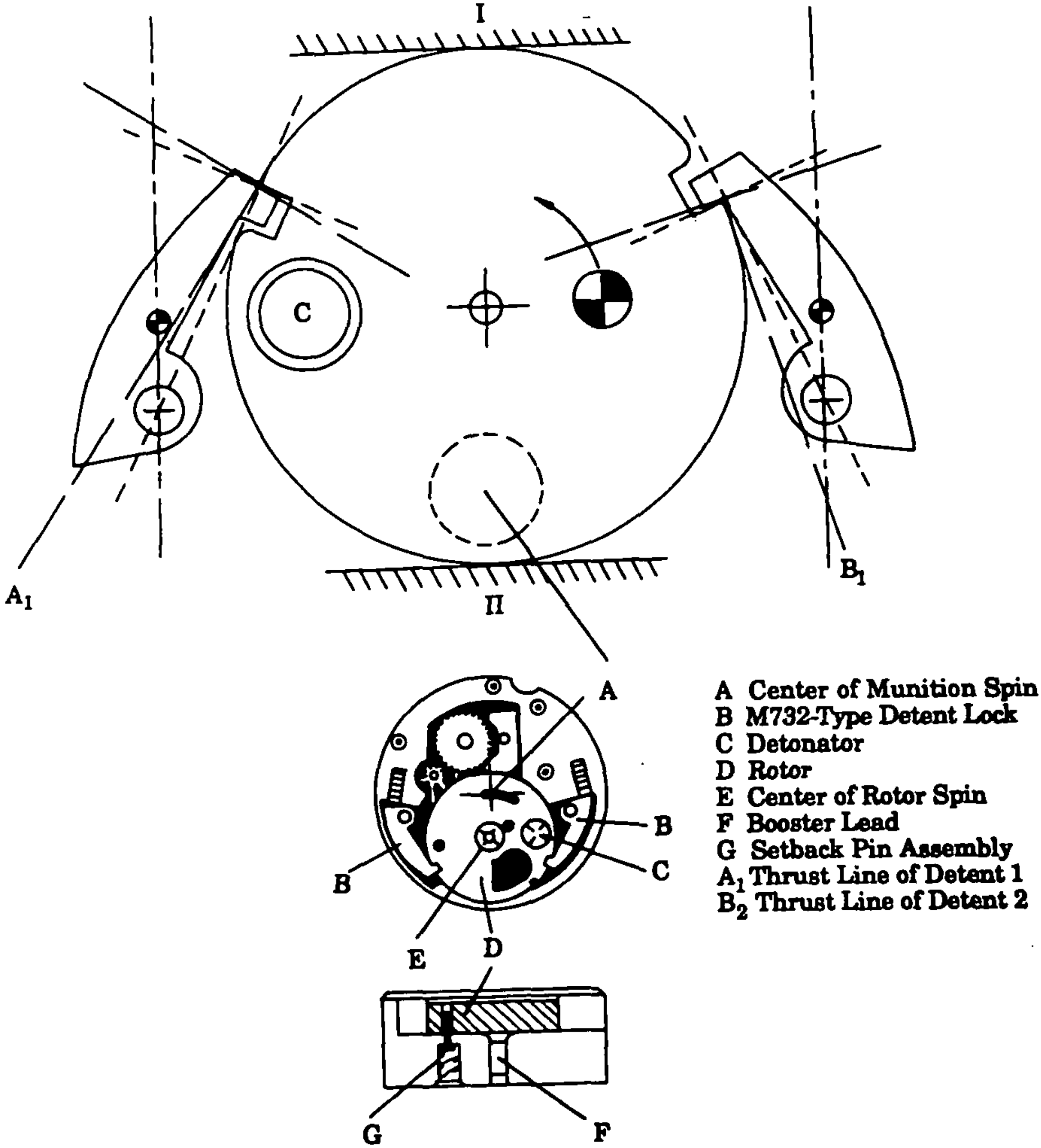


Figure 10-8. SAD Mechanism With M732-Type Detent Lock

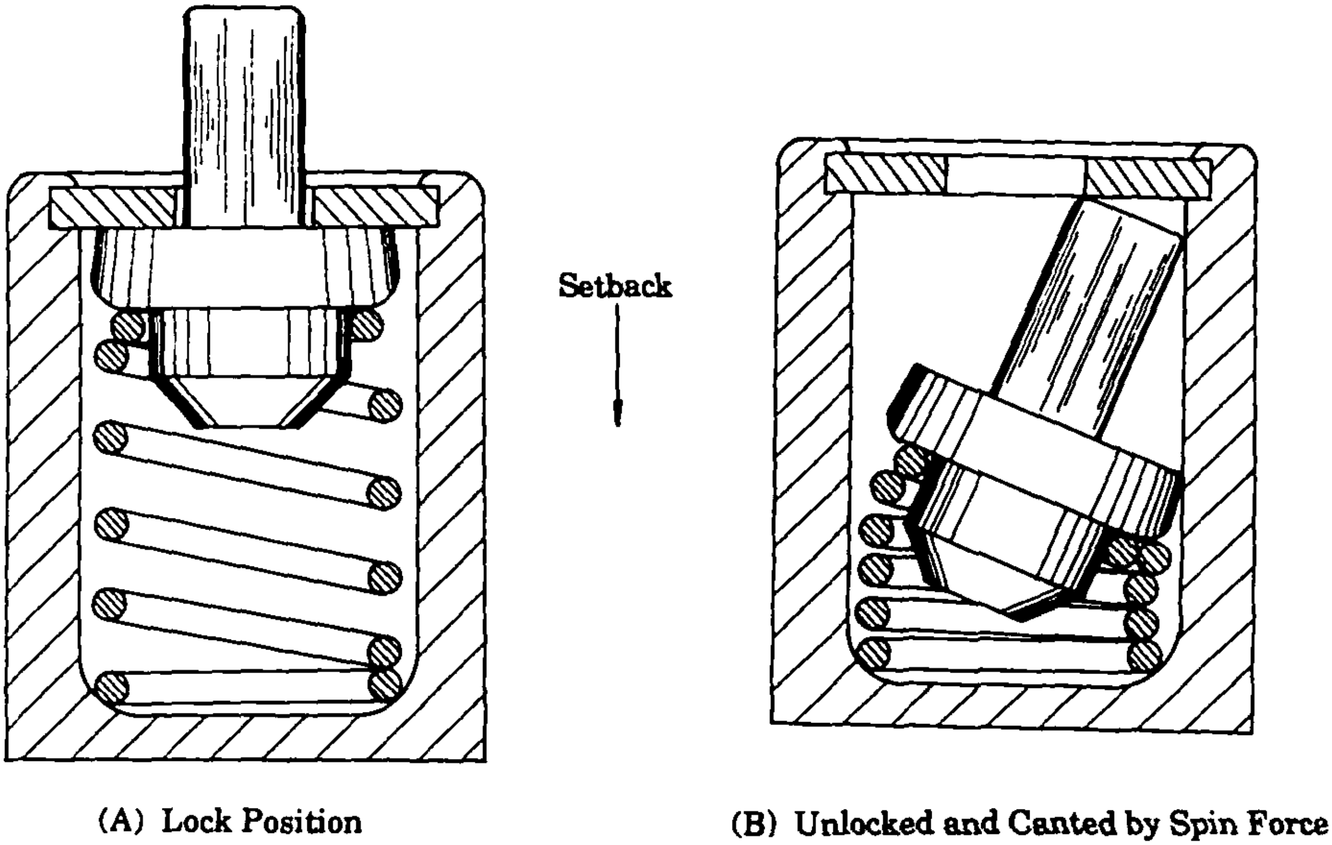


Figure 10-9. Setback Pin Design

10-3.3 ROTARY SHUTTERS

Because the bursting charges of high-explosive (HE) projectiles are relatively insensitive to shock, a comparatively powerful detonation is necessary to initiate them. This additional force is provided by a booster charge. For example, the Booster M21A4 is used in certain fixed, semifixed, and separate-loading projectiles. Fig. 10-10 shows this booster and two major parts: (1) the booster cup that contains an explosive charge and (2) a brass body that contains an explosive lead and a detonator-rotor assembly. The latter provides an out-of-line feature within the booster to make it safe if handled alone. The rotary shutter is used to pivot the detonator into alignment with the other explosive elements in the fuze and the booster. The center of gravity of the rotor is not on the centerline of the rotor pivot and not on the spin axis; therefore, the centrifugal force that develops will rotate the rotor. Detents are used to lock the rotor in both the unarmed and armed positions.

The shutter action is described in par. 6-5.4 and illustrated in Fig. 6-26. The torque caused by the projectile spin is calculated with Eq. 6-50, in which the driving torque term G is

$$G = m_s\omega^2 r_s r_p \sin\phi, \text{ N}\cdot\text{m (lb}\cdot\text{ft)} \quad (10\text{-}13)$$

where

r_s = distance from the projectile axis to the center of the pivot pinhole, m (ft) (See Fig. 6-26.)

r_p = distance from the center of the pivot pinhole to the center of mass of the shutter, m (ft) (See Fig. 6-26.)

m_s = mass of shutter, kg (slug)

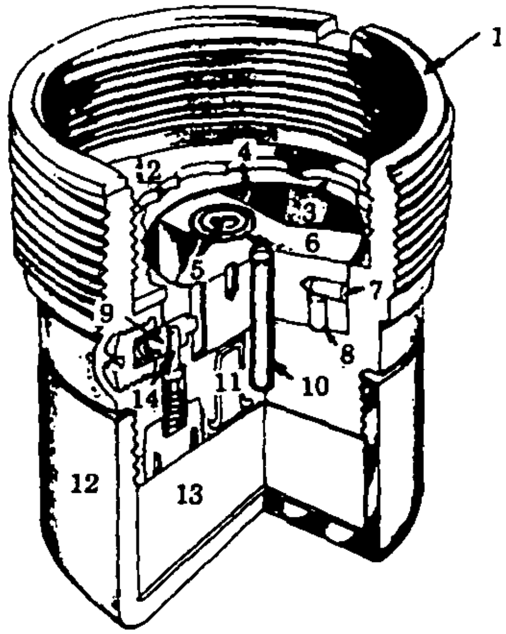
ω = angular velocity, rad/s

ϕ = angle between r_s and r_p, rad (See Fig. 6-26.).

With the limited space allotted to the rotor, r_s and r_p will be small—on the order of 2.54 mm (8.3×10^{-3} ft).

For the shutter to turn, G must be greater than the frictional torque G_f (after the locking detents are removed). When the angle becomes 180 deg, the driving torque ceases; therefore, the detonator must move into alignment before ϕ becomes 180 deg. Most rotors are designed so that ϕ is at most 150 deg at alignment.

Fig. 6-26 shows the actual rotary shutter of Booster M21A4. Basically, the shutter, which fits into a circular cavity, is a disk with two large segments removed. The segments are cut out to create an unbalance in order to shift the mass center to a point diametrically opposite to the detonator. This will ensure that the detonator can move toward the spin axis. Since these rotors can be sliced from an extruded



1 Body
2 Cover
3 Onionskin Paper
4 Rotor Stop Pin
5 Detonator
6 Rotor
7 Rotor Lockpin
8 Rotor Lockpin Lock
9 Centrifugal Pin
10 Rotor Pivot Pin
11 Lead
12 Booster Cup
13 Booster Charge
14 Centrifugal Pin Lockpin

Figure 10-10. Booster M21A4

bar or made by a sintered metal technique, it is not difficult to produce this shape.

If the frictional torque G_f effectively acts at the center of gravity, it will be

$$G_f = \mu W_s a' r_p \text{, N·m (lb·ft)} \qquad (10\text{-}14)$$

where

a' = setback or creep acceleration, g-units
W_s = weight of rotor, N (lb).

For the rotor to move, G must be greater than G_f or

$$\omega^2 r_s \sin\phi > a' \mu g \qquad (10\text{-}15)$$

where

g = acceleration due to gravity, m/s^2 (ft/s^2).

In this example, r_s = 5.6 mm (1.83 × 10^{-2} ft), ϕ = 35 deg, and μ = 0.2. Using Eq. 10-15, the spin rate required for arming at these conditions is 3490 rad/s (555 rev/s) for setback and 78 rad/s (12 rev/s) for creep conditions. Thus the booster will not arm during setback but will arm once the projectile is out of the muzzle. Arming probably occurs largely in that interval when setback changes to creep and the g forces are momentarily zero.

To obtain a rough estimate of the time to arm, the designer may use the expression

$$\phi - \phi_0 = \frac{\ddot{\phi} t^2}{2} \text{, rad} \qquad (10\text{-}16)$$

where

$\phi - \phi_0$ = angular displacement, rad
$\ddot{\phi}$ = angular acceleration (assumed constant for the time t), rad/s^2
t = arming time, s.

From Eq. 6-50—with the conditions m_s = 0.0234 kg (0.0016 slug), ω = 12,000 rpm, r_p = 2.54 mm (8.3 × 10^{-3} ft), and I = 1.9 × 10^{-6} kg·m^2 (1.4 × 10^{-6} slug·ft^2)—the initial acceleration, $\ddot{\phi}$ = 0.154 × 10^6 rad/s^2. If $\phi - \phi_0$ = 1.71 rad, then t will be 4.7 ms.

Once the arming time is within the proper order of magnitude, the designer may solve the problem by numerical integration or he may build a model and test it. Usually a certain amount of computational work is worthwhile; however, this depends upon how valid the assumptions are and how closely the mathematics describe the actual conditions.

10-3.4 FIRING PIN DETENTS

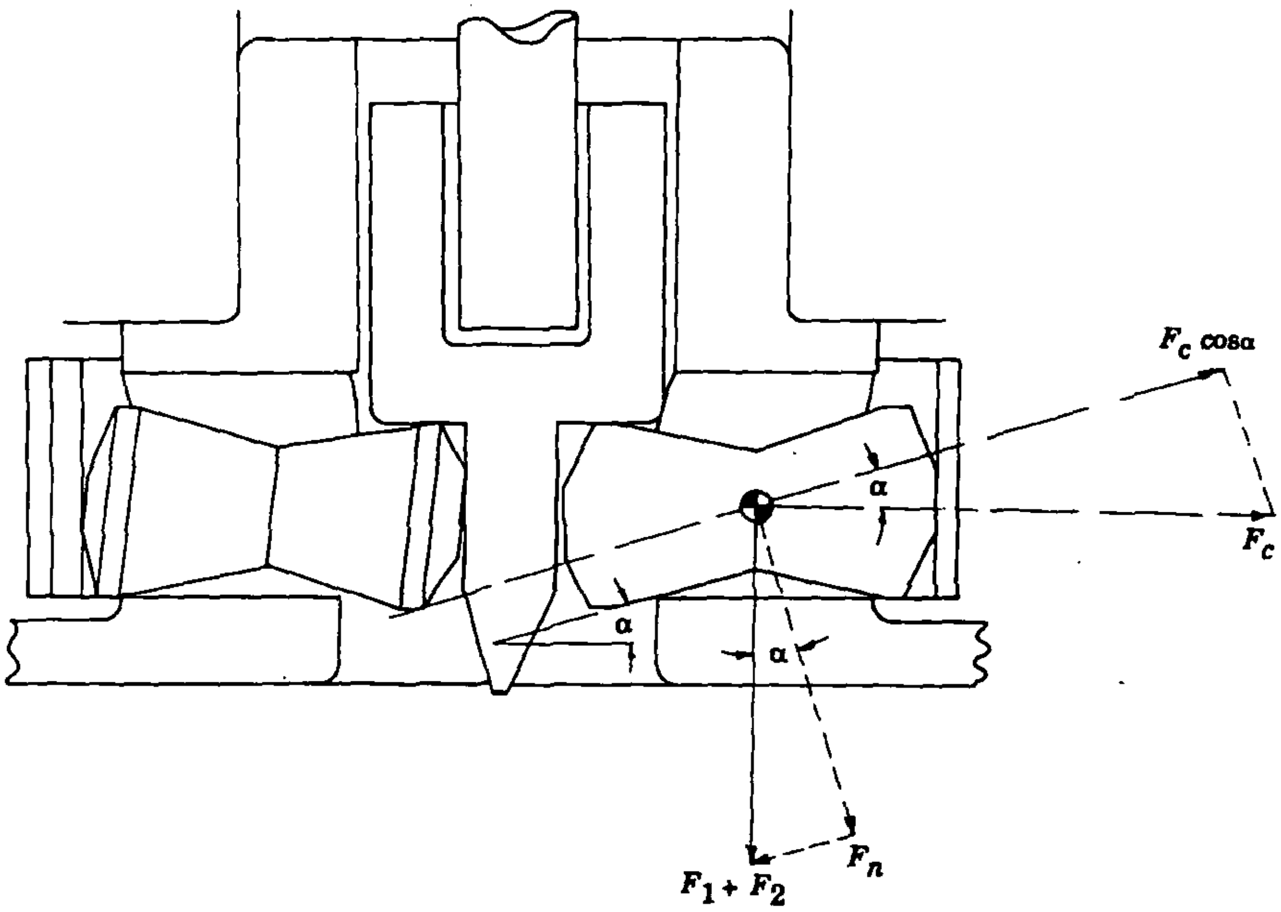
In detenting a firing pin in a point-detonating (PD) fuze, past practice has been to angle the detents forward at less than 90 deg to the spin axis. This enabled the friction from setback, which is low just inside the muzzle, to resist the centrifugal force, which is peaking at that point. Even though this method accomplishes the desired result, it has a failing in a nose-down drop by which the force component can arm the detents simultaneously.

Four detents can solve this problem, i.e., two at 90 deg to the spin axis and two angled forward at less than 90 deg to the spin axis. In the interest of simplicity, however, two properly configured detents, as shown in Fig. 10-11, can also solve the problem. This design is used in PD Fuze MK 27-1 for the 40-mm projectile.

10-3.5 SPECIAL CONSIDERATIONS FOR ROCKET-ASSISTED PROJECTILES

When designing fuzes for use with rocket-assisted projectiles (RAPs) (Fig. 10-12), certain factors must be considered. Mechanical time fuzes for these rounds require longer running times and might undergo angular acceleration during flight (while the timing mechanism is still in operation). Also the levels of setback and spin in rocket-assisted projectiles normally will be lower for the same ranges than the levels for gun-fired projectiles.

In addition to designing the fuze so that it will have to sense two different environments before arming, special measures are necessary to provide safety in the event of a rocket motor malfunction. Rocket motors malfunction if the



Where F_1 = force of setback on detent, N(lb)
F_2 = 1/2 force of setback on firing pin, N(lb)
F_c = centrifugal force on detent, N(lb)
F_n = normal setback force on detent, N(lb)

Figure 10-11. Hourglass Detent Design

motor fires when firing is not desired and produces a longer range than planned. Alternatively, the motor may not fire when desired and produce a shorter range. In the longer range case a sensor to function the projectile in the air before it passes beyond the intended target is desirable. In the shorter range case, the ability of the fuze to remain unarmed for any projectile that falls short of the target is desirable.

10-4 MECHANICAL TIME FUZES (MTF)

Mechanical time fuzes (MTF) are used to provide a preset functioning time and are applicable to projectiles set for airburst. They are committed to function at a set time after launch rather than when they sense the target. A large variety of timing mechanisms has been used in fuzes in the past (Ref. 6).

These fuzes are used primarily with smoke, illuminating, HE, and submunition and mine-dispensing rounds. They contain a power source, which is usually a main spring; a time base, an escapement; a gear train counting element; and a pyrotechnic output. For artillery ammunition, they are settable up to 200 s with ±0.5% accuracy for older fuzes and ±0.1% accuracy for current fuzes. For details of the clockwork design, see par. 6-6.

Although MTF are still in the inventory in large quantities and are still being produced, they are gradually being replaced by the more accurate electronic time fuzes. They currently have little or no utility against air targets.

10-4.1 CLOCKWORK DRIVE

For currently used fuzes, the clockwork is driven by a prewound power spring. Older fuzes in spinning projectiles were sometimes driven by the action of two centrifugal

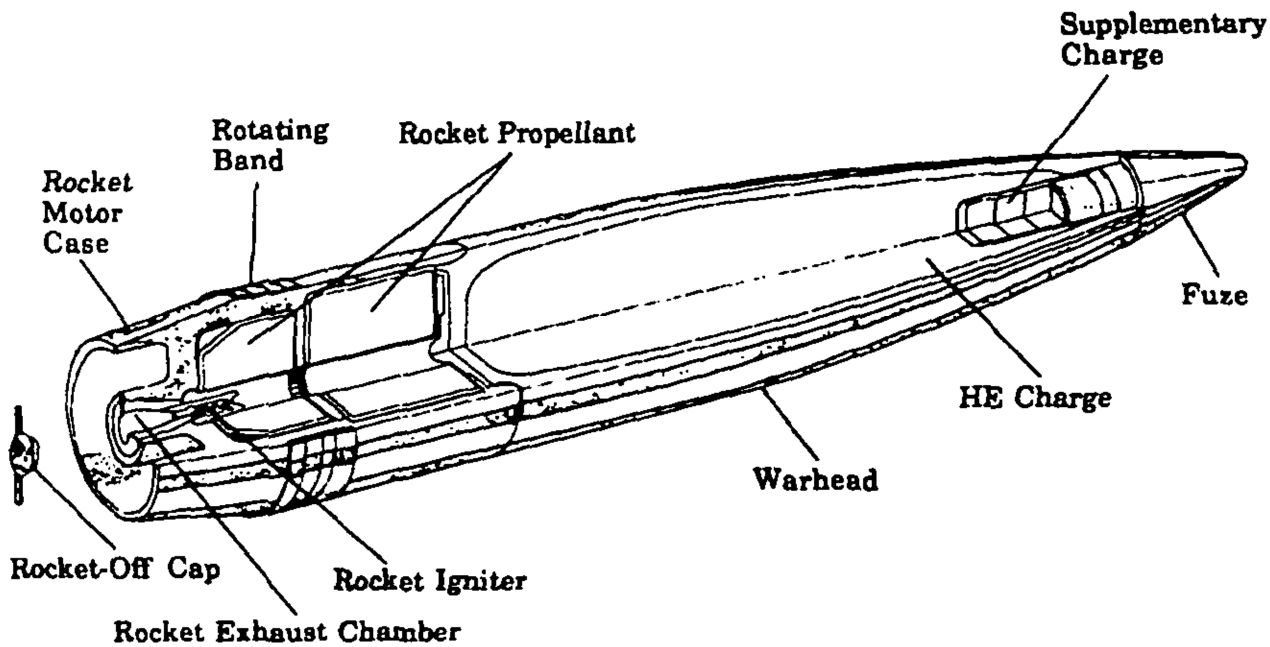


Figure 10-12. Rocket-Assisted Projectile (Ref. 5)

weights, as shown in Fig. 10-13, in the centrifugal field produced by the spinning projectile. Although this latter drive is no longer used because of its spin dependency, it is described here to illustrate a design approach. Fuze, Mechanical Time Superquick (MTSQ), M502A1 is an example of a fuze having a centrifugal drive (Ref. 7). The centrifugal weights move radially and apply a torque to the main pinion, which is geared to the escapement wheel and lever. Because it is independent of spin, the prewound spring mechanism is adaptable to guns of different twists of rifling. An example of this kind of drive is the newer arrangement, MTF M577, discussed in par. 1-5.2. In addition to a prewound power spring, the fuze uses a timing

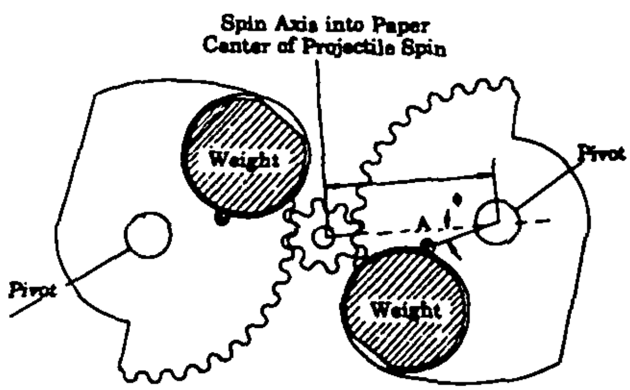


Figure 10-13. Centrifugal Drive for Mechanical Time Fuze

scroll and a digital counter system for increased setting accuracy. The salient feature for increased timing accuracy is the folded lever escapement (Fig. 6-39) with its torsion spring on the spin axis of the fuze.

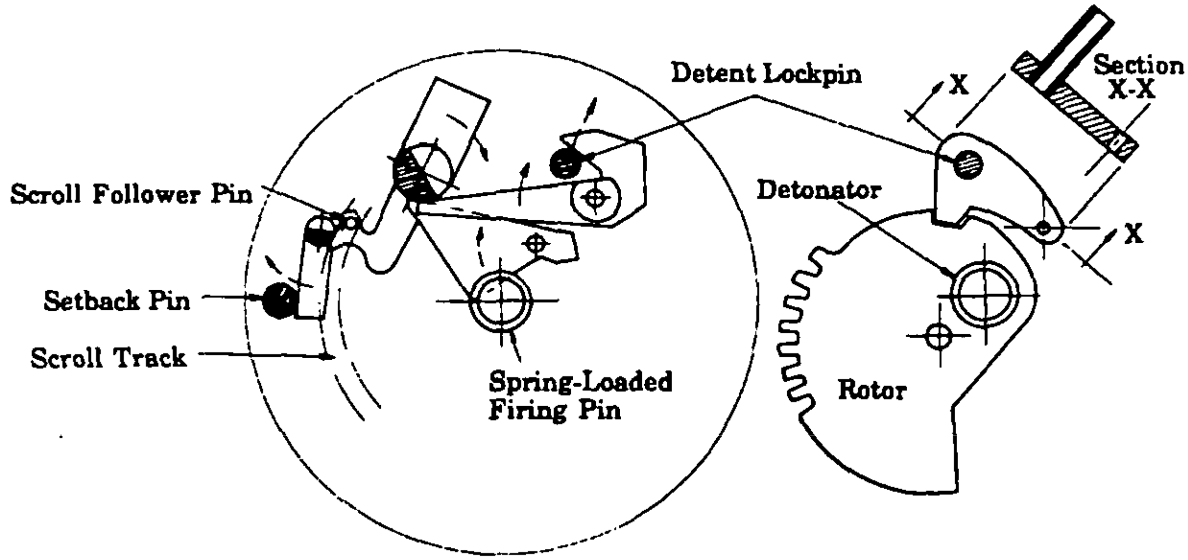
10-4.2 DESIGN OF ONE COMPONENT

A centrifugal drive fuze can be used only in spin-stabilized projectiles because centrifugal force is required to drive the timing mechanism. The centrifugal weights, acting as the power source for the escapement, move radially outward and create torques on the centrifugal gears about their shafts. This forces the main pinion to turn.

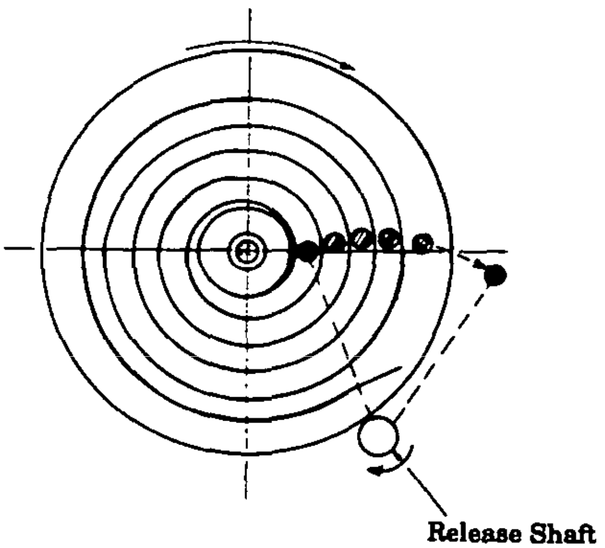
A timing disk, controlling a spring-loaded firing pin, rotates with the main pinion so that the centrifugal gear rotates the timing disk at a rate controlled by the escapement lever. Thus the clockwork measures the functioning delay because the explosive train is not initiated until the firing pin is released. The firing pin is released when the firing notch in the timing disk presents itself.

10-4.3 M565 FUZE

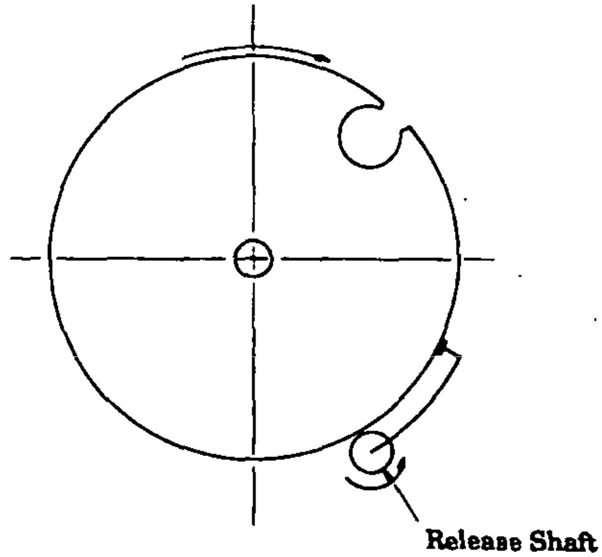
This fuze is upgraded from the obsolescent MTSQ M502A1 (discussed in par. 10-4.1) in that the centrifugal sector gears are replaced with a power spring, a separate arming delay is included by means of a runaway escapement, and a centerline through-bore is provided to accept a flash-through point-detonating impulse. The method of setting is the older system of ogive rotation with timing marks engraved around the intersection of the base of the setting ogive and the fuze base. The fuze uses a timing disk firing pin release. (See Fig. 10-14(C).) The safety and arming



(A) Safety and Trigger Levers and Rotor Detent of M577 Fuze



(B) Timing Scroll of M577 Fuze



(C) Timing Disk of M565 Fuze

Figure 10-14. Parts Schematics of MT Fuzes

(S&A) mechanism is located in an adapter, which is screwed to the base of the fuze.

10-4.4 M577 FUZE

Continual upgrading in the performance of mechanical time (MT) fuzes has resulted in the development of the M577 fuze. In addition to improved timing accuracy, emphasis has been placed on additional overhead safety since this fuze is used in improved conventional munition (submunition) projectiles.

Setting accuracy from 1 to 199 s in 0.01-s increments is provided through a digital-counter assembly with hundreds, tens, and seconds wheels, which is observable through a window in the ogive. The timing accuracy is greatly enhanced by the use of a three-center escapement with a folded lever and a torsion spring located on the spin axis (par. 6-6.1.3, Fig. 6-39). The accuracy is 0.1% for flights up to 115 s, which is a great improvement over the 0.5 to 1% accuracies for the older tuned, two-center Junghans escapements.

Additional overhead safety is provided by not releasing the S&A rotor until 2 to 4 s before the set firing time. This feature is intended to ensure there is no arming until the round has cleared friendly areas. Both the M565 and the M577 fuzes have rotor arming delays to 61 m (200 ft) by means of runaway escapements. For the M577 fuze this feature becomes important only at very low time settings.

A combination setback/spin detent-lock system, as shown in Fig. 10-14(A), restrains both the rotor and firing pin during handling and while they traverse the bore.

The fuze can be set in the safe, PD, or time modes. It uses a timing scroll system, shown in Fig. 10-14(B), in lieu of the timing disk of the M565 fuze, shown in Fig. 10-14(C).

10-5 ELECTRONIC TIME FUZES (ETF)

Electronic time fuzes are gradually replacing mechanical time fuzes for submunition, grenade, and mine-dispensing munitions. They offer the following advantages over the mechanical time fuzes:

1. Improved setting and timing accuracy
2. Remote setting capability
3. Self-checking (interrogation) prior to firing
4. No requirement for critical machine tooling or skills during production.

The power source is usually batteries of long shelf life, high regulation, and small size (discussed in par. 3-5.1.3), and the circuitry is encapsulated for increased resistance to shock and moisture.

10-5.1 TIMER OPTIONS AND DESIGN

Electronics provide many options in timer and setter design that enhance the capabilities and performance of fuzes. Setting can be accomplished mechanically, by electrical contact, or by remote means, such as induction, RF, X ray, and optical. Combinations of these methods can be used to advantage.

Electronic timers can be interrogated (checked) for proper operation prior to launch either by contact or remote means.

Various modes of fuze operation can be selected, e.g., time, proximity, PD, and PD with delay, and thus provide a single fuze capability for a variety of targets and ammunition.

10-5.2 M724 FUZE

The in-service ETF is the M587E2 fuze and its variant is the M724 fuze. The M587E2 fuze has a booster and is used in HE rounds, whereas the M724 fuze, with no booster, is used in cargo rounds. These fuzes can be set over a range of 0.3 to 199.9 s in 0.1-s increments by use of the M36E1 fuze setter—discussed in par. 9-5.3—which operates and verifies fuze operation in less than 1 s. The fuze can remain set for 1 yr.

The M587E2 fuze contains a PD selection and an independent mechanical cleanup, as shown in Fig. 10-15, for function on impact in the event of a timing failure. The assembly consists of an electronic head (E-head) and a rear fitting that contains an SAD and explosive train. The E-head contains the timing functions, power conditioning circuits, interfacing circuits, and memory circuits, which allow the XM36E1 fuze setter to select the time automatically.

The E-head also contains the power converter transformer, power supply, a metal oxide semiconductor (MOS) scaler/logic and overhead safety controls, and a metal nitride oxide semiconductor (MNOS) counter, impact switch, and the electric detonator. A spin-switch design acting as a launch timing initialization signal is part of the fuze and is depicted in Fig. 10-16.

A newer ETF, the M762 fuze, was developed to eliminate the necessity of using the M36E1 fuze setter, or "black box" method. This fuze can be set by hand or induction, and remote setting prior to gun loading is another capability.

10-5.3 M762-TYPE FUZE

This advanced, electronic time fuze, shown in Fig. 1-34, is briefly described in par. 1-5.3. A visual readout in the form of a liquid crystal display (LCD), shown in Fig. 2-4(C), is viewed through a window in the ogive. This modern system minimizes the time to read as well as the number of errors.

Start of the electronics is dependent upon closure of a spin switch, which must experience a continuous spin environment of at least 1000 rpm before closure. The power source is a lithium reserve battery energized by hand rotation of the ogive or by an inductive setting pulse.

The nose of the fuze contains a crush switch for PD action and a receiving coil that obtains setting data from outside the fuze by remote inductive setting prior to ramming. Hand setting is also a capability through rotation of the ogive.

Safety features in the S&A mechanism are a piston actuator to drive the slider into the armed position, a setback lock, and a spin detent. The piston actuator provides delayed arming after 450 ms for the PD mode. In the time mode the actuator fires at the set time minus 50 ms. This gives improved overhead safety similar to that found in the M577 fuze.

10-6 AUTOMATIC CANNON FUZES

HE projectiles for automatic cannons, 20 through 35 mm, are the smallest rounds requiring a fuze. These fuzes must have all the safety features of those used in larger caliber projectiles; in addition, they must survive higher spin rates and setback forces (approximately 35 to 100,000 rpm and 50 to 100,000 g's). These fuzes must also survive an extremely rough handling environment due to the high-speed feed mechanisms with rapid starts, stops, and vibrations.

Spatial constraints are severe, and miniaturization of the components is necessary if the round is to have a sufficient

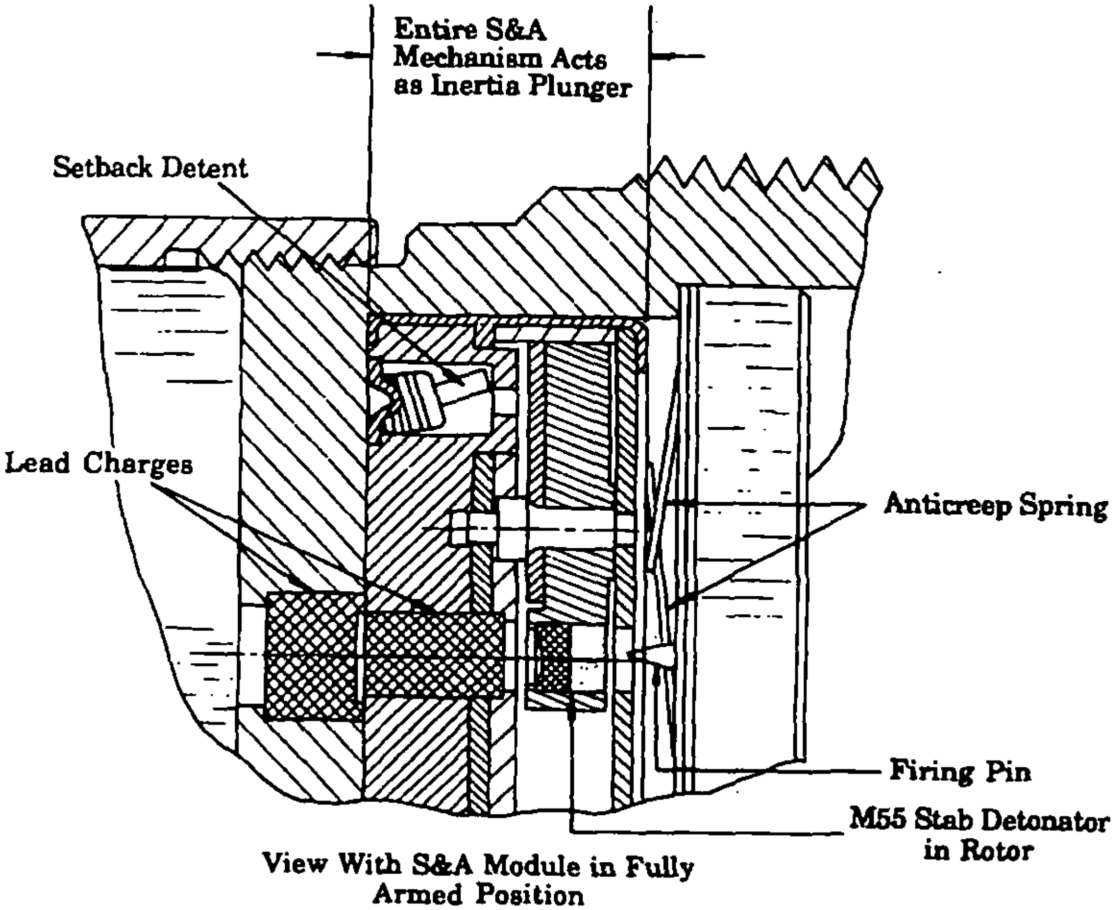


Figure 10-15. Mechanical Backup Initiation Design

volume of high explosive to be effective. There is great opportunity for ingenuity in this kind of ordnance. Fuzes with delayed arming (out to 90 m (300 ft)) and delayed firing after impact (at least one full length of the projectile in the target) presently exist.

The great differences in magnitude between handling and gun environments reduce the complexity of safety devices. A shear wire is often sufficient to obtain handling safety, as shown in Fig. 10-17, and the spin is sufficiently high to permit the use of stiff, C-ring-type centrifugal locks, as shown in Fig. 6-29 (A).

10-6.1 TYPICAL AUTOMATIC CANNON FUZES

The Navy's MK 78 PD fuze, as shown in Fig. 10-17 for the 20-mm round, contains a disk rotor held safe by a setback block and shear wire. It has a minimum delayed arming that provides a safe distance of only 0.3 to 0.6 m (1 to 2 ft) outside the gun muzzle. The M505A3 PD fuze, shown in Fig. 6-29(A), was developed to increase this delay. Delayed arming of 3 to 6 m (10 to 20 ft) is obtained by use of a ball rotor, discussed in par. 6-5.6. Other designs that produce delayed arming to approximately 18 m (60 ft) with a spiral unwinder ribbon (par. 6-4.5) are the Oerlikon fuzes shown in Figs. 10-18(A) and (B). For further developments in increased arming times, see the internal bleed dashpot, discussed in par. 8-2.3.2, for the M758 PD fuze, which has delayed arming distances of 9 to 90 m (30 to 300 ft).

10-6.2 AUTOMATIC CANNON FUZE M758 (FAMILY)

The US Army has developed a basic fuze design, the M758 (par. 8-2.3.2), for use in 20- through 35-mm rounds. This fuze has a delayed arming capability of 9 to 90 m (30 to 300 ft) by means of a pneumatic dashpot timing system. It can have a self-destruct feature for use over friendly troops or a no self-destruct feature for use with aircraft-fired rounds to prevent the aircraft from overtaking the fragments. The salient features of this series are the large number of die-cast parts and nonprecision tolerances, all of which are in the interest of economy. The fuzes have two independent safety features—one is actuated by centrifugal force and the other is actuated in a delay mode by setback force and the pneumatic dashpot.

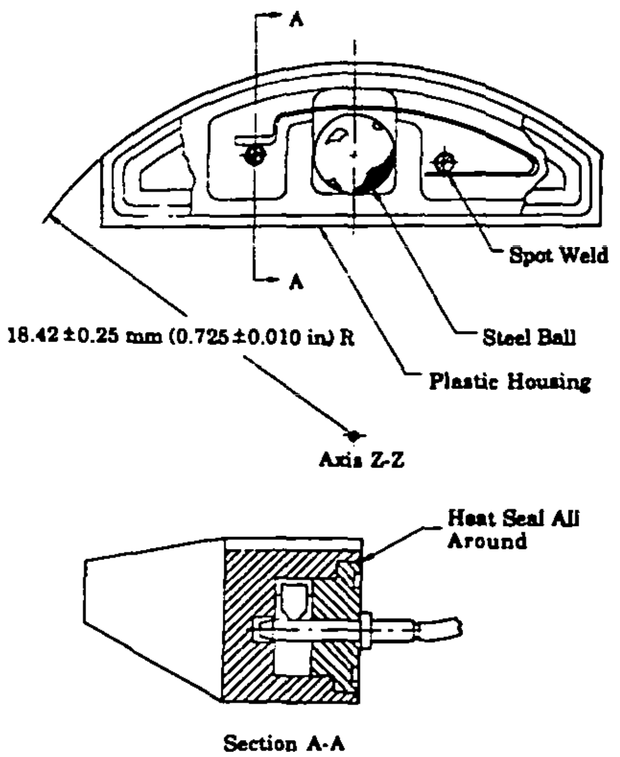


Figure 10-16. M724 Spin Switch

10-7 FUZE TECHNOLOGY FOR CANNON-LAUNCHED GUIDED PROJECTILES (CLGP)

To provide the field artillery with the ability to engage both stationary and moving hard-point targets with a high degree of first-round kill probability, a cannon-launched, nonspin, guided projectile, called the COPPERHEAD, has been designed and is shown in Fig. 1-6.

This round allows the flexibility of using standard propellant charges and interchangeable loading with conventional rounds. The nonspin aspect, however, removes one of the cannon environments normally used to enable the fuze; consequently, a substitute means has been devised, as described in par. 10-7.1.

10-7.1 UNIQUE CONSIDERATIONS

The substitute means of a second environment for the cannon-launched guided projectile (CLGP) is a magnetically induced barrel-exiting signal that generates an arming signal. This system serves another purpose, i.e., sensing a minimum exit velocity below which the fuze will not function. This information is important to determine that the minimum velocity exists to ensure stability of the fin-stabilized round and avert a short-round accident, i.e., insufficient distance.

10-7.2 EXAMPLE OF A CLGP

The M712 nonspin COPPERHEAD high-explosive antitank (HEAT) projectile (Fig. 1-6) can be used interchangeably with conventional ammunition in the 155-mm howitzer. The COPPERHEAD is fin-stabilized, fin-guided, and follows a ballistic trajectory. The guidance system can be designed for IR, millimeter wave, or light amplification by stimulated emission of radiation (laser) designation.

The fuzing system M740, a block diagram of which is shown in Fig. 10-19, is redundant in the interest of higher reliability. Both S&A mechanisms are locked safe independently by a setback release latch and a second latch that requires two independent actions for its removal. During unlatching the setback release latch winds an arming spring, which in turn starts the time-delayed motion of the rotor. If the second latch is not removed within 80% of the delayed travel time (1.2 s nominal) of the rotor, the rotor will return to the safe position.

The action that removes this second latch depends upon the projectile exceeding a muzzle velocity of 183 ± 30 m/s (600 ± 100 ft/s) and upon the availability of electrical power from the on-board battery within 0.6 s after launch.

Projectile exit from the gun tube is sensed by two magnetic induction second environment sensors (SES) that are mounted flush with the projectile surface and spaced 38.1 mm (0.125 ft) apart along the axis. An electronic logic circuit (SESE) receives the SES signals and determines whether or not the proper projectile velocity has been achieved. If this velocity has been achieved and electrical power is available, explosive actuators fire and remove the second latches from the rotors. Premature functioning of the second latches, prior to unlocking of the first latches, will lock the acceleration-responsive rotor locking weight in the lock position and prevent the rotors from arming.

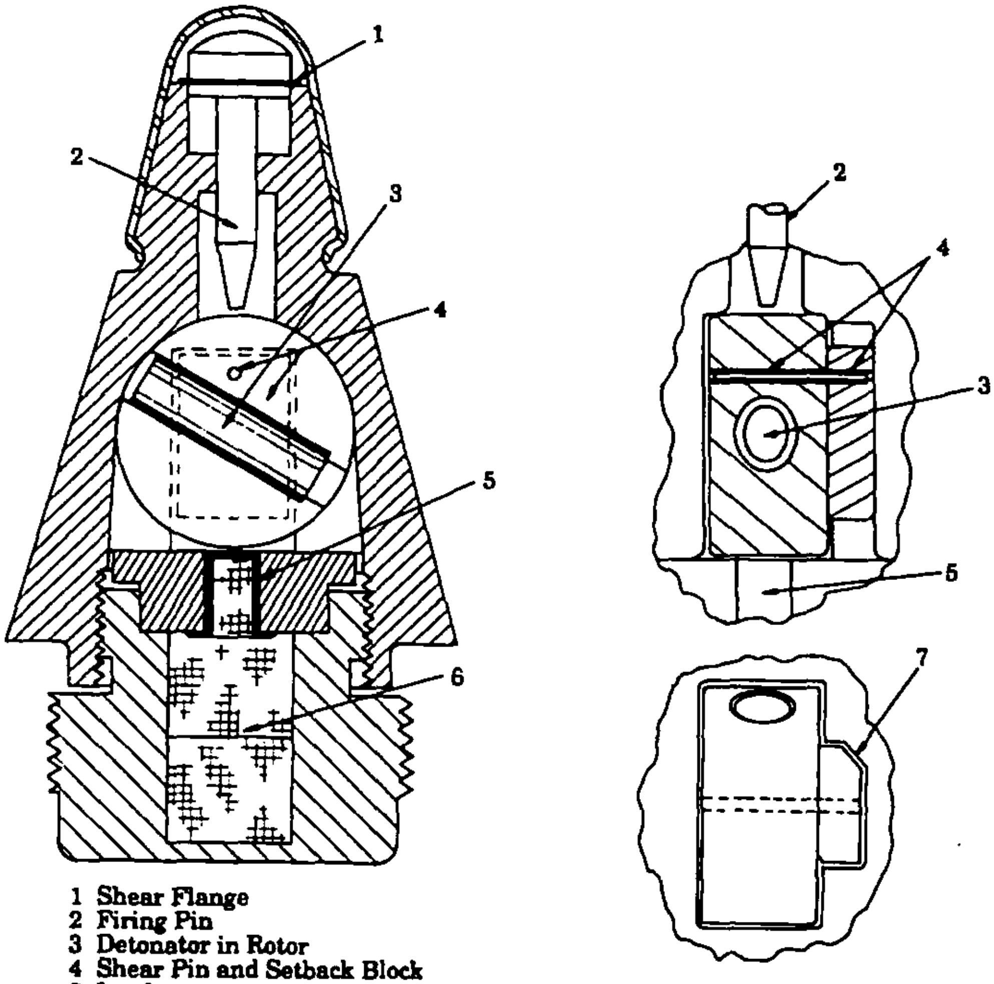
The rotors are further delayed by runaway escapement mechanisms. Final electrical arming of the firing circuit occurs during the guided phase of flight but only after receipt of a target acquisition signal from the guidance electronics.

On impact, the shaped-charge warhead is detonated by electrical energy from target-detecting sensors—a nose-mounted direct sensor and several shock-wave sensors. The shock-wave sensor ensures detonation on graze impacts.

The fuze module housing contains viewing windows that disclose a green zone with S imprinted or a red zone with A imprinted so that the safe (S) or armed (A) status of the rotor(s) can be determined prior to gun loading.

10-8 ELECTRONIC PROXIMITY FUZES

These fuzes use conventional S&A mechanisms for gun-launched fuzes. The target-detecting system, however, provides initiation at a predetermined distance in front of the target for maximum effectiveness. The most common and most used type is the RF fuze. These fuzes are also widely used in guided-missile rounds. Their usefulness against air-



1 Shear Flange
2 Firing Pin
3 Detonator in Rotor
4 Shear Pin and Setback Block
5 Lead
6 Booster
7 Antimalassembly Chamfer

Figure 10-17. 20-mm Fuze MK 78 (Ref. 8)

craft and ground targets is explained in Chapters 1 and 3 (pars. 1-4.1.3 and 3-2.2, respectively).

10-8.1 SENSING TECHNIQUES, OPTIONS, AND DESIGN

Although the RF system was the first and most widely used sensing technique for proximity fuzing, other methods are used because of their special properties (pars. 1-4.1.3, 1-5.4, 1-6.3, and 1-8.3).

Inductive sensing has been used for antitank rounds for which intervening nonmetallic obstructions cannot interfere by causing premature initiation. This method is useful in medium standoff situations to improve the standoff distance for shaped charges (par. 3-2.3).

Electrostatic sensing offers the capability of firing near an aircraft because of the electrostatic envelope surrounding the target. The system can discriminate between signals from electrostatically charged trees and raindrops and offers some selectivity over the RF types. See par. 3-2.4 for additional discussion.

Capacitive sensing has a very limited operating area because it triggers within 50 mm (2.0 in.) of the target or an obstruction, but it offers high resistance to electronic countermeasures (ECM). Additional discussion of capacitative sensing is in par. 3-2.8.

An electro-optical system reacts to the IR emissions emanating from jet engines. It offers accurately controlled burst positions, improved reliability, no degradation of effectiveness when fired low over waves, and extreme immunity to countermeasures when used in antiaircraft munitions. See par. 3-2.6 for additional discussion.

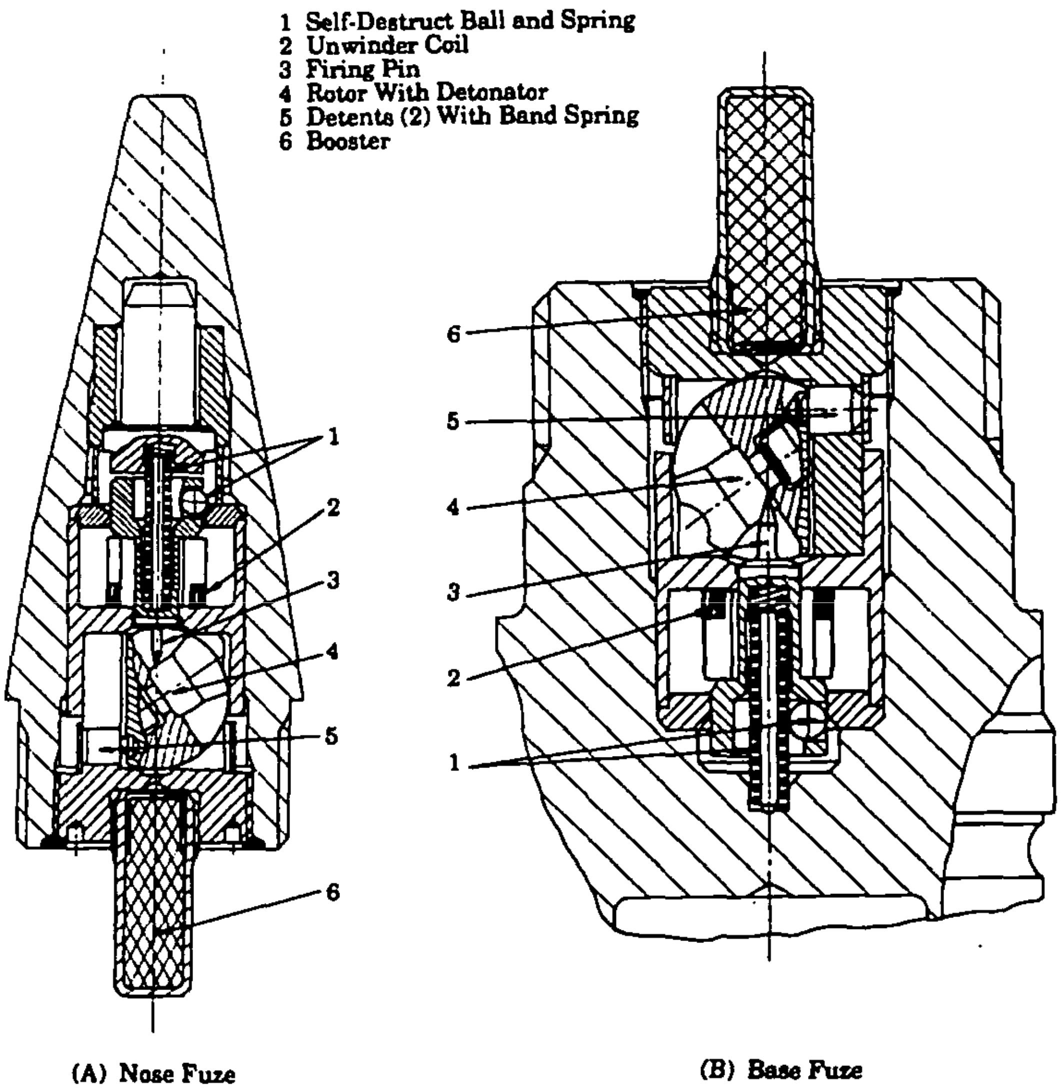


Figure 10-18. 35-mm Fuze, Oerlikon Design (Ref. 9)

10-8.2 M732 FUZE

The M732 fuze is an electronic RF proximity fuze known as a controlled variable time (CVT) fuze. One method of protection against ECM is to limit exposure time, i.e., the time during which the fuze is radiating. This is accomplished by using an electronic timer, settable before firing by hand rotation of the ogive, which is engraved around the periphery of the fuze shown in Fig. 10-20.

An extensive description of this fuze is contained in par. 1-5.4. Briefly, the fuze has an RF oscillator that contains an antenna, a silicon RF transistor, and other electronic components. The antenna pattern is designed to provide an optimum burst height over a wide range of approach angles. The amplifier contains an integrated circuit (IC) that has a differential amplifier, a second-stage amplifier with a full wave Doppler rectifier, transistors for the ripple filter, and a silicon-controlled rectifier (SCR) for triggering the fire-pulse circuitry.

The power supply, 30 V nominal at 100 mA load current, is a spin-activated battery. The electrolyte is sealed in a copper ampule, which is cut open on setback and allows distribution within the cells.

An electronic timer assembly to turn on the radiating phase is included as an IC variable duty-cycle multivibrator chopper that chops the resistor-capacitor (RC) charging curve and thereby permits a 150-s delay time. A ratiometer with finger contacts is rotated as the ogive is turned during setting.

The SAD usually is a standard system with the rotor held by setback and centrifugal detents, and the arming time is controlled with a runaway escapement giving a constant arming distance independent of muzzle velocity.

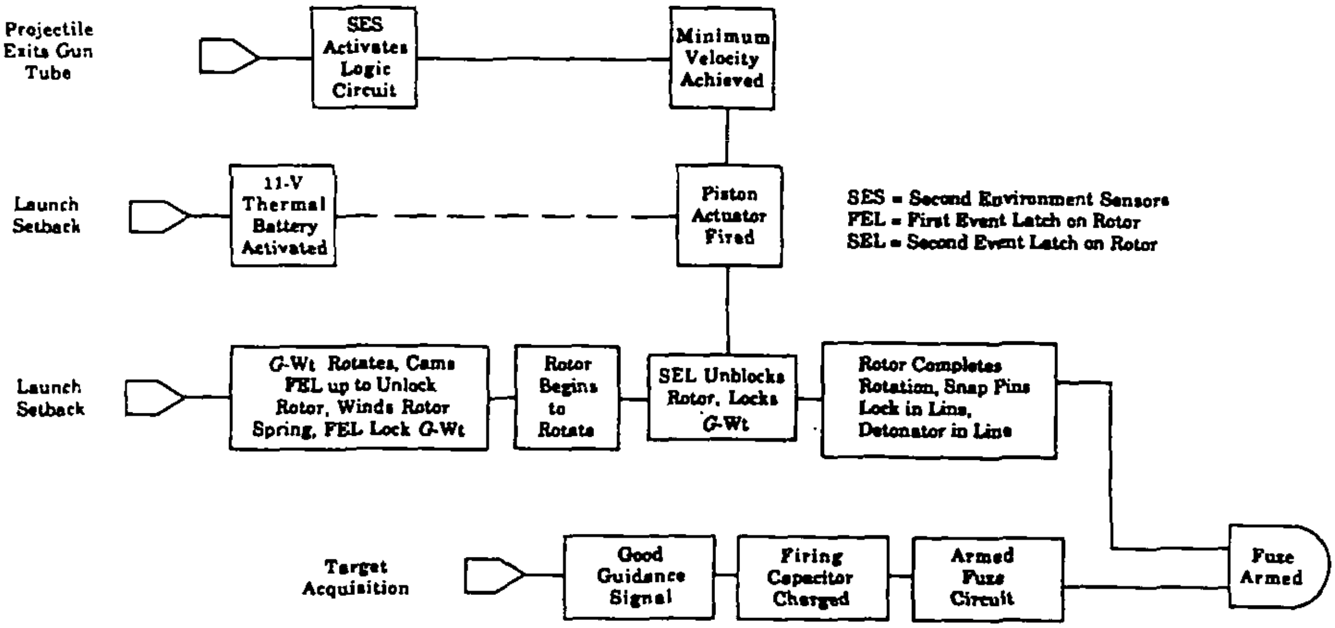


Figure 10-19. Block Diagram of M740 Fuze Arming Sequence

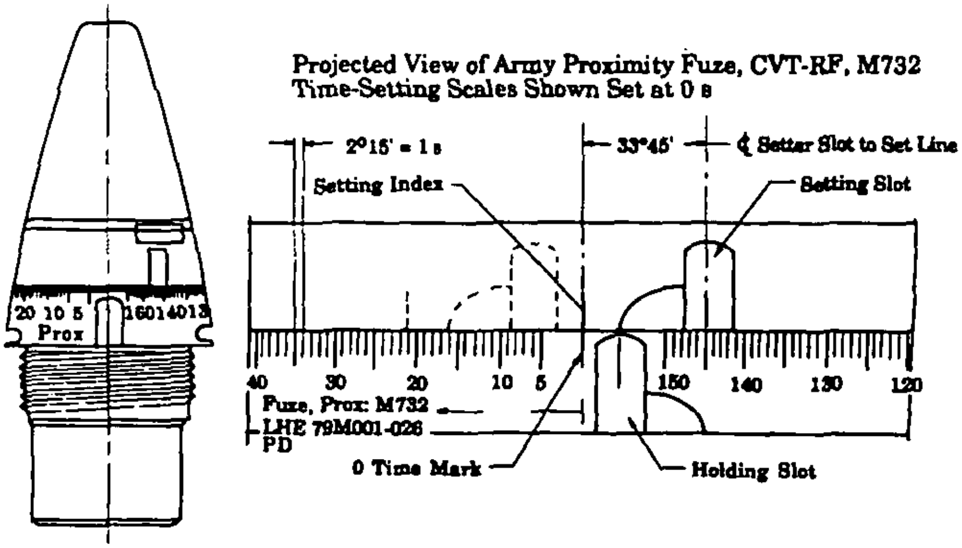


Figure 10-20. Fuze M732 (Ref. 10)

A PD backup mode is accomplished by means of a movable detonator carrier within the S&A mechanism. On impact the detonator in its carrier compresses an anticreep spring that allows the detonator to impale on a fixed firing pin.

10-9 SUBMUNITION FUZES

Improved conventional munitions (ICM) or cargo rounds—discussed in pars. 1-3.1, 1-3.1.1, 1-3.4, 1-3.4.2, 1-3.6, and 1-13—are the latest development in artillery rounds.

Fig. 10-21 depicts the cargo projectile M483 for the 155-mm howitzer. Its contents are the M42 shaped-charge, antivehicle grenade, shown in Fig. 1-26, with the M223 fuze, shown in Fig. 1-51.

The purpose of these rounds is to reduce the overkill of the conventional HE projectile by dispersing the energy. Target acquisition and lethality are also enhanced by the shotgun pattern on the target area.

The M42 submunition is explained in detail in par 1-3.6 and its fuze, the M223, in par. 1-13. The fuze is a simple arrangement of a slider/detonator out-of-line safety that is

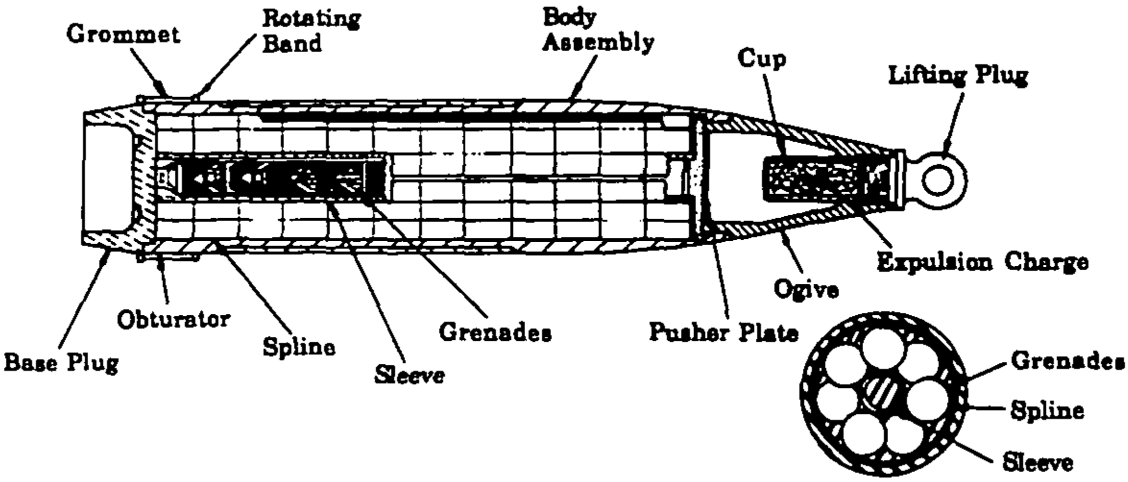


Figure 10-21. Projectile M483 With Submunition M-42 (Ref. 5)

spring loaded toward the armed position. It is held safe by a screw-bolt firing pin armed by means of a trailing ribbon that puts a drag on the bolt. The spinning grenade does the rest. The fuze fires on impact due to the inertia of the firing pin assembly.

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CHAPTER 11
FUZES LAUNCHED WITH LOW ACCELERATION

Munitions launched under conditions of low acceleration, i.e., less than 10,000 g, are addressed, and the launch environment of low acceleration coupled with long time duration and a general lack of spin is discussed. The operating accelerations of rockets, guided missiles, grenades, and mortar projectiles are categorized. Rockets are defined, in contrast to guided missiles, as free-flight missiles without guidance other than the initial aiming toward the target. Methods of guiding rockets, such as on-board intelligence, radio command from the launcher, or wire linkage, are presented. Arming environments for rocket safety and arming (S&A) mechanisms are discussed; airflow, rocket-motor gas pressures, and long duration acceleration are also discussed. The use of an electroexplosive device as a nonenvironmental lock is presented as a way to provide additional safety. Environmental sensing devices, such as the sequential leaf mechanism, drag sensor, zigzag mechanism, and fluidic generator, are discussed and their applications in several rocket fuze designs are illustrated. A general description of guided missile fuzing is given, and the frequent use of redundancy to ensure reliability is emphasized. The geometrical relationship of the sensor, the S&A mechanism, and the boostering systems in relation to the missile warhead is explained. A hypothetical design including the relevant equations for a missile fuze double-integrating mechanism is given. A specific surface-to-air missile, the PATRIOT, is described. The redundancy of its safety and arming devices (SAD) is explained as are the counterbalances introduced to militate against side accelerations during maneuvering. A command self-destruct (SD) feature, which is automatic in the event of control-signal loss, is presented. In addition, the use of rotary unlocking solenoids as a supplementary safety feature to the g sensors is shown. The HELLFIRE air-to-surface missile and its fuze, the M820, is included as an example of a simple system for small guided missiles. The lowest of the low-acceleration munitions is the hand grenade. The widely used pyrotechnic time fuze is presented, along with a more detailed explanation of an electrically fired impact fuze. Advantages and disadvantages of the two approaches are given. Design equations for the firing spring for both grenades are given. Methods of surface implanting both antiarmor and antipersonnel minefields are discussed: artillery, aerial, command, and towed dispensers. The ground-emplaced mine-scattering system (GEMSS) and the VOLCANO and ADAM fuzes are discussed. Submunition dispensing systems for use with projectiles, rockets, and airborne canisters are described. The purpose of the munitions and submunitions is discussed. Fuze M230 for the M73 submunition is used as an example.

11-0 LIST OF SYMBOLS

a = acceleration of the mechanism, g-units
a_1 = first new acceleration of the mechanism, m/s^2 ($in./s^2$)
a_2 = second new acceleration of the mechanism, m/s^2 ($in./s^2$)
d_w = diameter of wire, m (in.)
E = Young's modulus of elasticity, Pa ($lb/in.^2$)
F_r = restraining force, N (lb)
F_s = initial tension on the slider, N (lb)
G = torque that is proportional to deflection $k\theta$, N·m (in.·lb)
g = acceleration due to gravity, m/s^2 ($in./s^2$)
H_s = potential energy, N·m (in.·lb)
I_A = second moment of cross-sectional area, m^4 ($in.^4$)
k = spring constant, N/m (lb/in.)
ℓ = length of spring, m (in.)
r = lever arm of force F_y, m (in.)
r_s = radius arm of the striker that swings through π radians, m (in.)
S = distance, m (in.)
T_c = time constant, s
t = time, s
v_t = terminal velocity as t becomes infinite, m/s (in./s)
W = weight of the slider, N (lb)
x = displacement of slider, m (in.)
x_0 = initial displacement of slider, m (in.)
$\ddot{x}$ = acceleration, m/s^2 ($in./s^2$)
$\dot{x}$ = velocity, m/s (in./s)
θ = angular displacement of coil, rad

11-1 INTRODUCTION

Munitions with accelerations of less than 10,000 g may be classified together for the purpose of describing the force fields useful for arming. These munitions can be rockets, guided missiles (GMs), grenades, or some mortar projectiles. Rocket accelerations are classified in three ranges: up to 40 g, from 40 to 400 g, and from 400 to 3000 g. The last range is usually obtained by an assist, such as a gun-boosted rocket. Guided missiles generally have accelerations of less than 100 g, hand grenades have only a few g's, but propellant-launched grenades may experience accelerations up to 1000 g. The acceleration of mortar projectiles depends upon the amount of charge used.

The forces available to arm fuze components in munitions launched with low acceleration are smaller than those in high-acceleration projectiles. Fortunately, the time duration of this acceleration is comparatively long, from 2 to 4 s in some rockets. Most munitions launched with low acceleration are fin-stabilized; hence centrifugal forces are not available for arming.

A differentiation will be made between rockets and guided missiles. In military use the term "rocket" describes a free-flight missile that is merely pointed in the intended direction of flight. On the other hand, "guided missiles" can be directed to their target while in flight by a preset or self-reacting device within the missile, by radio command to the missile, or by wire linkage to the missile. A "ballistic missile", although commonly grouped with guided missiles, is guided in the upward part of its trajectory but becomes a free-falling body in the latter stages of its flight through the atmosphere. In this case there is sufficient accuracy in conjunction with weapon yield to allow targeting of either soft or hard targets with an acceptable probability of destruction.

11-2 ROCKET FUZES AND SAFETY AND ARMING DEVICES (SAD)

Most rockets are fin stabilized; thus spin is not available as an arming environment. The designer must therefore resort to the use of other environments or nonenvironmentally operated features to achieve the desired level of safety. Other forces available to the designers of rocket fuzes are wind forces, gas pressure from the burning propellant, and creep (deceleration).

Early fin-stabilized rocket nose fuzes used wind-driven vanes for arming, which were unlocked by the forces of acceleration. The wind-vane fuzing systems, however, were susceptible to handling damage and the ingress of moisture. In some cases, a shroud surrounded the vane to protect it.

During burning of the rocket motor propellant, pressure from the resulting gases is exerted on the base of the rocket head. Since this pressure is fairly constant for a given rocket motor and since the magnitude is several hundred kilopascals (several hundred pounds per square inch), entrance of the gas into the fuze can be controlled and used to start, as well as to delay, the arming of a base fuze. Special design precautions are necessary to prevent the ingress of combustible products into the inlet orifice. This is usually accomplished by a wire mesh filter.

Most of the current stockpile of rocket fuzes—discussed in pars. 1-3.2 and 1-9—are entirely sealed, with no external pull pins or vanes, and use only acceleration as the arming environment. Generally, these acceleration double-integrating mechanisms have withstood the test of time as good discriminators among launch, handling, and accidental release shocks. One known exception is discussed in par. 6-4.9 along with the measure taken to overcome this deficiency. This example emphasizes the desirability of two independent safety features.

In addition to an acceleration sensor, newer rocket and missile fuzes use a second environmental sensor, such as a drag sensor, or a nonenvironmental lock, such as an electro-explosive device. The nonenvironmental lock is initiated by either on-board power, e.g., battery or generator, or a charge induced from external power sources, usually at launch.

11-2.1 THE 2.75-in. ROCKET FUZE FAMILY

Pars. 1-3.2.2 and 1-9.1 and Figs. 1-13, 1-45, and 2-6 describe the 2.75-in. rocket fuze, which has only one safety system, i.e., a mechanism operated by acceleration that is time governed by a runaway escapement. As noted, this mechanism is time proven and used in many fuzing systems; however, since it results in a single safety feature, it does not meet the safety provisions of MIL-STD-1316 (Ref. 1).

Par. 2-10 discusses the launch environment acceleration envelope for rocket fuzes. Table 2-2 gives the range of forces on rocket fuzes during launch and free flight. Low-acceleration aspects of rocket performance are covered in par. 5-3.2.2, and the ballistic environment of a rocket munition is depicted in Fig. 5-2. An acceleration versus arming-time curve for typical rocket accelerations in a temperature range of −18° to 60°C (0° to 140°F) is shown in Fig. 6-33.

Most fuzes for the 2.75-in. rocket family use a *g*-weight system, which is controlled by a runaway escapement. This SAD also protects against a short motor burn (Fig. 2-6). It returns the rotor to the safe position after cessation of the incomplete acceleration signature. The same action occurs during rough handling, including drops. The one exception is during parachute delivery with a fouled chute. Here again, a second environmental safety feature is desirable.

11-2.2 SAFETY AND ARMING DEVICE WITH DRAG SENSOR

Shoulder-launched high-explosive antitank (HEAT) rocket grenades use a base fuze with a nose trigger. The fuze employs a sequential leaf acceleration arming mechanism, which is discussed in par. 6-5.3, and a spring-armed rotor. Recently, fuze M754 has included a second environmental safety device in the form of a drag sensor. The drag sensor unlocks or locks the rotor depending upon the position of the rotor at the time of the onset or lack thereof of a 2- to 4-*g* drag force that endures for 4 ms. Fig. 11-1 depicts the sequence of operation of the drag safety system.

11-2.3 MULTIPLE LAUNCH ROCKET SYSTEM (MLRS) FUZE

The M445 fuze for the MLRS, shown in Fig. 1-11, is described in par. 1-9.2 and illustrated in Fig. 1-46. The two safety systems locking the unbalanced rotor are a zigzag setback mechanism, discussed in par. 6-4.6, and an electro-explosive switch. The switch is fired by voltage generated by ram air operated through a fluidic generator (par. 3-5.2.2). Fig. 11-2 is a block diagram of the operation of the M445 fuze, Fig. 11-3 shows the safety and arming (S&A) mechanism in the safe and armed positions, and the anti-

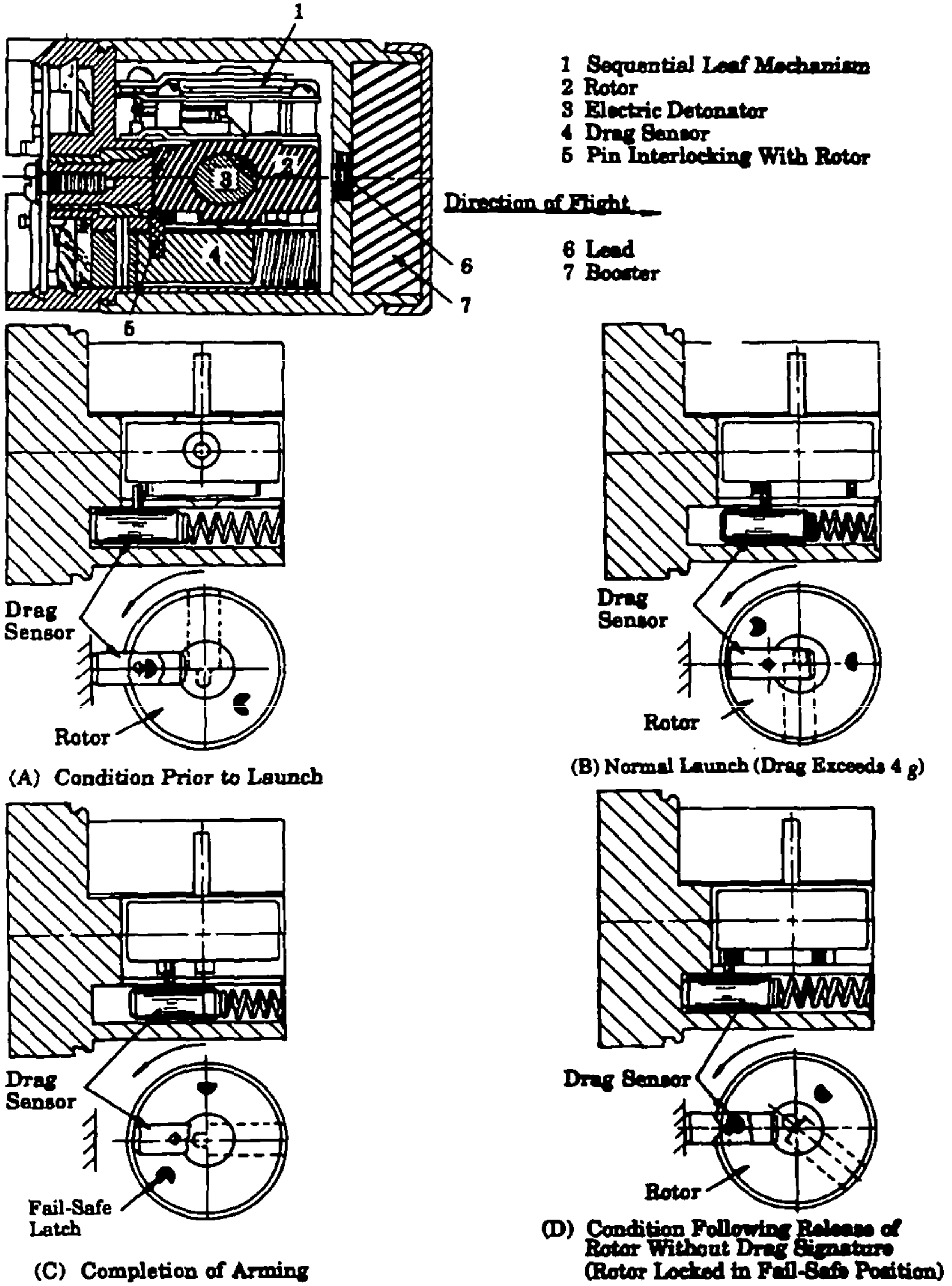


Figure 11-1. M754 Fuze, Drag Sensor

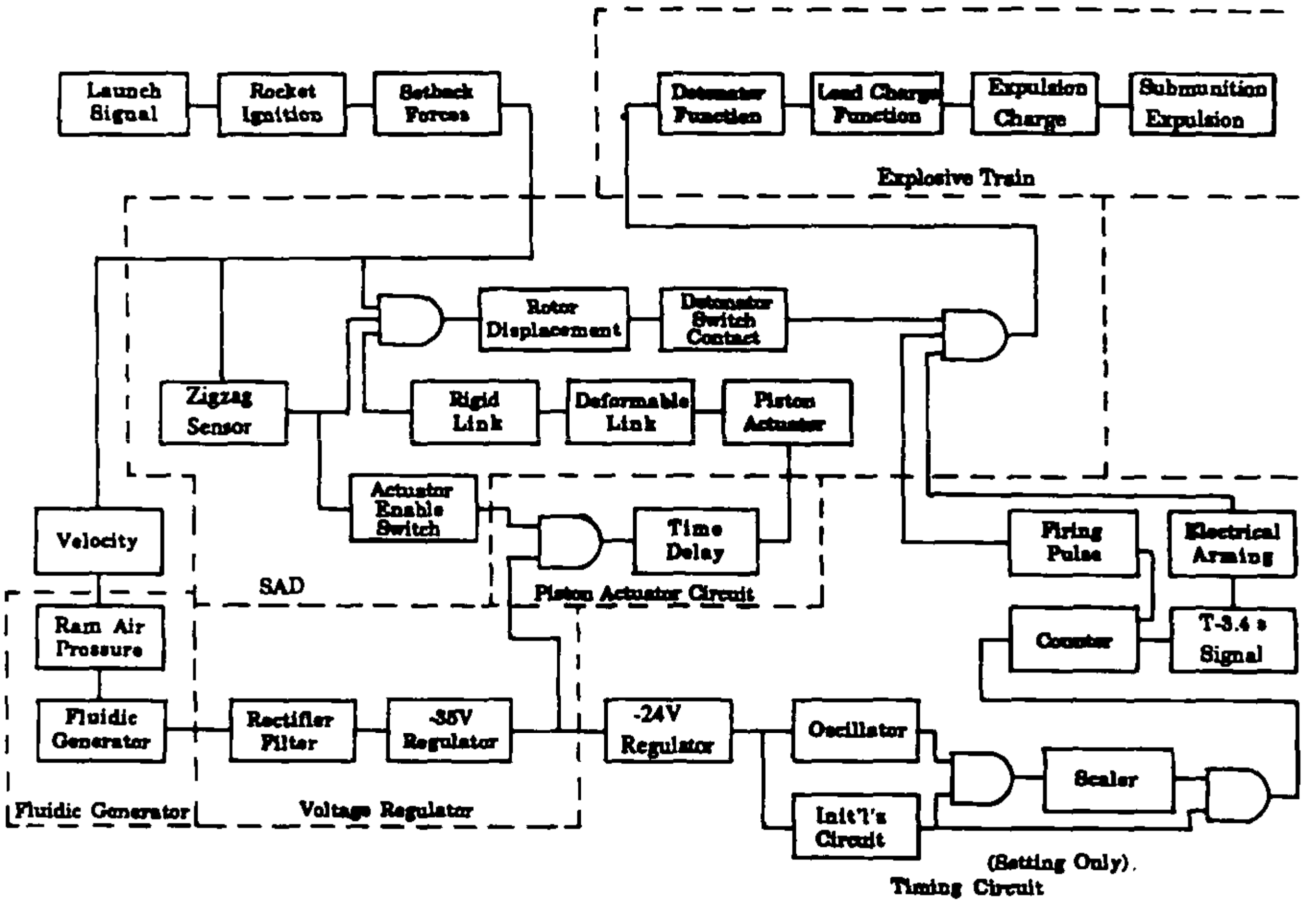


Figure 11-2. Block Diagram of M445 Fuze

malassembly link is shown in Fig. 11-4. Position A shows the lever in an interference position caused by an armed rotor; in this condition, installation of the S&A mechanism into the fuze is prevented. A status switch controlled by rotor rotation enables the fuze setter to distinguish between an armed and unarmed fuze. The fuze can be set only if unarmed prior to launch.

11-3 GUIDED MISSILE FUZES

Guided missile fuzes, as do other types of fuzes, contain an arming mechanism and an explosive train (Ref. 2). The various fuze components, however, may be physically separated from the warhead as well as from each other. The initiation sources may be separated from the S&A mechanism, which also may be separated from the warhead; the only connection between the two components may be a length of detonating cord or an electric cable. S&A mechanisms for missiles are discussed in Ref. 3.

The guided missile is a large, expensive item with a requirement for high functioning probability. Therefore, multiple fuzing is commonly employed since the probability of failure decreases exponentially. For example, one missile warhead detonating system may consist of two parallel S&A mechanisms, each containing a detonator. Then five lengths of detonating cord fitted with PETN relay caps may connect the output of these mechanisms to three warheads. Only one of the multiple paths needs to be completed for successful missile operation.

Even though several of the fuzes previously described might operate in guided missiles, the firing conditions warrant designs peculiar to missiles alone. At the present time, most missiles are limited to an acceleration of about 60 *g*; therefore, the arming mechanism must be designed to operate within this acceleration. The launch of some small guided missiles, such as TOW, produces an acceleration of 390 *g*, but the fuze requires only 21-*g* acceleration to arm.

The environment most widely used in both rocket and guided missile SADs is the acceleration imparted to the weapon during boost. Since the magnitude of this acceleration is comparable to the magnitude of the acceleration experienced in handling or accidental drops, however, the safety mechanism usually requires that this acceleration be sustained for a major portion of the boost time. In other words, the safety mechanism completes its function only after a minimum impulse has been imparted to the missile. Other versions of this type of S&A mechanism perform an

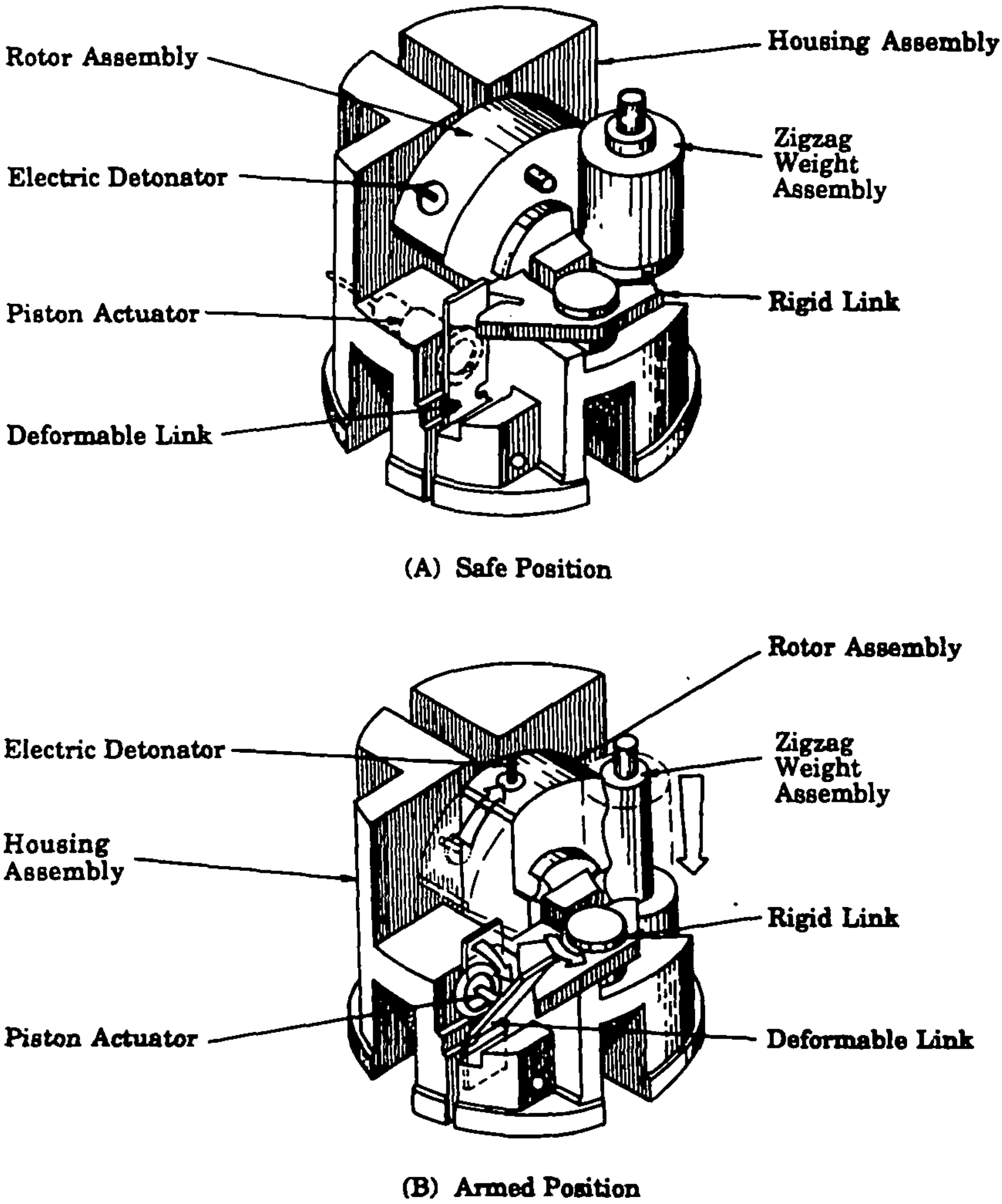


Figure 11-3. M445 Fuze Safety and Arming Device; Safe Position and Armed Position

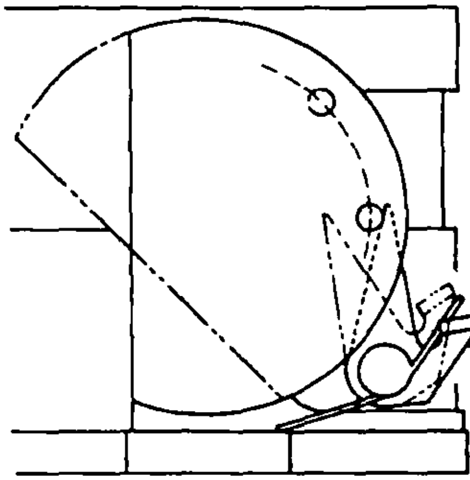


Figure 11-4. Antimalassembly Feature for M445 Fuze

integration on the acceleration versus time curve. In these mechanisms arming will not be completed unless a certain minimum velocity has been acquired by the missile. Still another variation is an integration of the acceleration versus time history. These mechanisms arm only after the missile has traversed a certain minimum distance. In addition, missile SADs employ other environments, such as deceleration and dynamic air pressure, as a second arming signature. Ballistic drag can also be used to advantage to provide environmental safety beyond the point of boost termination. In ballistic missile applications the use of deceleration experienced on reentry into the atmosphere is an excellent source of energy to actuate a SAD.

Suppose an arming device is needed for a hypothetical missile that has the following requirements: (1) to arm under an acceleration of 11 g if this acceleration lasts for 5 s and (2) not to arm under an acceleration of less than 7 g for a period of 1 s. Consider the arming device shown in Fig. 11-5. Setback forces encountered during acceleration of the missile apply an inertial force to the slider. Thus after a specified time, the detonator is aligned with the booster and the latch drops to lock the slider in the armed position. If at any time during this process acceleration drops below 7 g, the slider must be returned to its initial position by a return spring. Because of its weight, the slider would move too fast under these accelerations. Hence a restraining force is necessary, and a clockwork escapement may be used to regulate the motion. The following data and assumptions help to determine the size of springs and weights: (1) neglect friction in the system, (2) a tangential force is needed to overcome the initial restraint of the clockwork, (3) the weight to be determined includes the inertial effects of the whole system, and (4) the spring is not stretched beyond its elastic limit.

To prevent motion of the slider under setback accelerations of less than 7 g, an initial tension $F_t = kx_0$ is given to the assembled spring. The differential equation of motion can be used to determine the restraining force F_r

$$\frac{W}{g}\ddot{x} = aW - kx - F_r - F_t,\ \text{N (lb)} \qquad (11\text{-}1)$$

where

$\ddot{x}$ = acceleration of the slider with respect to the mechanism, m/s² (in./s²)
W = weight of the slider, N (lb)
g = acceleration due to gravity, m/s² (in./s²)
a = acceleration of the mechanism, g-units
k = spring constant, N/m (lb/in.)
x = displacement of slider, m (in.)
F_r = restraining force, N (lb)
F_t = initial tension on the slider N (lb).

By assuming that the velocity of the slider reaches a steady value quickly and then remains constant until the arming process is completed, a long arming time can be realized. The expression for the velocity $\dot{x}$ of the slider is

$$\dot{x} = v_t\,[1 - \exp(-t/T_c)],\ \text{m/s (in./s)} \qquad (11\text{-}2)$$

where

v_t = terminal velocity as t becomes infinite, m/s (in./s)
T_c = time constant, s
t = time, s

in which the velocity $\dot{x}$ is zero at $t = 0$ and approaches v_t, which is the terminal velocity as t becomes infinite. The time constant T_c of the equation fixes the time for $\dot{x}$ to reach 37% of v_t. By integrating Eq. 11-2 to obtain x, differ-

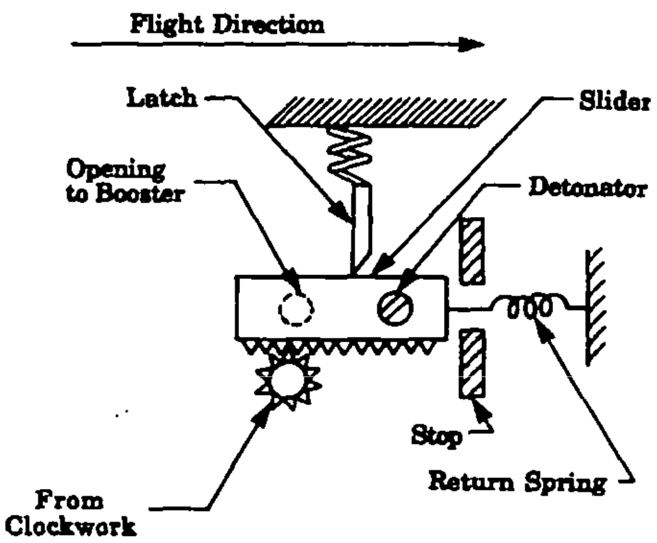


Figure 11-5. Safety and Arming Mechanism

entiating it to obtain $\ddot{x}$, and substituting these three terms (x, $\dot{x}$, and $\ddot{x}$) into Eq. 11-1, F_r is determined as

$$F_r = (aW - kx_0 + kv_tT_c) - kv_tt - \left(\frac{W}{g}\frac{v_t}{T_c} + kv_tT_c\right)\exp(-t/T_c), \text{ N (lb)}. \quad (11\text{-}3)$$

Eq. 11-3 contains three terms, a constant term as expected, a time-dependent term that decreases to compensate for the increase in the spring force, and a transient term that is necessary to allow the weight to accelerate to the velocity v_t. The time-dependent force is typical of the forces produced in an unwinding clock. Hence a clockwork escapement is applicable. Eq. 11-3 determines the design of the clockwork. With this force function the clockwork will produce the required arming delay.

At any other acceleration, a_2, the time to arm will be different. By substituting F_r in Eq. 11-1 and using a new acceleration a_2, the time to move the distance S may be found by solving the transcendental equation

$$S = -\frac{W}{gk}(a_2 - a_1)\cos\sqrt{\frac{gk}{W}}t + \frac{W}{gk}(a_2 - a_1) + v_tt + v_tT_c\,[\exp(-t/T_c) - 1], \text{ m (in.)} \quad (11\text{-}4)$$

where

a_1 = first new acceleration of the mechanism, m/s^2 (in./s^2)

a_2 = second new acceleration of the mechanism, m/s^2 (in./s^2).

Since solutions of these equations are obtained by interpolation formulas, it is better to estimate slider weight and spring constants, than to calculate arming time and adjust as necessary. Note that W and k always occur as a ratio.

11-3.1 PATRIOT S&A DEVICE

The PATRIOT is a large 0.41 m diameter × 5.3 m long (16.0 in. diameter × 17.5 ft long) surface-to-air guided missile, which is proximity fuzed with provisions for ground-controlled self-destruct firing. It is similar in size and purpose to the Russian surface-to-air missile (SAM). The missile is launched from a vehicle with initial guidance from the ground. Upon sensing a target, it returns data to ground control that completes the necessary guidance for run-in. There is an automatic self-destruct (SD) operating 2 s after loss of guidance signal, as well as a command SD. These functions are processed by the S&A electronics, which are dual in nature and employ complementary metal oxide semiconductor (CMOS) logic coupled with a dc-dc converter/fire circuitry. This increases the missile-supplied 28 V dc power to 100 V dc. The increased voltage is stored in silicon-controlled rectifier (SCR) switched capacitor networks, which upon receipt of the fuze fire or self-destruct signal, will energize either of the two explosive trains.

The mechanical portion of the S&A mechanism (Fig. 11-6) is also a dual system for high reliability and uses two unbalanced rotors controlled by runaway escapements. The rotors are locked safe by a rotary solenoid and a spring-loaded setback weight, both of which are interconnected. The unbalance of the rotors is 180 deg out of phase to negate the effects of side accelerations due to maneuvering; thus the responses must be axial. Also the solenoid locks are rotary to avert the effects of transverse accelerations. The system is fully recyclable for testing during assembly.

The solenoids control direct locks on the rotors, as well as a direct lock on the spring-loaded setback weight, which in turn locks the rotors. Arming occurs at 11.9 g's in a time bracket of 3.1 to 4.2 s. The arming distance is 500 to 1000 m (1640 to 3281 ft). Fig. 11-6 is a schematic drawing of the PATRIOT S&A mechanism. The size of the mechanism is 127 mm × 127 mm × 82.6 mm (5.0 in. × 5.0 in. × 3.25 in.). It weighs 22.2 N (5 lb). The warhead is a fragmenting type coupled with directed energy.

11-3.2 HELLFIRE FUZE M820

The HELLFIRE air-to-surface guided missile is similar to other guided missiles in that it employs a minimum sustained acceleration to unlock the rotor after removal of a solenoid launch latch. It is a single-channel system used in many of the smaller guided missiles, and it uses a basic S&A system common to GMs in general. The fuze is described in detail in par. 1-3.3.3 and is shown in Fig. 1-18. A functional logic diagram of this fuze is shown in Fig. 11-7.

11-3.3 HARPOON FUZE

The air-launched HARPOON fuzing system consists of two basic assemblies: the fuze FMU109/B, shown in Fig. 11-8, and the pressure probe FZU30/B, shown in Fig. 11-9. The fuze is a cylindrical component located in the rear portion of the warhead. It contains an S&A mechanism, electrical switching, and the necessary mechanical and electrical logic systems for contact fuzing. The pressure probe is mounted above the fuze assembly on the missile skin and contains an arming wire switch, pyrotechnic squib, and an extendable probe.

At launch from the aircraft a solenoid is energized and releases a lock on the air-operated piston assembly and the rotor. Missile power fires a squib, which extends the pressure probe into the dynamic airstream. The pressure differential is sensed by ram air and static air ports on the probe and acts on the bellowfram piston assembly. If the pressure differential exceeds the bias spring force, the spring is compressed and cocks the rotor flection spring. This action causes the rotor to rotate toward the armed position at a rate governed by a verge escapement to achieve delayed arming.

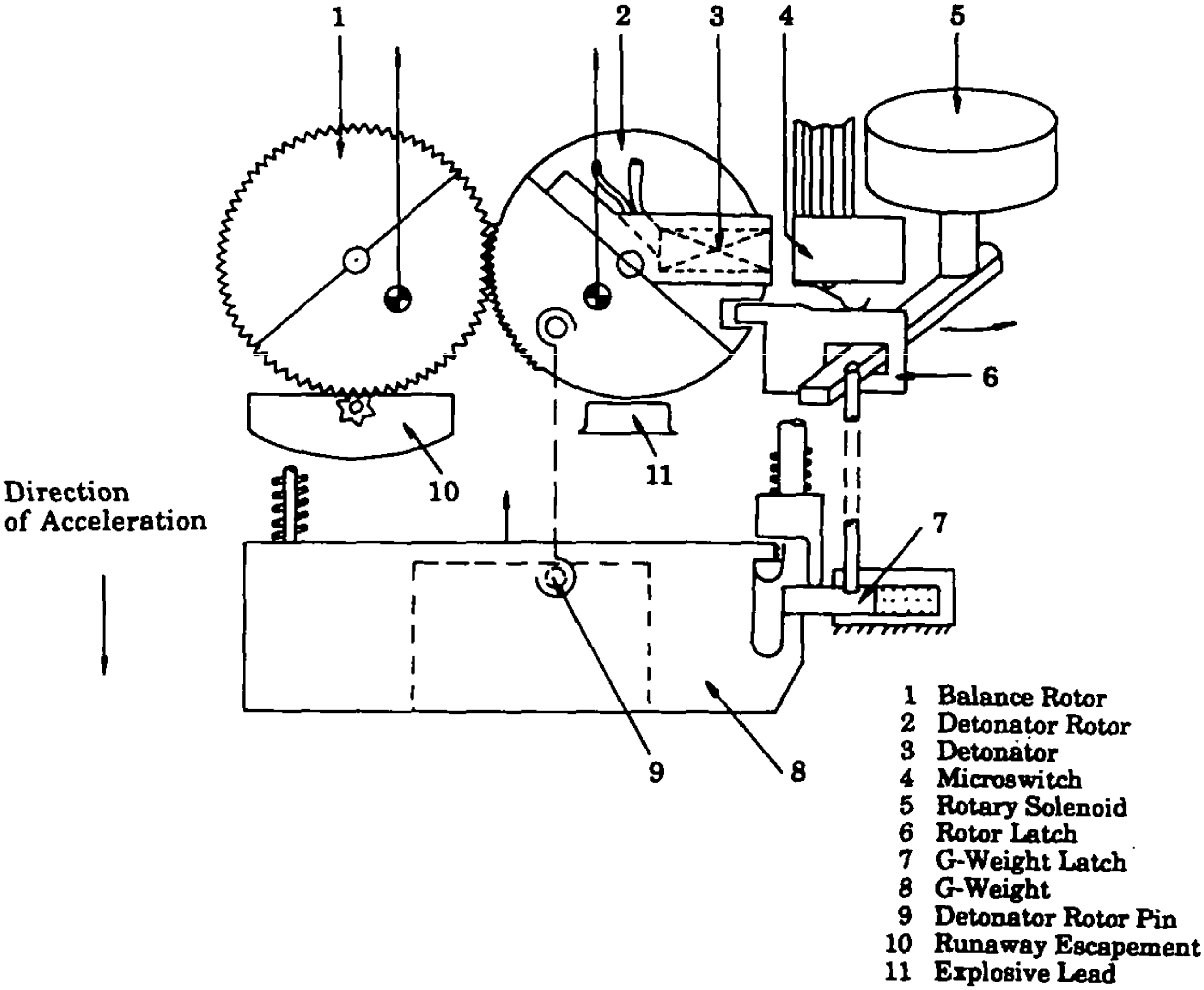


Figure 11-6. PATRIOT Safety and Arming Device

Rotor motion is monitored by a telemetry switch at approximately 1-s intervals to indicate rotor position. During the last 7.5 deg of rotor motion, the delay and instantaneous detonators are switched into the firing circuitry and voltage is applied to the firing capacitors. Upon completion of the arming cycle, the rotor is locked by the action of the solenoid cam, which depresses the rotor locking ball into a slot in the rotor. Target impact is sensed by a g-switch, which completes the firing circuit and initiates the explosive train.

11-4 GRENADE FUZES

The discussion that follows covers the impact-type hand grenade and grenades launched by several other methods.

11-4.1 HAND GRENADES

Hand grenades are discussed in par. 1-3.5.1 with emphasis on the common pyrotechnic delay type fuze, M213, shown in Fig. 1-22. This fuzing system has several drawbacks that can be remedied by using a fuze that fires at impact. An impact system using electrical initiation, shown in Fig. 11-10, has been developed. Fig. 11-10(A) shows the M217 electric fuze with thermal battery, arming delay switch, impact switch, electric detonator, booster, and a schematic drawing of the circuitry. Fig. 11-10(B) is an enlarged view of the impact switch; Figs. 11-10(C) and (D) are thermal switches used in the system.

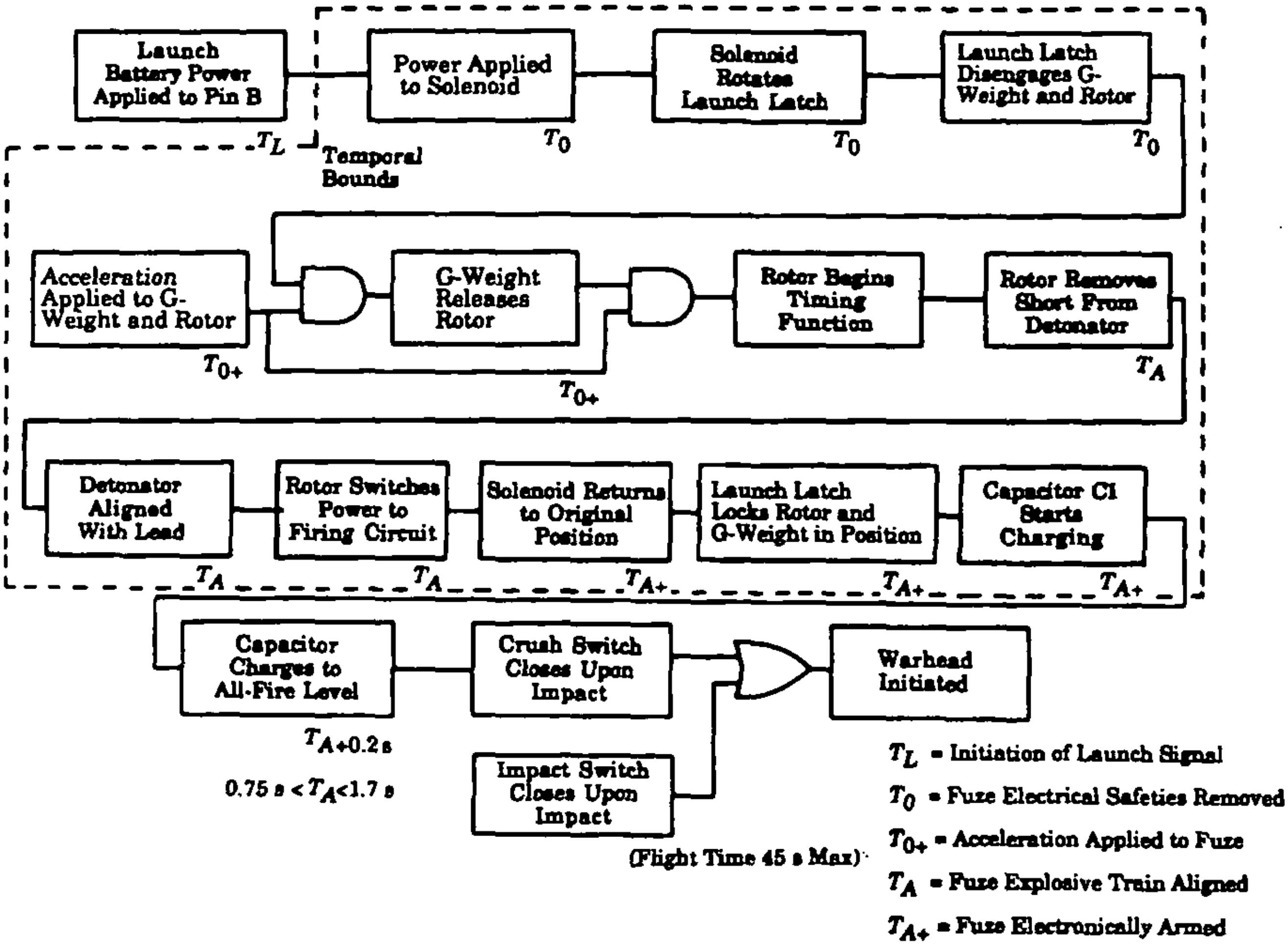


Figure 11-7. Functional Logic Diagram of M820 Fuze

Electrically operated impact fuzes are obviously more complex and more expensive; therefore, they have not replaced the pyrotechnic time delay fuze. The M217 impact fuze includes both an impact function and an overriding time delay SD function.

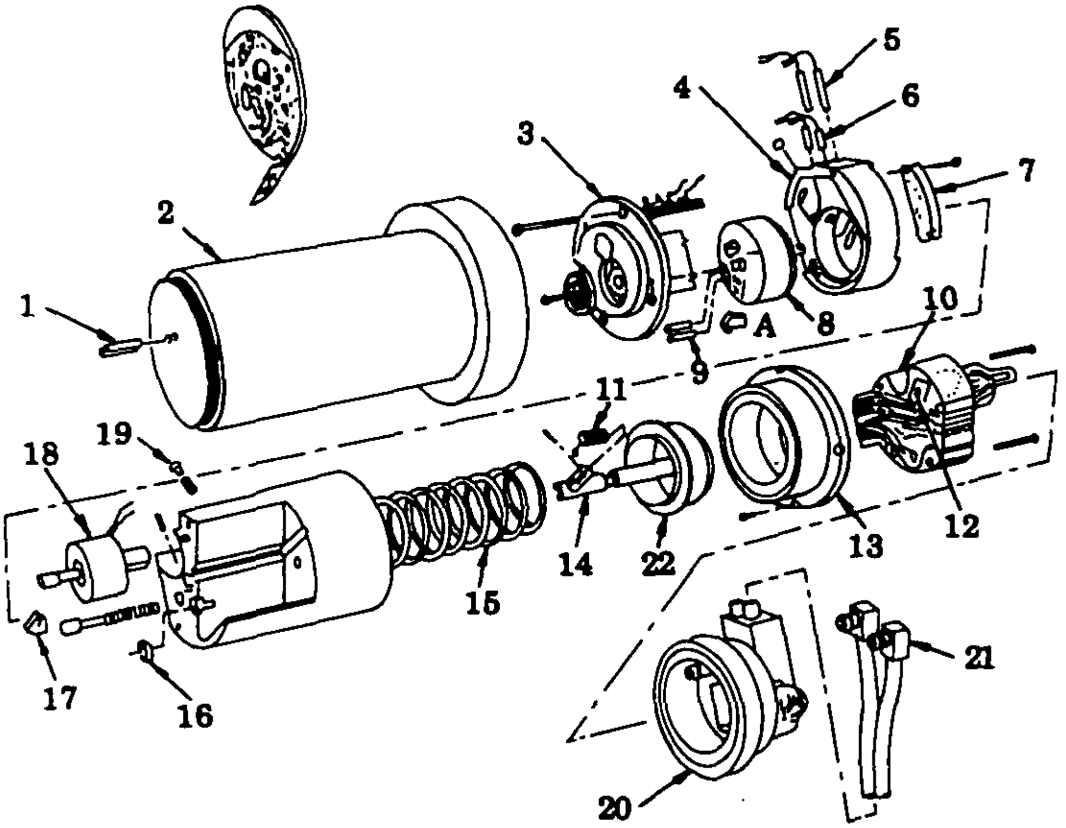
The thermal battery of the fuze reaches its activation temperature within 0.5 s after ignition of the primer by the striker. The thermal arming switch completes arming at about 1.5 s after throwing the grenade. Impact sensitivity is equivalent to a 152-mm (6-in.) drop on a hard surface. If no impact occurs or if the impact is too weak to close the impact switch, the SD switch closes after about 4.5 s and acts as a time delay system.

The 1.5-s delayed arming time ensures that the grenade is about 18.3 m (60 ft) from the thrower before detonation occurs. Since a dropped grenade will strike the ground in approximately 0.5 s, this delay protects against immediate impact function if the grenade is accidentally dropped after withdrawal of the safety pin.

The impact switch is essentially omnidirectional and is sensitive enough to activate on the softest of targets. A lower limit, however, is set by the requirement of having the grenade pass through light foliage without closing this switch. Other sensitivity-limiting factors are that (1) no switch closure must occur from the force of throwing an armed grenade and (2) no switch closure must occur from spin forces about any axis of the grenade during throwing. The arming and SD switches are activated by heat from the battery. Further details of the M217 Fuze are in Ref. 4.

The M217 is initiated in the same fashion, i.e., with a bouchon striker and release lever system, as the standard service grenade fuze M213. The design of a torsion-type wire coil spring for this striker is presented in the discussion that follows.

The striker assembly used in almost all present-day hand grenades consists basically of a firing pin attached to a torsion-type wire coil spring (Fig. 1-22 and 1-49). When a grenade is assembled, the firing pin is cocked, which winds the spring. The spring force F_s is equal to



1 Output Leads
2 Main Housing
3 Base Plate
4 Detonator Holder Body
5 Delay Detonators
6 Instantaneous Detonators
7 Escapement
8 Rotor
9 Explosive Leads
10 Electronic Components
11 Rotor Flection Spring
12 Mk 4 Triggering Device
13 Piston Housing
14 Piston Assembly
15 Bias Spring
16 Rotor Bearing
17 Rotor Stop Lever
18 Solenoid
19 Piston Lock
20 Housing End Cap
21 Pressure Lines
22 Bellofram

Figure 11-8. HARPOON GM Fuze FMU-109/B

$$F_s = \frac{EI_A}{\ell r}\theta, \text{ N (lb)} \qquad (11\text{-}5)$$

where

E = Young's modulus of elasticity, Pa (lb/in.^{2})
ℓ = length of spring, m (in.)
r = lever arm of force F_s, m (in.)
θ = angular displacement of coil, rad
I_A = second moment of cross-sectional area, m^4 (in.^{4}), which can be expressed as (Ref. 5)

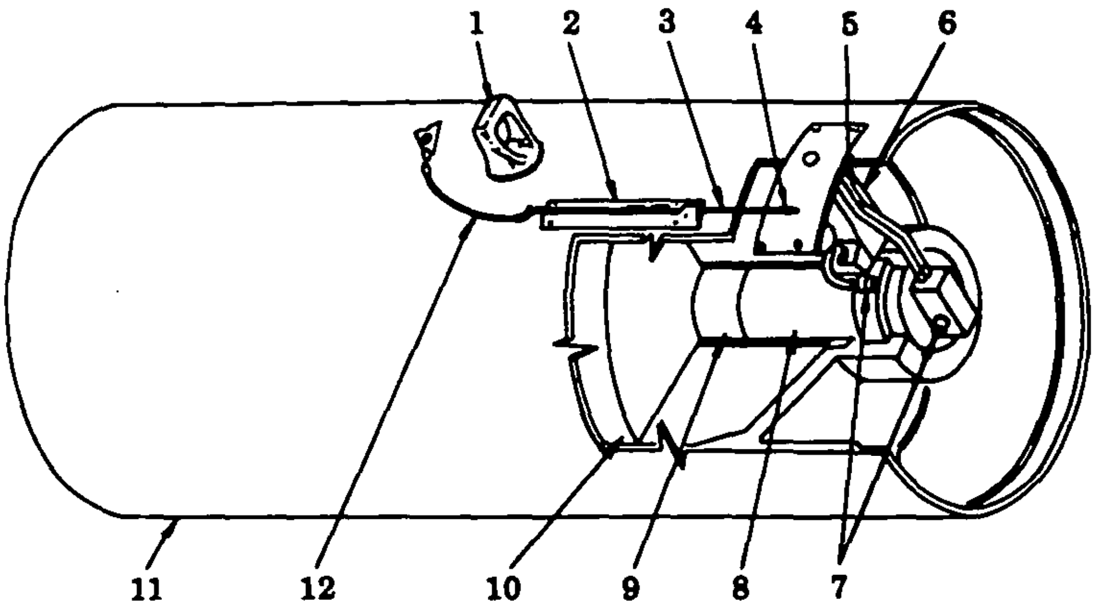
$$I_A = \frac{\pi d_w^4}{64}, \text{ m}^4 \text{ (in.}^4\text{)} \qquad (11\text{-}6)$$

where

d_w = diameter of wire, m (in.).

Typical spring dimensions might be

ℓ = 0.0127 m (0.50 in.)
r = 0.0127 m (0.50 in.)
d_w = 8.89×10^{-4} m (0.035 in.)
E = 2.1×10^{11} N/m^2 (30×10^6 lb/in.^{2})
θ = π rad.



1 Forward Suspension Lug
2 Arming Wire Conduit
3 Arming Wire
4 Probe Switch
5 Pressure Lines
6 Pressure Probe FZU-30/B
7 Electrical Cabling
8 Fuze, Guided Missile, FMU-109/B
9 Booster Mk 44 Mod 0
10 Explosive
11 Warhead Section, GM, WAU-3(V)/B
12 Lanyard

Figure 11-9. Pressure Probe FZU-30/B Assembly on Warhead Fuze for HARPOON GM

Therefore, by Eq. 11-6

$$I_A = \frac{\pi(8.89\times10^{-4})^4}{64}$$
$$= 3.07\times10^{-14}\ \text{m}^4\ (0.074\times10^{-6}\ \text{in.}^4)$$

and by Eq. 11-5

$$F_s = \frac{2.1\times10^{11}\times3.07\times10^{-14}}{1.27\times10^{-2}\times1.27\times10^{-2}}\pi$$
$$= 125.6\ \text{N}\ (27.9\ \text{lb}).$$

Fragmentation hand grenades almost always use percussion primers (par. 1-3.5.1). The energy needed to initiate the percussion primer is obtained from the potential energy H_s stored in the spring and released when the striker swings.

This potential energy can be expressed as

$$H_s = G\theta = \int_0^{\pi} k\theta r_r d\theta,\ \text{N·m (in.·lb)} \quad (11\text{-}7)$$

where

G = torque that is proportional to deflection $k\theta$, N·m (in.·lb)
k = spring constant, N/rad (lb/rad)
r_r = radius arm of the striker that swings through π radians, m (in.).

Since r_r = 12.7 mm (0.50 in.) and k =124.5 N/rad ($\frac{28}{\pi}$ lb/rad), then

$$H_s = 2.49\ \text{N·m (22 lb·in.)}.$$

If we assume that the striker assembly is only 50% efficient because of friction, the energy available as the striker hits the primer is 1.24 N·m (11 lb·in.).

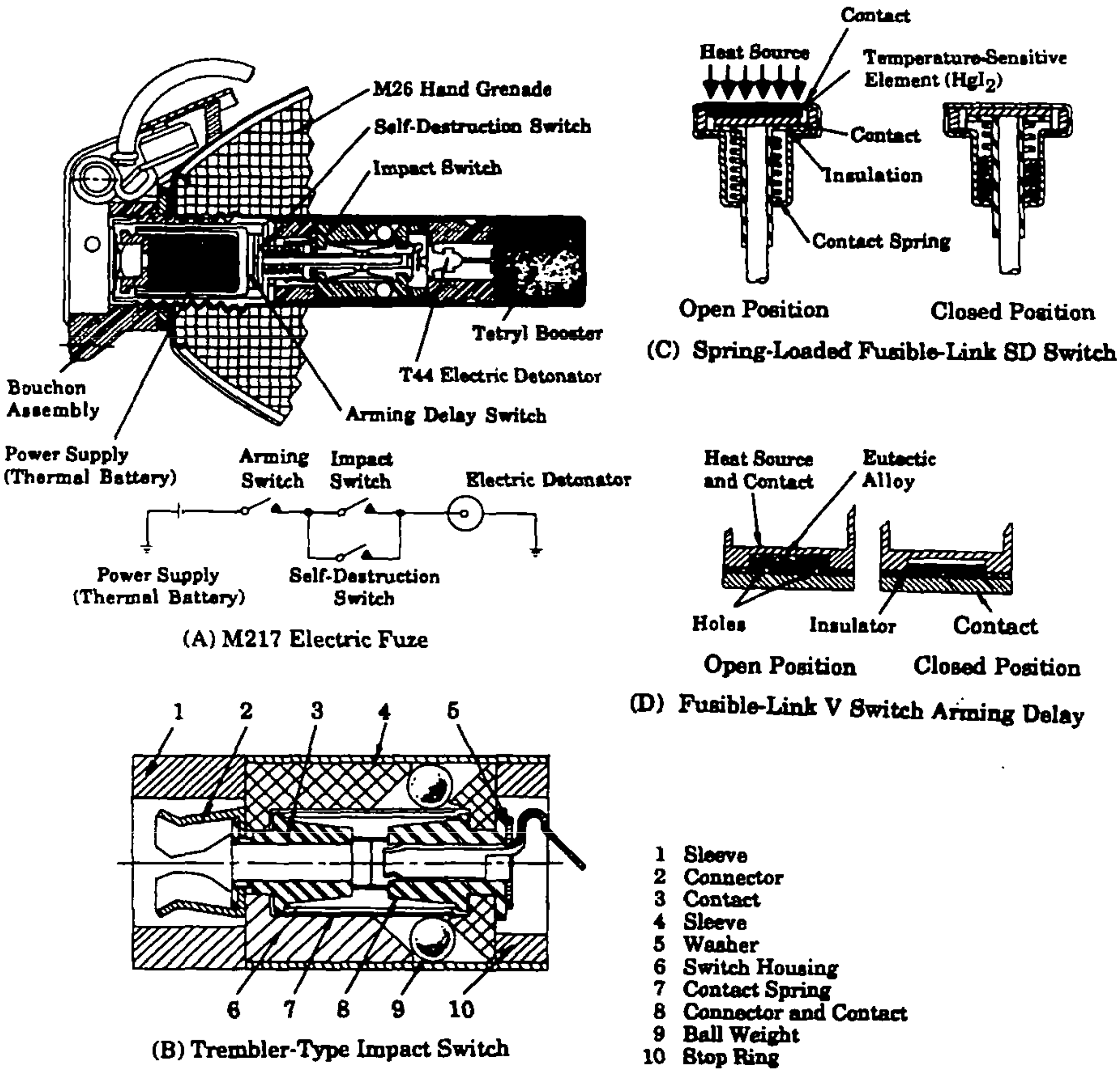


Figure 11-10. Hand Grenade Fuze, M217 (Ref. 4)

11-4.2 LAUNCHED GRENADES

Par. 1-3.5.2 discusses the original rifle-launched grenades, in which the grenades were fitted over the muzzle of the rifle and propelled by blank cartridges. Modern rifle-launched grenades are propelled from a 40-mm barrel attached to the side of an M16 infantry rifle (Fig. 1-23). These grenades also can be propelled from a 40-mm grenade launcher, M79 (Fig. 1-24).

As discussed in par. 1-12.2, the fuzing for a launched grenade, such as the M551 PD Fuze, depends upon setback and spin forces for safety and delayed arming by means of a runaway escapement. The fuze is shown in Fig. 1-50. The hammer weights are used to drive the firing pin into the detonator on direct impact or on graze impact by rotating around a fulcrum.

11-5 SCATTERABLE MINES

Par. 1-3.4.2 defines the family of scatterable mines (FASCAM) as mines planted on the surface by hand, by cargo-carrying munitions, by aircraft, or by towed dispensers. A delivery matrix is given in Table 1-1. A listing of the current family of mines follows:

1. Antipersonnel Mines:
   Area denial artillery munition (ADAM)
   Ground-emplaced mine-scattering system (GEMSS) (M74)—Ground vehicle deployment
   Modular-pack mine system (MOPMS) (XM132)—Remotely activated ground dispenser delivered
   GATOR (BLU-92/B)—Aircraft delivered
2. Antiarmor Mines:
   Remote antiarmor mine RAAM—Artillery delivered
   GEMSS (M75)—Ground vehicle deployment
   MOPMS (XM131)—Remotely activated ground dispenser delivered
   GATOR (BLU-91/B)—Aircraft delivered
   M56—Helicopter delivered.

Newer items being added are

1. Universal mine dispensing system (UMIDS) (VOLCANO)
2. Off-route antitank mine system (ORATMS)—Pursuit deterrent munition
3. Improved conventional mine system (ICOMS).

All of these systems are in response to the threat implied by the enemy's numerical advantage in troops and armor. A great effort has been made to attain commonality in fuzes by keeping variations to a minimum and commensurate with the specific environments of the launch system.

11-5.1 GEMSS FUZE

The GEMSS is designed for rapid emplacement of large, preplanned minefields in areas controlled by friendly forces. The accuracy, rapidity, and lower manpower requirements are the key elements involved. The mines are deployed by a towed M128 mine dispenser, shown in Fig. 11-11, with integral wheeled chassis.

The mines are dispensed by centrifugal force from a large rotating drum. The primary use of GEMSS is for minefield emplacement in screening operations prior to attack or behind the forward line of troops to support predesignated secondary defensive positions. Clearly marked lanes must be provided in the latter situation in order to withdraw friendly units. GEMSS is also useful to protect the flank or

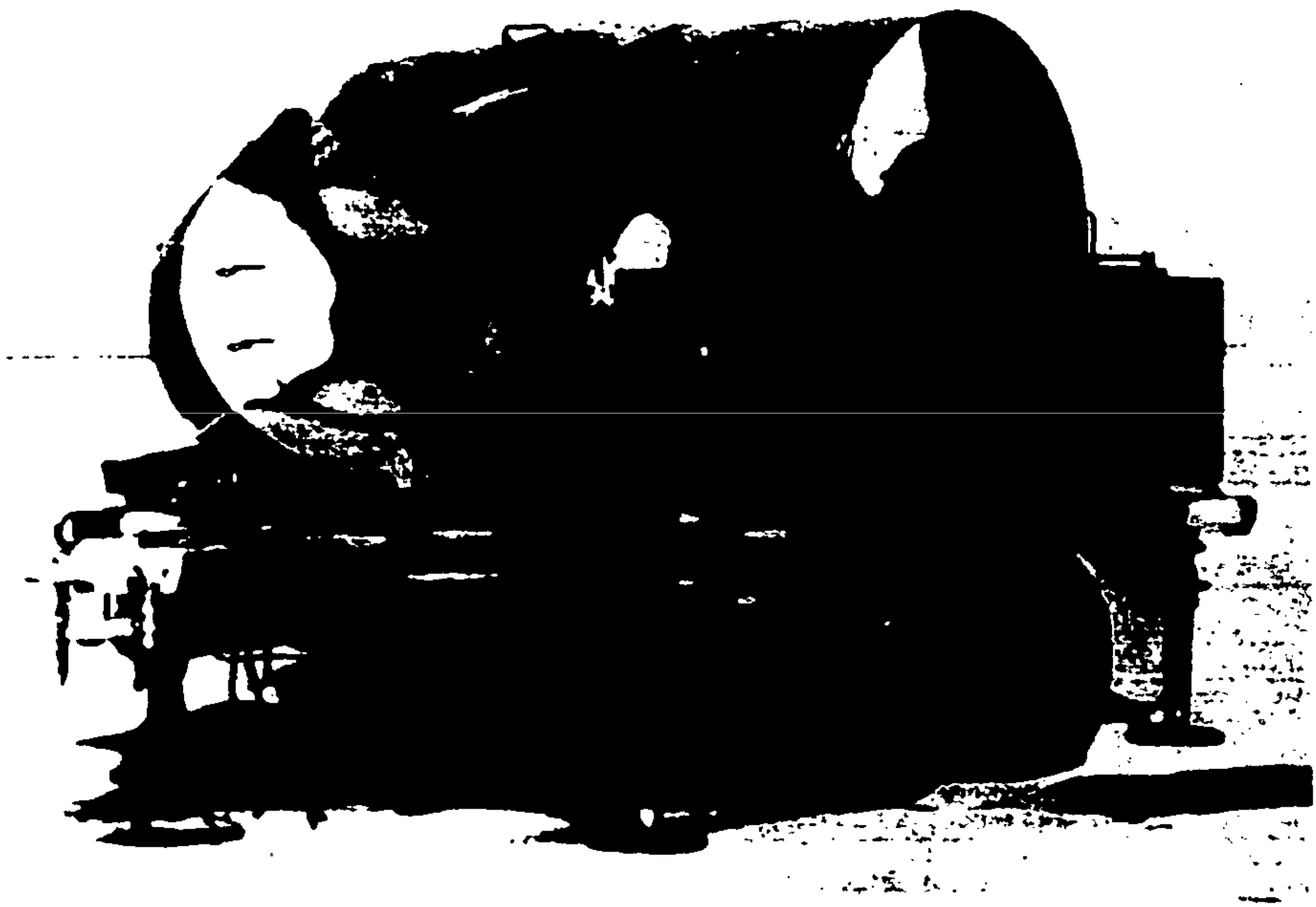


Figure 11-11. Ground-Emplaced Mine-Scattering System Dispenser

to impede the enemy along suspected counterattack approaches.

Two types of mines are used. One is antiarmor, M75, activated by magnetic influence, and the other is antipersonnel M74, activated by projected trip-lines. Both types have antidisturbance features and preselectable SD timers. The basic fuze design for both mines is shown schematically in Figs. 1-48 and 11-12. Both fuzes are spin armed—16 rps nonarm, 42 rps arm, and the second safety device is a magnetic coupling device (MCD) activated upon exit from the dispenser. The firing circuits are enabled after impact by an electronic delay timer.

11-5.2 VOLCANO FUZE

The fuze for the VOLCANO system mines is shown in Fig. 11-12 with variations to suit a specific environment. The two mines are cylinders with length-to-diameter ratios of <1 that have spring fingers around their circumferences to prevent settling on the edges. The antitank-antivehicular (AT/AV) mine uses the Miznay-Shardin principle of armor penetration (Fig. 1-20). The antipersonnel (APERS) mine has a fragmenting outer case. The former is fired by valid magnetic target signatures, whereas the latter is fired by trip lines deployed by a gas generator after the mine comes to rest.

Five AT/AV mines and one APERS mine are assembled in an expendable tube with a propulsion device. The tube contains an S&A mechanism that prevents mine expulsion when it is not attached to a launcher rack. The rack supports 40 tubes and can be used on a helicopter or on various ground vehicles. Provisions exist to jettison the entire rack or individual mines in an abort (unarmed) condition.

The fuzes use a bore rider with pyrotechnic delay, which withdraws 2 min after impact, and a MCD, which receives a

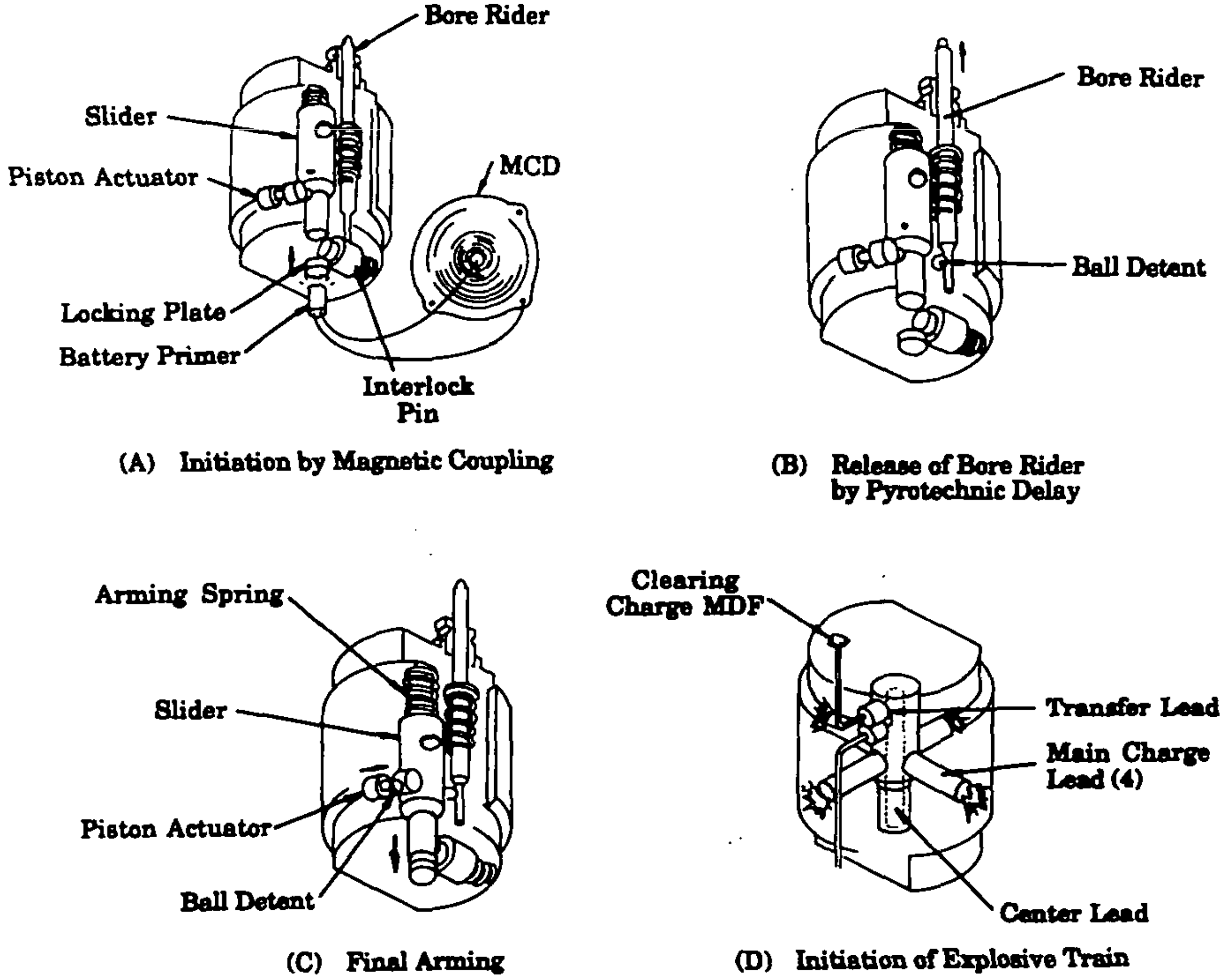


Figure 11-12. Fuze Action for VOLCANO Mines

signal at ejection. This initiates the arming sequence, which starts a predetermined SD delay and energizes a pyrotechnic battery that removes a bore-rider safety lock (piston actuator).

The AT/AV mine fuze can be initiated by a correct target signature, a low-voltage detector, a timer malfunction, or SD time elapse. The APERS mine fuze can be initiated by a physical movement, a trip line, a low-voltage power supply, a timing error, or an SD time elapse.

Fig. 11-12 depicts the operation of the fuze for both the AT/AV mine and the APERS mine. The APERS mine does not use the clearing charge mild detonating fuse (MDF) shown in Fig. 11-12(D), because shaped charge action is not required.

11-5.3 ADAM MINE AND FUZE

An area denial artillery munition (ADAM), shown in Fig. 11-13, is a cargo round (M483 155-mm howitzer projectile) similar to the RAAM described in par. 1-3.4.2. In this munition, however, the antitank mines are replaced with antipersonnel mines. The ADAM can be used to supplement the RAAM minefields and thus protect the RAAM.

The mines, 36 per munition, are wedge shaped for efficient stacking in the projectile. The body of the mine is strong in order to withstand gun launch and ground impact. When the mine is initiated, the liquid explosive surrounding the kill mechanism ignites; this action breaks up the body and propels the kill mechanism upward. The kill mechanism, having a time delay, reaches the optimum height for maximum effectiveness against personnel before detonation.

The arming sequence for each mine begins during projectile launch. The S&A mechanism provides a barrier to the firing train until it is properly armed. Three separate, sequentially ordered environments must be sensed by the S&A mechanism to become fully armed.

In the safe position two barriers block the firing train between the detonator and the lead. These barriers are locked into position by two spring-loaded sliders, and the sliders are locked into position by the setback pin. Upon setback, the setback pin is withdrawn and the long slider unlocked. Spin in the gun forces the sliders out of position so that the barriers are free to move. Upon ejection, the barriers move out of position into a cavity and leave a hole through which the microdetonator fires. After ejection, the spin decays, the sliders move back into line, and thus the barriers are locked out of the blocking position. The SAD is then fully enabled, in the armed position, and the firing train is aligned.

Immediately prior to ejection, the projectile battery activation rod shears off a shorting bar on each mine and thereby removes the electrical short across the detonator. The rod also depresses a battery ball on each mine to activate the battery and begin an electrical arming sequence.

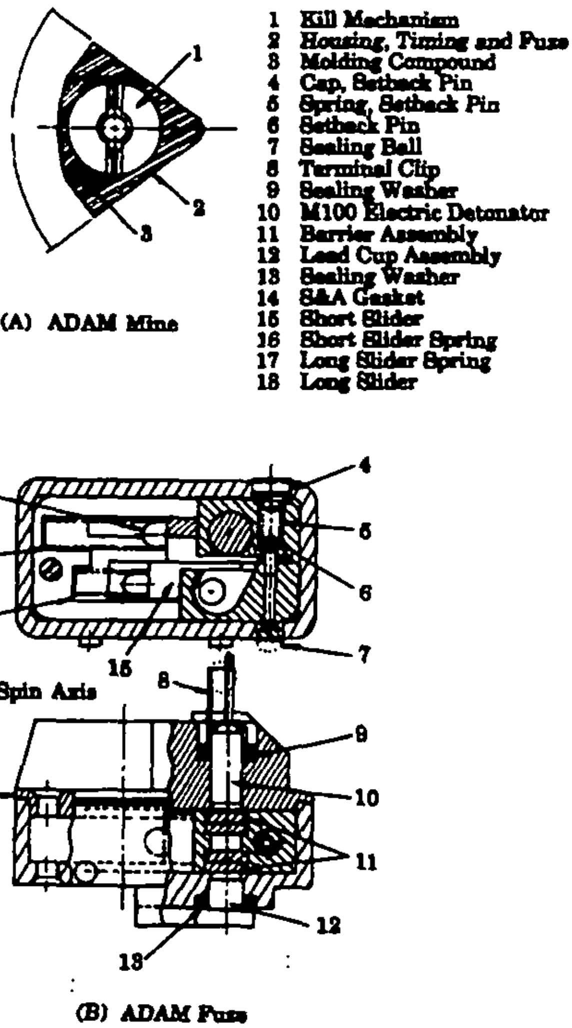


Figure 11-13. ADAM Mine and Fuze (Ref. 6)

Battery activation initiates the timing and logic circuits. The mines tumble through the air, impact the ground, and come to rest in a random orientation. After a short delay following impact, a propellant gas system is electrically initiated to deploy seven trip-line sensors, and after another short delay, each mine is electrically enabled for activation by intruders.

The mine can be functioned by pulling on a trip line with sufficient force to shear a break wire in the mine. A disturbance, such as a jar or roll from one face to another, will also function the mine. Either action will cause a fire pulse to be sent to the detonator.

11-6 SUBMUNITION FUZES

Submunitions as payloads of projectiles, rockets, and airborne canisters make up a class of munitions characterized by their relatively small size, which is comparable to the hand grenade. Their numbers include antiarmor and antipersonnel damage mechanisms. Dispensing is usually by pyrotechnic ejection from the base of projectiles or the nose of rockets. Dispensing from canisters can also be by pyrotechnic means or by linear shaped charges used to open a canister released over the target area.

Stabilizing methods assume various forms, such as ballutes, which are fabric bags inflatable by ram air, hinged metal drag plates, trailing ribbon loops, and aerodynamic ribs to cause spin. Figs. 1-26, 1-27, 1-51, and 11-14 illustrate several of these methods.

Fuze M230, shown in Fig. 11-14, for the M73 Submunition is carried and dispensed from the helicopter-launched 2.75-in. rocket. The stabilizer is a fabric bag inflated by ram air. The resulting drag forces shear a safety pin and allow the slider/interrupter to align under control by an escapement time delay. This arming delay provides protection against firing by intermunition collisions at deployment. The firing or triggering mechanism is a near omnidirectional sensing mass, which holds a firing pin locking ball in place under conditions of unstable equilibrium. This sensing mass is dislodged at impact and releases the cocked firing pin.

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2. K. A. Van Oesdel, *Primary Factors That Affect the Design of Guided Missile Fuzing Systems*, NAVWEPS

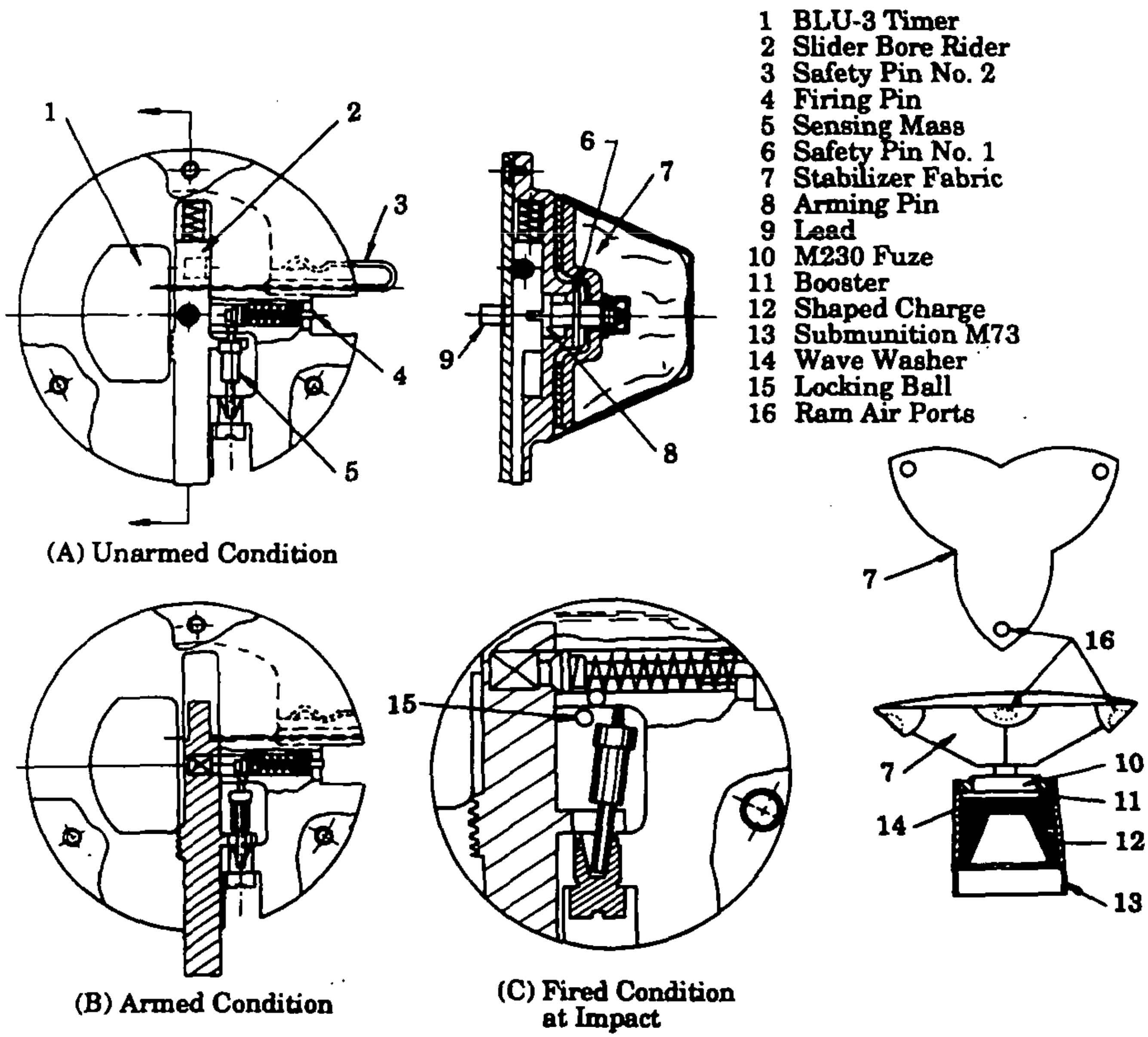

Figure 11-14. Grenade Fuze M230 (Ref. 6)

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3. *A Compendium of Mechanisms Used in Missile Safety and Arming Devices* (U), Part I, Journal Article 27.0 of the JANAF Fuze Committee, March 1962. (THIS DOCUMENT IS CLASSIFIED CONFIDENTIAL.)

4. AMCP 706-240, Engineering Design Handbook, *Grenades*, December 1967.

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6. MIL-HDBK-145, *Active Fuze Catalog*, 1 October 1980.

CHAPTER 12
STATIONARY AMMUNITION FUZES

The fuzing aspects of stationary ammunition, which in many instances are quite different from those of other conventional ammunition, are discussed. Other ammunition travels to the target, whereas stationary ammunition, which includes mines and boobytraps, requires that the target approach it. The great changes in the deployment, safety, and self-destruct philosophy of mines and minefields are explained, and examples of the latest technologies in antipersonnel and antitank mines are cited. Both the older type pressure-operated and the newer generation of influence and self-deployed, trip-line mines are covered. Examples of the reversing Belleville spring, tilt rod, and pull-release mechanisms used in the earlier mines are presented along with the design equations associated with these mechanisms. Triggering of the newer generation of antitank mines by magnetic, seismic, or acoustic influence means is covered. The new generation of surface-laid antipersonnel mines with self-deployed trip lines and controlled self-destruct features is discussed and examples and illustrations are presented. Boobytraps are described as munitions designed to detonate when triggered by stepping upon, lifting, or moving harmless looking objects. Examples of a friction-initiated pull device and a mousetrap pressure-release firing device fuzing mechanism are discussed and illustrated. An improvised boobytrap system using a conventional hand grenade, cord or wire, and an empty can is illustrated as an example of the type of ingenuity often used in the field.

12-0 LIST OF SYMBOLS

B = parameter, see Eq. 12-2, dimensionless
d_i = inner diameter, m (in.)
d_o = outer diameter, m (in.)
d_w = diameter of wire, m (in.)
E = modulus of elasticity, Pa (lb/in.^{2})
F = spring force, N (lb)
h = initial distance of leaf from center point, m (in.)
I_A = second moment of area of section AA, m^4 (in.^{4})
ℓ = length of the spring, m (in.)
r = lever arm of force F, m (in.)
t_s = leaf thickness, m (in.)
y = spring deflection, m (in.)
σ_{max} = maximum stress on inner edge of spring, Pa (lb/in.^{2})
θ = angle of twist for spring coils, rad
ν = Poisson's ratio for the material, dimensionless

12-1 INTRODUCTION

Fuzes for stationary ammunition—discussed in par. 1-11—contain a triggering mechanism and an explosive output charge. Incendiary and chemical charges are used occasionally. This ammunition—addressed in par. 1-3.4—is often hidden from view by burying it in the ground, planting it underwater, or disguising it in harmless looking objects (booby traps). The fuzes are initiated by mechanical or electrical stimuli through either contact or proximity action of the approaching target.

Newer mines—discussed in par. 1-3.4.2—are laid on the surface by aerial delivery, artillery, or dispenser. The dispenser can be a towed unit, shown in Fig. 11-11, that ejects mines as it moves along or hand-placed modules with a remote control dispensing capability. Although visible, the minefields are made resistant to enemy clearing tactics by interspersing antiarmor mines with antipersonnel mines.

Fuzes for the newer surface-laid mines use spin, setback, and dispenser-induced—bore riders or magnetic sensors—environments for safety and arming, as discussed in par. 1-11.2. Triggering can be effected by trip wires (automatically ejected), magnetic flux change, radar, or seismic signals. Self-destruct is incorporated to facilitate minefield clearance in order to permit subsequent movement of friendly troops.

12-2 LANDMINES

12-2.1 LANDMINE TYPES

Landmine use and description is presented in par. 1-3.4 and in Ref. 1. The antiarmor mines are usually designed with shallow concave mild steel plates, as shown in Figs. 1-19 and 12-1 to produce a forged fragment of highly directed energy able to defeat up to 102 mm (4 in.) of belly armor on vehicles at 0.6 to 0.9 m (2 to 3 ft) standoff. As with all shaped charges, mechanisms and overburden within and immediately above the concave void must be cleared prior to detonation of the main charge in order to permit maximization of the directed energy. This is accomplished by a two-stage initiation, i.e., firing of small clearing charges—shown in Fig. 12-1—30 ms prior to firing of the main charge. Because aerial, artillery, or towed dispenser-delivered mines can land with either face upward, the dual concave arrangement shown in Fig. 12-1 is employed with a gravity-operated interrupter to select the upward clearing charge automatically.

Antipersonnel mines have several variations. The bounding mine, which can be buried or surface laid and triggered by trip line or crushing, is projected 0.9 to 1.5 m (3 to 5 ft) upward before detonation. Another type of surface-laid mine, shown in Fig. 12-5, uses trip lines and has a fragmenting case without the bounding feature.

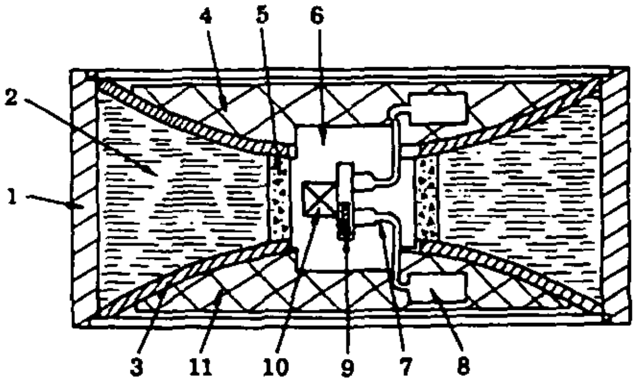


Figure 12-1. Remote Antiarmor Mine

A typical projectile-delivered antiarmor mine, the remote antiarmor mine (RAAM), is shown in Fig. 12-1. The RAAM is a magnetically fuzed artillery-delivered mine—shown in Fig. 1-21—with 10 projectiles that can produce a 250- by 300-m (820- by 984-ft) minefield in a very short time. The density is a function of the height of dispersal from the cargo munition. This mine is projected from the base end of the 155-mm mine round. The fuze senses the forces of spin and setback from the ejection phase. The mine is armed after ground impact and awaits a proper armored vehicle magnetic signature.

12-2.2 REVERSING BELLEVILLE SPRING TRIGGER

Reversing Belleville springs provide a convenient method for initiating landmines. When a force is applied to this special type of Belleville spring in one of its equilibrium positions, the spring flattens and then moves rapidly into its other equilibrium position. As indicated in Fig. 12-2, the spring does not require any external force to snap through to the second position after passing the flat position. These springs are designed by using the equations that follow. In applying the equations, it is important that dimensions be consistent. The spring force F is given by

$$F = \frac{4E}{d_o^2(1-\nu^2)B} \times \left[\left(h-\frac{y}{2}\right)(h-y)\,t_s + t_s^3\right] y,\ \text{N (lb)} \qquad (12\text{-}1)$$

where

F = spring force, N (lb)
E = modulus of elasticity, Pa (lb/in.^{2})
d_o = outer diameter, m (in.)
d_i = inner diameter, m (in.)
h = initial distance of leaf from center point, m (in.)
y = spring deflection, m (in.)
t_s = leaf thickness, m (in.)
ν = Poisson's ratio for the material, dimensionless
B = parameter given by

$$B = \frac{6(d_o-d_i)^2}{d_o^2\pi\ln(d_o/d_i)},\ \text{dimensionless.} \qquad (12\text{-}2)$$

Maximum spring force occurs when

$$y = h - \sqrt{\frac{h^2-2t_s^2}{3}},\ \text{m (in.)} \qquad (12\text{-}3)$$

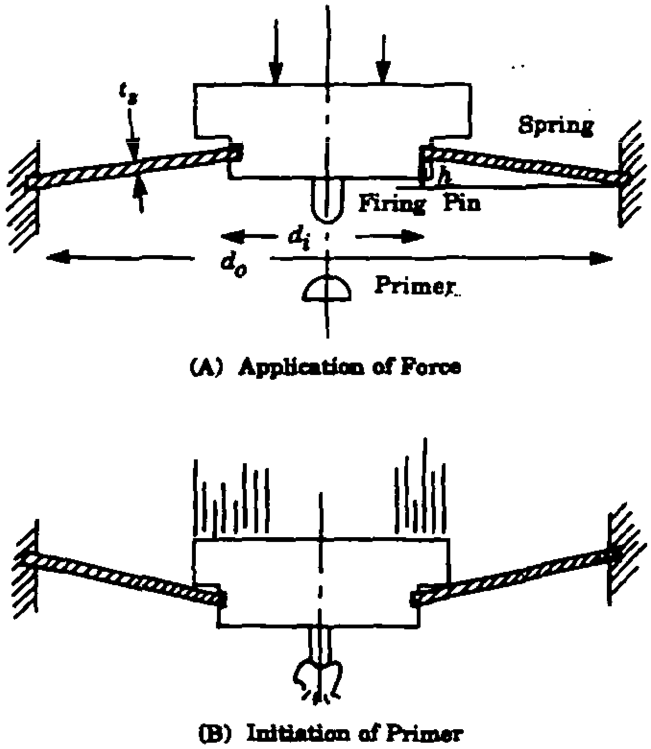


Figure 12-2. Action of Reversing Belleville Spring

Maximum stress σ_{max} occurs on the inner edge of the spring when $y = h$ and is given by

$$\sigma_{max} = \frac{4Eh}{1-\nu^2} \times \left[\frac{h\left(\frac{d_o - d_i}{d_i} - \ln\frac{d_o}{d_i}\right)}{2\left(\ln\frac{d_o}{d_i}\right)(d_o - d_i)^2} + \frac{t_s}{2d_i(d_o + d_i)} \right], \text{ Pa (lb/in.}^2\text{)}. \quad (12\text{-}4)$$

For purposes of reliable initiation, the designer may prefer to place the detonator where the firing pin has the maximum kinetic energy. This position is found by further derivations based on the previous equations (Ref. 2).

Suppose a reversing Belleville spring is needed for a mine that is actuated by a minimum force of 156 N (35 lb). According to the space available, d_o may be 51 mm (2 in.) and d_i = 12.7 mm (0.5 in.). For nonmagnetic and nonmetallic mines a phenolic laminate ($E = 9.3 \times 10^9$ Pa (13.5×10^5 lb/in.^{2}), $\nu = 0.3$) is used for the spring material. This leaves the spring height h and the thickness t_s to be determined. Eq. 12-3 gives the deflection y for maximum pressure in terms of h and t_s. As a trial, let t_s = 0.64 mm (0.025 in.) and h = 6.4 mm (0.25 in.) so that y becomes 2.7 mm (0.108 in.). Substitution of these values in Eq. 12-1 gives the maximum spring force F as 654 N (147 lb), which is too great for a 156-N (35-lb) actuating force.

For a second trial h is reduced to 3.8 mm (0.15 in.), from which y at the maximum load becomes 1.7 mm (0.067 in.). Then from Eq. 12-1 the maximum force becomes 146 N (33 lb). This value falls within the specified limit.

It remains to determine whether the spring material will withstand the stresses caused by this load. Eq. 12-4 indicates that the maximum stress in the spring σ_{max} is 3.0×10^8 Pa (43,000 lb/in.^{2}), which is not excessive for a phenolic laminate.

12-2.3 CLAYMORE TRIGGERING DEVICE

The Claymore mine is used as an antipersonnel weapon of the fragmenting type. One application had the mine mounted on the side of a vehicle with underlying protection from backblast; this provided protection from an ambush when the mines were fired electrically on command. This mine is also adaptable to mounting on posts, trees, stakes, and tripods. The blast is usually directed horizontally toward enemy troops.

A triggering device—shown in Fig. 12-3—is used with a trip line to cause detonation of one Claymore mine. The system is a switch spring biased to the open circuit position. In

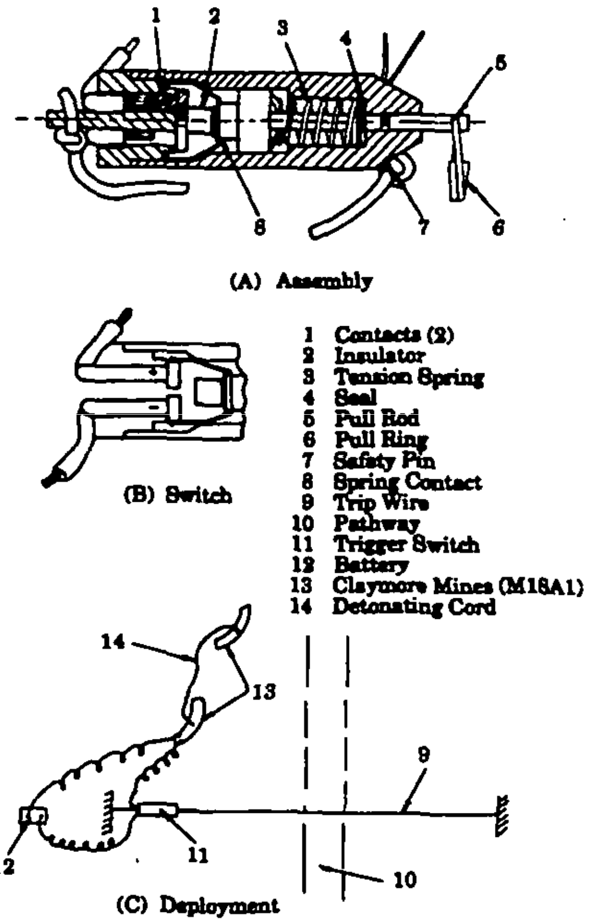


Figure 12-3. Claymore Triggering Device (Ref. 3)

compressing the spring the trip line closes the contacts. A battery is required in conjunction with the switch. A number of mines can be triggered from the first by interconnecting lengths of detonating cord.

12-2.4 MAGNETIC SENSORS

Several magnetic systems are available for target sensing and triggering; among these is electromagnetic induction, which is explained in par. 3-2.5.

The compass principle, or magnetic dip needle, is another. In this arrangement a magnetized needle is mounted to permit rotation or deflection by a change in the magnetic field of the earth from the near presence of a moving vehicle and can alert and/or trigger the mine fuze.

Common to each system is the proximity aspect, which makes it unnecessary for the vehicle to strike or crush the mine fuze. Accordingly, enhancement of target acquisition is obtained to a significant degree.

For the shaped charge mine it is necessary for the sensor system to have sufficient intelligence to assure that triggering is done only when the vehicle is straddling the mine. (See par. 1-3.4.)

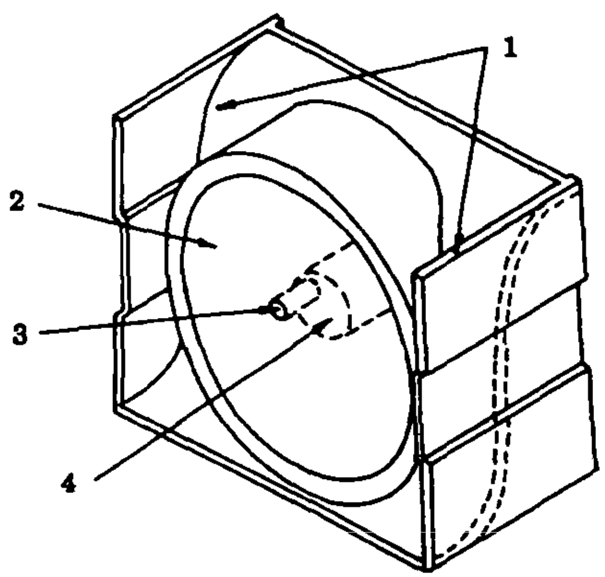
A magnetic sensor is also used to arm a fuze and thus furnishes an additional arming environment. The fuze for the BLU 91/B mine—shown in Fig. 12-4—has such a system. Fig. 11-12 shows the arming system of the fuze in sequence: (A) the magnetic coupling system interaction with the delivery canister upon separation, (B) the release of the bore rider, which is initially blocked during canister storage and further delayed by a 2-min pyrotechnic delay after impact, (C) final arming, and (D) initiation of the clearing charge mild detonating fuse (MDF) and then the main booster. This fuze also senses valid targets by their magnetic signatures.

12-2.5 ACOUSTIC SENSORS

Acoustic sensors can be used as an alerter system to detect the presence of a potential target and to turn on a radar system, which can identify, locate, and track the potential target for off-route mines. If the target is an improper one or not coming within range, the system will shut down to conserve its battery power supply, although the acoustic element will continue to operate. An acoustic triggering system is impractical because it can be falsely triggered by spurious noises or intentional noises produced by the enemy.

12-2.6 SEISMIC SENSORS

The seismic sensor for a mine is discussed in par. 3-2.9.



1 Flettner Rotor
2 AT Mine
3 Bore Rider
4 Fuze

Figure 12-4. Mine BLU 91/B (X1-1)

12-2.7 TRIP LINES

Trip lines are lines that, when pulled or stumbled into, fire an explosive charge that can throw fragments from its position on the terrain or eject a fragmenting submunition, which bursts at waist or chest height of the intruder.

Two methods of deployment are used. Personnel can string the lines across a potential pathway and secure the ends so as to trigger the device upon movement, or after impact aerially delivered mines can eject multiple trip lines outward to approximately 18 m (60 ft) (Fig. 12-5). Small anchor attachments snag in grass, bushes, and earth.

Another type of trip-line system can be designed not only to trigger the charge on pull but also to fire the system if the line is severed.

12-2.8 TILT ROD

Fuze M607 (formerly T1200 E2) is designed for use in the heavy antitank mine M21 (Fig. 1-19), which is usually buried to an approximate 150-mm (6-in.) depth. The fuze—shown in Fig. 12-6(A) and (B)—can be fired by a vertical crushing force, Fig. 12-6(D), of 1.29×10^3 N (290 lb) or by a 16.7-N (3.75-lb) horizontal force or as shown in Fig. 12-6(E) by canting a 610-mm (24-in.) tilt rod through 20 deg.

Safety with this fuze is entirely nonenvironmental and relies on care by the operating personnel. After the fuze is installed in the mine, a sheet metal collar secured by a ring and cotter pin, shown in Fig. 12-6(C), is removed as a last operation. The supporting collar prevents operation by protecting the frangible plastic collar from breakage under loading. Fig. 12-6(F) shows the fuze with the safeties removed.

The mine and fuze can be used without the tilt rod extension with full dependence placed on an overhead crushing load.

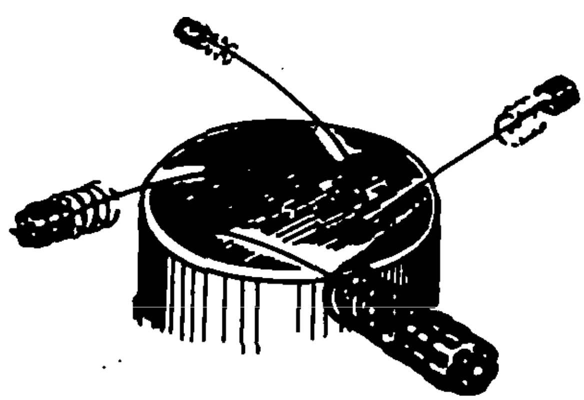


Figure 12-5. AP Mine With Trip Lines

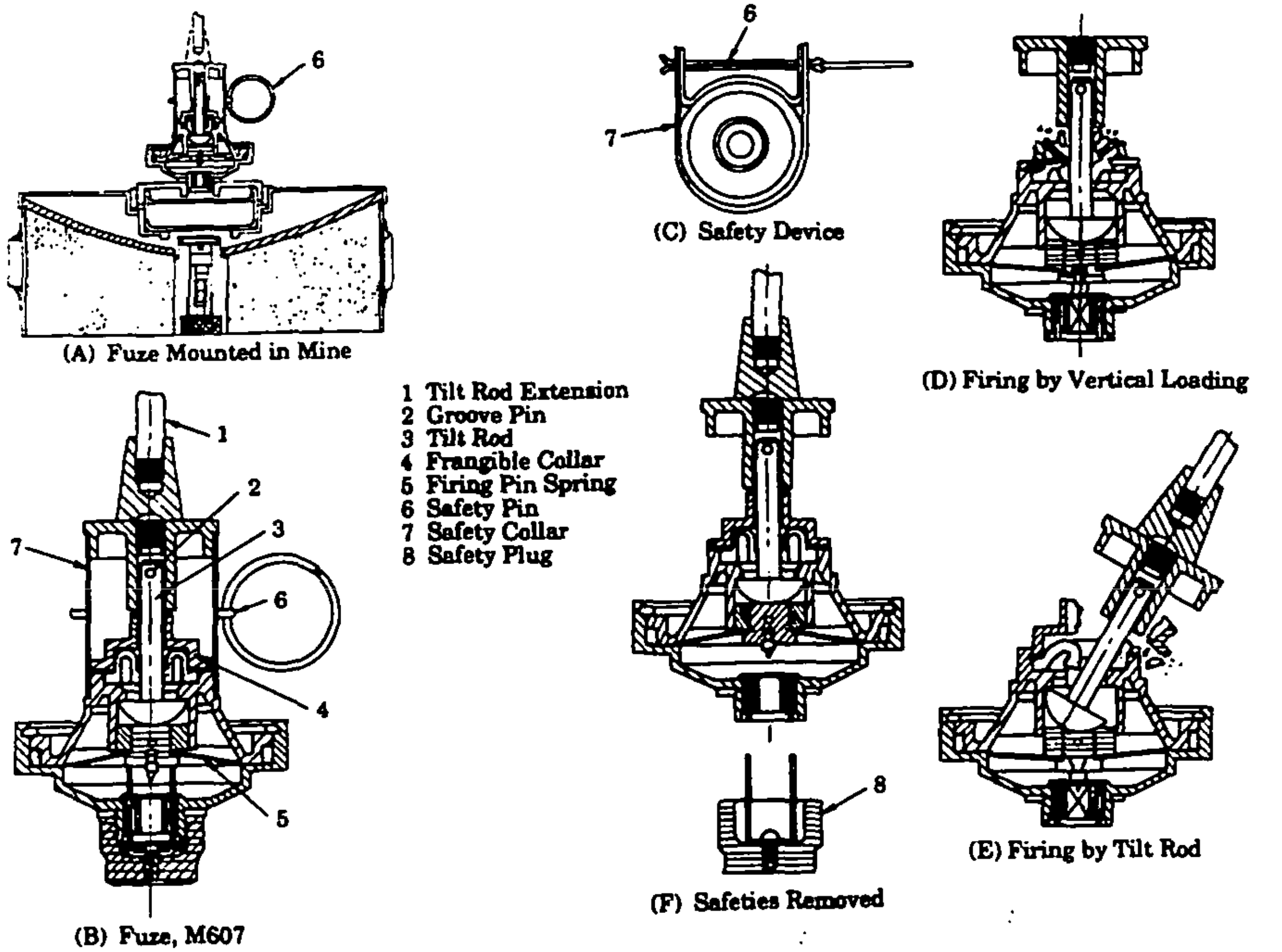


Figure 12-6. AT Mine Fuze, M607 (Ref. 4)

12-2.9 BOOBYTRAPS

Boobytraps are explosive charges fitted with a detonator and a firing device, and all are usually concealed and set to explode when an unsuspecting person triggers the firing mechanism by stepping upon, lifting, or moving harmless looking objects (Ref. 5). The pressure-release-type firing device (mousetrap) is an example. Fig. 12-7 illustrates the action of the M5 Firing Device. The release plate has a long lever so that a light weight will restrain it. The spring propels the firing pin against the primer when the release plate lifts. The firing pin spring turns the firing pin through an angle of about 180 deg.

The explosive train in the fuze consists simply of the firing pin and a percussion primer. A tube directs the flash to the base cup, which is coupled at the threads. No delay is used. Safety is provided by a safety pin inserted and held by a cotter pin to prevent the release plate from lifting. The firing pin spring is of the torsion type in which a wire coil is wound as the device is cocked. This spring force is calculated from

$$F = \frac{EI_A}{\ell r}\theta, \text{ N (lb)} \qquad (12\text{-}5)$$

where

I_A = second moment of area of section AA, m^4 ($in.^4$)
ℓ = length of spring, m (in.)
r = lever arm of the force, m (in.)
θ = angle of twist for spring coils, rad.

For this spring the approximate dimensions might be ℓ = 12.7 mm (0.50 in.), r = 12.7 mm (0.50 in.), diameter of wire d_w = 0.90 mm (0.035 in.), so that $I_A = \frac{\pi d_w^4}{64} = 0.032 \times 10^{-12}$ m^4 (0.074×10^{-6} $in.^4$), $E = 20.7 \times 10^{10}$ Pa (30×10^6 psi), and $\theta = \pi$ rad. F then is 124.5 N (28 lb), and because of the 7:1 lever ratio, the force on the release plate will be about 17.8 N (4 lb). Thus a heavy book could serve as the bait for this boobytrap.

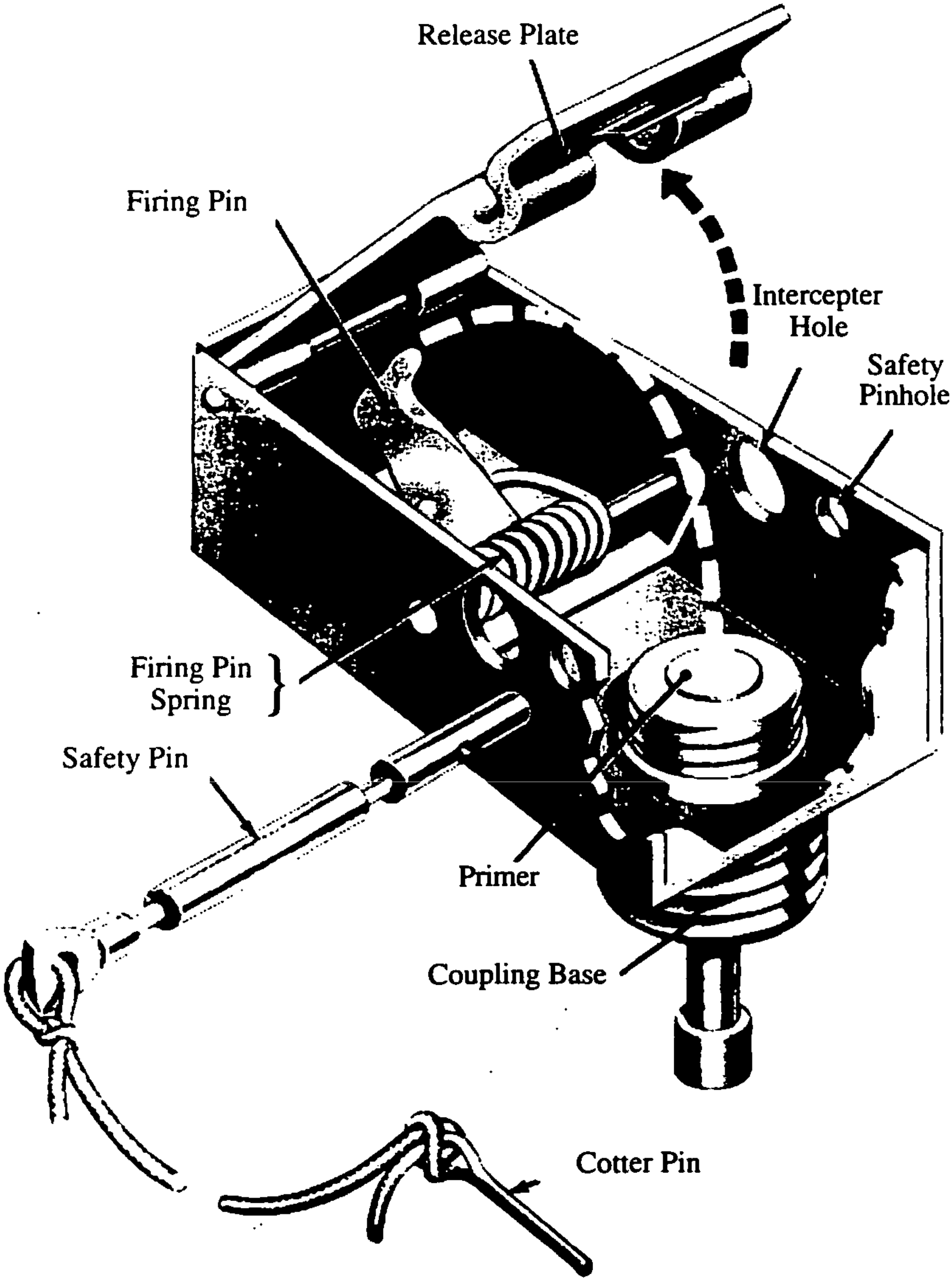


Figure 12-7. Pressure Release Firing Device

A different method of initiating boobytraps is employed in the M2 Firing Device, shown in Fig. 12-8. A friction device initiates a fuze from the heat created by an action similar to that of a safety match being pulled through a pair of striker covers placed face-to-face. The head of the wire, coated with a friction composition, usually a red phosphorus compound, is supported in a channel by a silicone compound. The igniter compound may be a mixture of potassium chlorate, charcoal, and dextrine.

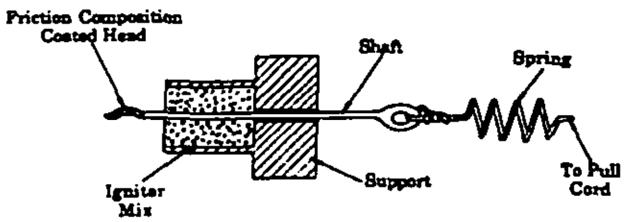


Figure 12-8. Firing Device, M2

In addition to serving as a seal, the silicone provides static friction on the shaft. When a force is exerted on the pull wire, the spring deflects until the force is large enough to overcome shaft friction. At this time the shaft slips through the explosive and wipes against the igniter mix. The friction generates enough heat to start the chemical reaction in order to ignite the charge.

Design of this mechanism, therefore, depends critically upon the force required to overcome shaft friction. The spring should store enough energy to extract the shaft once motion is started because the rise in temperature at the interface of the head and explosive is a function of shaft velocity.

In the absence of issued boobytrap mechanisms, considerable ingenuity has been evidenced in the field when necessity has been the mother of invention. Great care must be taken, however, to observe good safety practices. One example of an improvised system is shown in Fig. 12-9.

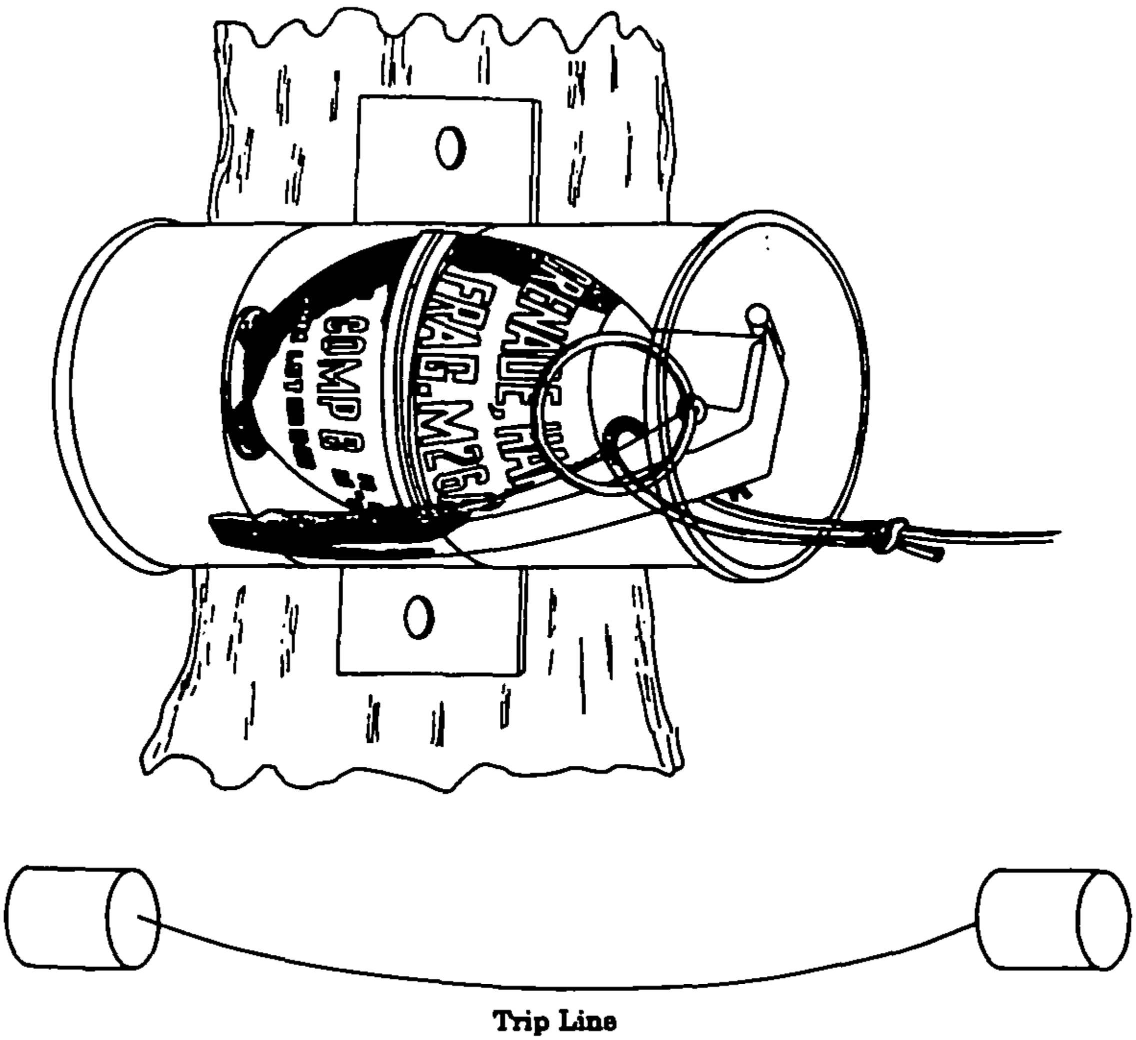


Figure 12-9. Improvised Boobytrap

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2. A. M. Wahl, *Mechanical Springs*, McGraw-Hill Book Co., Inc., New York, NY, 1963, pp. 155-75.
3. W. P. Morrow, *Claymore Triggering Device*, HDL-TM-71-39, Harry Diamond Laboratory, Adelphi, MD, December 1971.
4. MIL-HDBK-145, *Active Fuze Catalog*, 1 October 1980.
5. FM 5-31, *Boobytraps*, Department of Army, September 1965.

CHAPTER 13
DESIGN GUIDANCE

This chapter provides guidance on practices that have proven successful in designing modern fuzes. Problems encountered in contact contamination and corrosion are discussed, and the incompatibility of fuze materials with explosives is examined. Guidelines are provided for packaging designs, and typical examples of separate and "all-up round" packaging are illustrated. A checklist of the numerous producibility questions that should be addressed concerning fuze specifications and drawings, materials, fabrication processes, and safety is included. The various materials used in fuzes, such as potting materials, sealing materials, solders, plastics, and die-cast parts, are presented. Desirable design characteristics are discussed, and examples of proven materials for fuzing applications are provided.

Techniques and methods used to encapsulate electronic components in order to maintain function and integrity and to withstand storage are discussed. The principles for the use of lubricants to minimize friction, wear, and galling in fuze components are addressed, and a list of both liquid and solid film lubricants successfully used in fuze escapements, gears, and bearings is provided. The importance of tolerancing and dimensioning in determining the reliability and producibility of a fuze design is discussed. The numerous controls, guidelines, and requirements that must be considered in the selection of electrical and mechanical components for fuzes are discussed. Techniques used to increase ruggedness and relieve the effects of aging, moisture, and temperature are presented. Military standards (MIL-STD) that give valuable information and data on the selection and testing of electronic components are listed.

The advantages of computer-aided design (CAD) and computer-aided engineering (CAE), which store libraries of fuze components that can be called upon and converted to drawings, are discussed.

The use of fault tree analysis (FTA) and failure mode, effects, and criticality analysis (FMECA) as tools for identifying and controlling safety failure modes is discussed. Examples and references are provided for construction of FTAs and FMECAs.

Techniques used to assure the safety and reliability of fuzes after long-term storage are presented. The importance of attention to design details, a comprehensive test program, quality assurance, training, and storage factors is stressed.

A list with brief synopses of military handbooks appropriate to design guidance is provided.

13-1 NEED FOR DESIGN DETAILS

During the creation of a fuze, the primary objective is to satisfy all the specific functional, physical, performance, and safety requirements. Therefore, the fuze designer must be familiar with the myriad elements that affect these requirements. The design process is complicated by the fact that fuzes are subjected to more rigorous environments, without benefit of maintenance, than any commercial item. The emergence of new skills, technologies, manufacturing processes, and materials, however, has provided the designer with many new tools he can use to deal with the problems frequently encountered in fuze design.

The primary goal of this chapter is to provide a record of good design practice and thus forestall duplication of past experience and effort.

13-2 CHEMICAL COMPATIBILITY

Compatibility of metal-to-metal, metal-to-explosive, plastic-to-explosive, and explosive-to-explosive materials is an important factor affecting safety and reliability in fuzes. Failure to exercise caution can result in poor shelf life, reduced reliability, and in some cases a potential safety hazard. The most prevalent catalysts in deleterious chemical reactions in fuzes are moisture and atmospheric gases, entrapped chemical cleaning fluids, and gases evolved from organic plastics and explosive materials.

Humidity and salt air environments can cause degradation of fuze performance because they promote corrosion in metallic components and can foster the creation of galvanic cells, particularly when dissimilar metals are in contact. Another deleterious effect of humidity and salt atmosphere is the formation of surface films, which cause leakage paths and degrade insulation and dielectric properties. The harmful effects of these environments make the requirement for a sealed fuze and/or sealed container mandatory in most cases.

13-2.1 ELECTRICAL CONTACT CONTAMINATION

The widespread use of complementary metal oxide semiconductor (CMOS) circuits in fuzes has emphasized the problem of contact failure in low-level switching circuits. Since CMOS circuits are characterized by low voltages and currents, care must be exercised in the selection of the contacts employed. One of the most prevalent factors that causes contact failures is contamination, which results in excess contact resistance.

Many switch contact contamination problems are due to oversight. Fuze designers are apt to consider components as separate entities and thus give little attention to their materials of construction until a failure or high contact resistance occurs. Erratic contact behavior can be minimized by monitoring the choice of materials and by cleaning the surfaces in contact.

No contact material is adequate for all switching situations. Compromises always must be made by the designer, who must keep in mind the most critical characteristics to be satisfied. Ideally, the contact material should have the following characteristics:

1. Conductivity of copper or silver
2. Heat resistance of tungsten
3. Freedom from oxidation of platinum or palladium
4. Resistance of gold to organic film formation
5. Inexpensiveness of iron.

There are two distinct types of contact contamination: (1) organic or thin film contamination and (2) particle or particulate contamination (Ref. 1). The effect of particle contamination can be disastrous because it causes erratic behavior. Monitor tests can show low resistance for hundreds of operations and then a sudden rise to a very high resistance value. Because not all particles can be burned away by the contact current and voltages, particulate contamination can persist for a very long time. Organic film contamination, on the other hand, generally will cause a gradual rise in the contact resistance and can be partially burned away if the voltages are high enough.

Particle contamination can be caused by

1. Poor choice of insulating material
2. Poor cleaning of machined and finished parts
3. Use of poor grades of internal gas
4. Normal wear or erosion particles.

Organic film contamination can be caused by the following problems:

1. Poor choice of insulating materials
2. Inferior cleaning techniques
3. No bakeout of organic parts
4. Poor choice of soldering techniques
5. Poor hermetic sealing
6. Lubricating oils
7. Organic dyes present in anodized protective coatings.

When contamination by particle or organic film occurs, the following steps should be taken: (Ref. 2)

1. Determine whether the contact requirements are realistic.
2. Determine whether wiping action and contact pressures can be increased without adversely affecting the operation of the device.
3. Make an initial, simple chemical analysis of contaminant.
4. Determine whether the contamination problem is particle, organic film, or both. Some of the methods for analysis are solubility tests, spectrographic analysis, chemical spot tests, standard light microscopy, electron microscopy, electron diffraction, X-ray diffraction, radioactive tracing, infrared spectroscopy, and plastic replica.
5. Take appropriate steps to eliminate the contamination by a complete materials review of the metals, insulators, and gases used, an inspection of the manufacturer's quality control and cleaning techniques, and an inspection of the validity of test results for the hermetic seals.

13-2.2 CORROSION

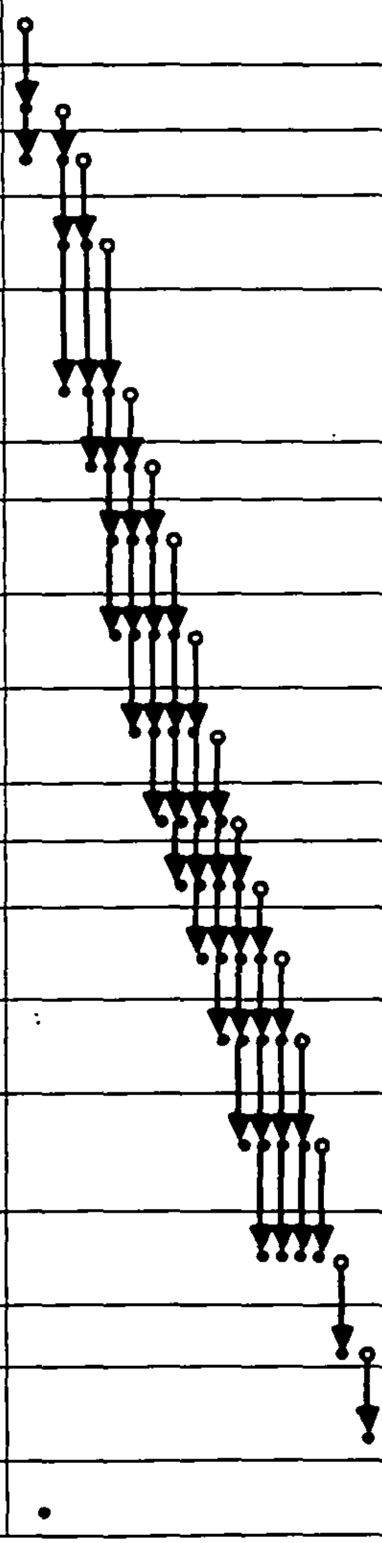
Corrosion in fuzes can be caused by a number of natural and induced environments. Of the natural environments water (humidity or rain) and salt fog are the most prevalent causes of corrosion in metallic structures. Each of these environments can act as an electrolyte for the conduction of electric current and thus cause galvanic corrosion of the less noble metal. Salt fog greatly intensifies the galvanic interaction between different metals and may ionize in water to form a strongly acid or alkaline solution, which can react chemically with the metal. Although salt fogs are characteristic of maritime areas, fogs containing a lower proportion of salt nuclei occur at inland localities far from the sea. Alkaline deserts, large salt lakes, and industrial wastes contribute locally to salt in the atmosphere.

Protection against water and salt corrosion must be a prime consideration in design. It is essential that the most corrosion-resistant materials that satisfy the strength, weight, mechanical, metallurgical, and economic requirements be selected. In general, the wider the separation of the metals in the galvanic series, the greater the probability of galvanic corrosion. Table 13-1 shows compatible couples of some of the more common metals used in fuzes. Materials well apart in the galvanic series should not be joined by screw threads because the threads will deteriorate excessively. Provisions for adequate plating, surface treatment, and finishing should be incorporated into the design. Whenever applicable, consideration should be given to O-ring or hermetic sealing to ensure that there will be no air or water transfer in the range of altitude and barometric extremes contemplated for service use.

Fretting corrosion is a type of scoring, abrasion, or microwelding that may occur when two metallic surfaces in contact undergo relative motion. Escapements and levers in fuzes have been known to fail due to microwelding of mating parts after being subjected to transportation vibration and high-frequency vibration conditioning. In general, the fretting phenomenon is more prevalent and progresses more rapidly in parts that have smooth surface finishes and close fits. Close fits prevent lubrication penetration into wear areas, and a smooth finish eliminates the small lubricant-retaining asperities present on rougher surfaces. Fretting also can result in increased wear, pitting, and a reduction in fatigue resistance.

Lubrication (discussed further in par. 13-7) of the escapement and other moving levers and parts has proven effective in eliminating the effects of fretting in fuzes. Another effective method is the use of electroless nickel plating on parts

TABLE 13-1. COMPATIBLE COUPLES (Ref. 3)

GROUP NO.	METALLURGICAL CATEGORY	EMF, V	ANODIC INDEX, 0.01 V	COMPATIBLE COUPLES
1.	Gold, solid and plated; gold-platinum alloys; wrought platinum	+0.15	0	
2.	Rhodium plated on silver-plated copper	+0.05	10	
3.	Silver, solid or plated; high-silver copper	0	15	
4.	Nickel, solid or plated; Monil metal, high-nickel-copper alloys	−0.15	30	
5.	Copper, solid or plated; low brasses or bronzes; silver solder; German silver; high-copper-nickel alloys; nickel-chromium alloys; austenitic corrosion-resistant steels	−0.20	35	
6.	Commercial yellow brasses and bronzes	−0.25	40	
7.	High brasses and bronzes; naval brass; Muntz metal	−0.30	45	
8.	18% chromium-type corrosion-resistant steels	−0.35	50	
9.	Chromium, plated; tin, plated; 12% chromium-type corrosion-resistant steels	−0.45	60	
10.	Tin plate; terneplate; tin-lead solder	−0.50	65	
11.	Lead, solid or plated; high-lead alloys	−0.55	70	
12.	Aluminum, wrought alloys of the duralumin type	−0.60	75	
13.	Iron, wrought, gray, or malleable; plain carbon and low-alloy steels, armco iron	−0.70	85	
14.	Aluminum, wrought alloys other than duralumin type; aluminum, case alloys of the silicon type	−0.75	90	
15.	Aluminum, cast alloys other than silicon type; cadmium, plated and chromated	−0.80	95	
16.	Hot-dip-zinc plate; galvanized steel	−1.05	120	
17.	Zinc, wrought; zinc-base die-cast alloys; zinc, plated	−1.10	125	
18.	Magnesium and magnesium-base alloys, cast or wrought	−1.60	175	

o = Indicates the most cathodic members of the series
● = Indicates an anodic member
Arrows indicate the anodic direction.

subjected to relative motion. This relatively inexpensive process, which can be applied to a variety of base metals, provides increased wear resistance, i.e., increased surface hardness, and an inherent lubricity characteristic.

There is additional information on the theory and control of fretting corrosion in Refs. 4 and 5.

13-2.3 EXPLOSIVES

Par. 4-2.2.3 briefly discusses the compatibility of various metals and explosive materials and emphasizes the potential safety hazard of lead azide in the presence of moisture together with copper-bearing alloys. The fuze designer should conduct a thorough study of the compatibility of all the explosive materials—both in the fuze and in the munition(s) in which they will be used—with the materials he has selected for his design. Several examples of the effects of outgassing of ammonia, a common product of many explosive compounds, follow.

Studies conducted by the Navy indicated the MK 48 Mods 3 and 4 Base Detonating Fuze had a 98% reliability after 10- to 15-yr storage in separate packaging but only a 75 to 80% reliability after only 6-yr storage in projectiles loaded with explosive "D" (ammonium picrate). The ammonia given off by the explosive "D" filler attacked and broke down the fuze-sealing materials (Bakelite® varnish and lacquer) by saponification and allowed the inherent moisture in the explosive to enter the fuze. The moisture caused corrosion of metal parts and affected the ignition properties of the black powder delay by deteriorating the primary mixes.

In a similar problem it was noted that prolonged storage at elevated temperatures (71°C (160°F) for 60 days or longer) would cause the bridgewire in the MK 96 Electric Detonator to open. The ammonia outgassing from the lead azide was reacting with the tungsten bridgewire, 0.00444 mm (0.000175 in.) in diameter, and eventually causing the wire to be etched away. Although this condition has never occurred in actual storage, changing to a platinum alloy bridgewire eliminated the potential problem.

The compatibility of explosives with a large number of plastics has been studied (Refs. 6 and 7). The following types of plastic have negligible effects on explosives and are themselves unaffected: acrylates; cellulosics; ethylenes; fluorocarbons; nylon; properly cured, unmodified phenolics; and silicones.

13-3 PACKAGING

Fuze operation and safety in transportation, handling, and storage depends to a large degree on how the fuze is packaged. Although specifications and packaging design have been standardized, the fuze designer should be familiar with how the various levels of shipment might affect his design.

This paragraph discusses concerns related to the fuze packaging designs developed by the tri-service community. Fuzes are packaged singly or in bulk (more than one) or are assembled to a round of ammunition in a standard exterior pack, which must meet the requirements of Level A overseas (maximum), Level B overseas (intermediate), or Level C domestic (minimum) military protection. The pack must survive the induced and natural environments that the packaged fuze or fuzed round will encounter during worldwide or domestic transportation, handling, and storage.

After manufacture, fuzes are shipped to the user either separately or assembled to a round. Once the fuze (separate or assembled) is packaged in the Level A exterior pack (68 kg (150 lbm) or less), it is unitized on a pallet for ease of handling. (Fuzes or fuzed rounds in packs having a mass of 68 kg (150 lbm) or more generally are packaged in self-contained pallet boxes and are not unitized; they are shipped as is.) The pallet may be transferred by truck, rail, ship, or aircraft to distribution areas, such as ammunition supply points, depots, or ammunition supply ships. During this logistical phase of the packaged fuze shipment, the unitized load (or pallet configuration) will experience vibrations as secured cargo and possible accidental drops into the holds of ships or onto docks. Upon reaching the distribution areas, the pallets generally are broken down to the standard exterior packs, which are then transferred to the user. The packaged fuze then may experience low-energy drops and loose cargo vibration during its movement by helicopter or truck or during ship-to-ship transfer at sea and manual handling by personnel.

To deliver a safe and operable fuze to the user, the package designer must specify preservative coatings, if required, and design packaging and packing to protect the fuze against direct exposure to extremes of climate, terrain, and logistical and tactical environments. The conditions, as defined in service regulations (Ref. 8), to be considered include, but are not limited to

1. Multiple mechanical and manual handling during transportation and storage
2. Shock and vibration during logistical and tactical shipments
3. Static and dynamic loading during transfer at sea, helicopter and aerial delivery, offshore or over-the-beach discharge, and delivery by combat vehicles to the service user
4. Natural environmental exposure experienced during shipment and in-transit storage to the service users
5. Uncontrolled open storage in all climate zones.

The packaging designer's first consideration when developing a package for a fuze is to attenuate transportation shock and vibration to protect the fuze during shipping from the manufacturer to the user. The packaging designer must consult the fuze designer to determine the fuze design parameters in order to develop a package that will maintain fuze reliability. Some of the design parameters to be considered are

1. What is the shock damage threshold, or level of fragility, the fuze can tolerate before becoming inoperable?

2. What fuze frequency ranges or stress levels are critical?

3. What fuze attitude or direction is most vulnerable?

4. What environmental temperature range is the fuze designed to sustain?

5. Is the fuze hermetically sealed?

After the packaging designer establishes the fuze design parameters, he can design a pack that will not only protect the fuze but also survive all induced and natural environments and meet all shipping regulations, i.e., Department of Transportation Code of Federal Regulation Title 49. The minimum factors that must be considered are

1. Temperature extremes of -54°C (-65°F) to 71°C (160°F)

2. Shocks induced by handling, such as 914-mm (36-in.), 2.1-m (7.0-ft), and 12-m (40-ft) drops

3. Vibration induced by various modes of transportation (5 to 500 Hz)

4. Propagation between fuzes (reduce or eliminate) to obtain as low a hazard classification as possible

5. Corrosion seal (water-vapor proof)

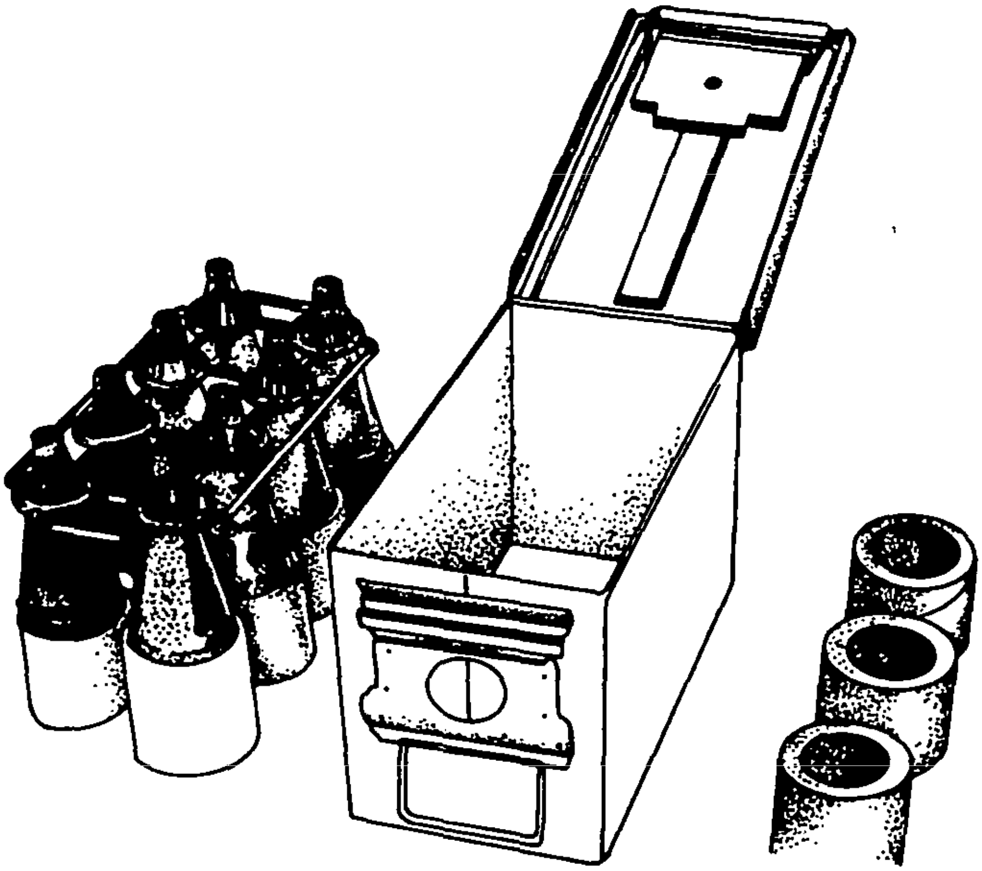
6. Type of field handling

7. Human engineering (ease of opening/closing pack, quick access).

Usually, a fuze is inherently rugged by design in order to meet operability requirements. Consequently, the package needs only to provide physical and mechanical protection to prevent internal or external damage to the fuze from the vibration and shock of normal transportation.

Examples of package designs providing physical and mechanical protection are

1. *Separately Packaged Fuzes*. For the most part, the packaging of separately packaged fuzes has been standardized. Fig. 13-1 is a typical package for Level A overseas shipment. Eight artillery or 10 rocket fuzes are placed in a metal box with top and bottom nesting supports, (polystyrene or polyethylene/paper tubes). This pack, for certain fuzes, has been successfully tested as a nonpropagating pack, which lowers the shipping classification and thereby reduces shipping and storage costs. The metal box is sealed against moisture with a rubber gasket and is equipped with a quick opening/closing hasp. Two metal boxes (16 or 20 fuzes) are overpacked in a wood, wire-bound box as shown in Fig. 13-2. Then 36 wire-bound boxes are unitized for



(A) Fuzes in Plastic Tubes (B) Metal Container (C) Plastic Tubes

Figure 13-1. Level A Unit Package, Nonpropagating (Plastic Tubes)

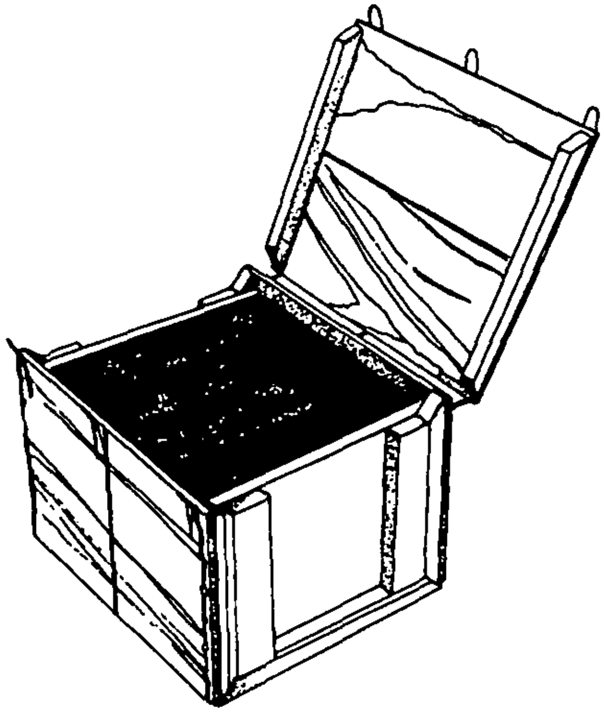


Figure 13-2. Level A Exterior Pack (Separately Loaded Fuzes)

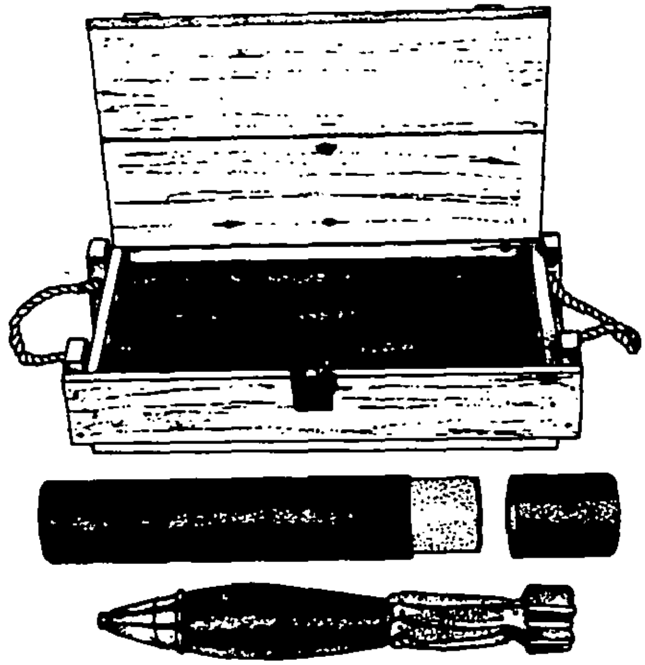


Figure 13-3. Level A Unit Exterior Pack (Fuze Assembled to 81-mm Mortar)

shipment to the user. For Level B overseas shipment, 36 metal boxes of packaged fuzes are placed in a pallet box. For Level C domestic (interplant) shipment, 24 assembled (or partially assembled) fuzes are packaged in a fiberboard box with the same nesting supports used in the metal box. The fiberboard boxes are overpacked with an inexpensive wood, wire-bound box and then unitized for shipment.

2. *Fuzes Assembled to Rounds*. A typical package for Level A overseas shipment of fuzes assembled to rounds consists of one fuzed round placed in a fiber container and three of these containers overpacked in a nailed wood box as shown in Fig. 13-3. Then 30 wood boxes are unitized for shipment. Generally, Levels B and C packaging for fixed rounds is the same as it is for Level A.

If a fuze is designed with a low damage threshold or has a critical frequency response, the pack must guarantee the operational reliability of the fuze by preventing the induced forces on the fuze from exceeding a specified fragility level. Such a pack would require cushioning material for an isolation medium, which is interposed between the fuze and exterior pack to protect the fuze from a maximum of 20 to 150 g. A packaging handbook should be consulted for this kind of packaging design problem.

13-4 PRODUCIBILITY

The importance and impact of producibility became evident during the industrial mobilization of World War II. The need to reengineer fuze designs to permit ease of manufacture by multiple producers proved that problems existed. The emergence of new skills, technologies, and materials emphasized the need to consider producibility in the initial design phase. This practice reduces the possibility of altering the functional characteristics of a design by changes to satisfy producibility, and it eliminates the incorporation of design features that make producibility difficult.

Military Handbook (MIL-HDBK) 727 (Ref. 9) defines producibility as "the combined effect of those elements or characteristics of a design and the production planning for it that enables the item to be produced and inspected in the quantity required and that permits a series of tradeoffs to achieve the optimum of the least possible cost and the minimum time, while still meeting the necessary quality and performance requirements.". That definition creates a difficult and challenging task for the fuze design engineer. It must be remembered, however, that even the most ingenious and experienced fuze designer cannot accomplish these objectives alone. The design engineer cannot possibly have an intimate awareness of all the production and quality assurance disciplines necessary to perform his mission. It is necessary, therefore, that the design engineer work with specialists in other production disciplines to assure optimum producibility.

A number of factors should be considered during performance of a producibility analysis. Many of the questions that should be addressed by the designer, the production engineer, and the documentation and quality assurance personnel are included in the list that follows:

1. *General Aspects of the Design:*

a. Have alternative design concepts been considered and the simplest and most producible selected?

b. Does a similar or proven concept already exist for any or all of the features of the design?

c. Does the design specify the use of proprietary items or processes?

d. Can multiple parts be combined into a single part?

e. Does the design specify peculiar shapes that require extensive machining or special production techniques?

f. Have design aspects that could contribute to hydrogen embrittlement, stress corrosion, or similar conditions been avoided?

g. Have all adhesives, sealants, encapsulants, plastics, explosives, and rubbers been adequately investigated and tested for compatibility?

h. Have galvanic corrosion and corrosive fluid entrapment been prevented?

2. Specifications and Standards:

a. Can military specifications be replaced with commercial specifications?

b. Is there a standard part that can replace a manufactured item?

c. Are specifications and standards consistent with the required factory-to-function environment?

d. Are nonstandard and source control parts adequately controlled and defined?

e. Can any specification be replaced or eliminated?

f. Do the specifications provide all the information necessary for the manufacture, assembly, and test of the design?

3. Drawings:

a. Are drawings properly and completely dimensioned in accordance with military specification DOD-D-1000 (Ref. 10)?

b. Are tolerances and surface finishes realistic, producible, and not tighter than the function requires?

c. Are the staking methods and control provisions adequate to ensure integrity of the parts?

d. Have all required specifications been properly invoked?

e. Have alternative manufacturing processes and materials been considered?

f. Are forming, bending, fillet and radii, fits, hole sizes, reliefs, counterbores, countersinks, and O-ring grooves standard and consistent?

g. Have dimensional analyses for fit, function, and interchangeability been performed?

h. Can standard gages be used to a greater degree?

4. Materials:

a. Have materials been selected that exceed the requirements?

b. Are specified materials difficult or impossible to fabricate economically?

c. Can a less expensive material be used?

d. Can the use of critical materials be avoided?

e. Can the number of materials be reduced?

f. Can other materials be used that would make the part easier to produce?

g. Are standard stock raw materials specified?

h. Is the material consistent with the planned manufacturing process?

5. Fabrication Processes:

a. Does the design require unnecessary secondary operations of forging, machining, casting, and other fabrication processes?

b. Can parts be economically assembled?

c. If high volume is anticipated, have automated assembly techniques been adequately addressed?

d. Are expensive tooling and equipment required for production?

e. Have special skills, facilities, equipment, and the mobilization base been identified?

f. Can parts be assembled and disassembled easily without special tools?

g. Can a fastener, roll pin, drive pin, or staking be used to eliminate tapping?

h. Are processes consistent with production quantity requirements?

i. Have heat-affected parts been considered for soldering, encapsulation (exothermic), or other thermal joining processes?

6. Safety:

a. Have all the requirements of MIL-STD-1316, *Safety Criteria for Fuze Design*, (Ref. 11) been satisfied?

b. Has electromagnetic radiation (EMR) protection been implemented in the design?

c. Have necessary safety precautions been implemented for assembly of electric and stab initiated detonators and booster and lead explosives?

d. Does the packaging adequately protect the fuze and explosive components from shock, vibration, and/or explosive propagation?

e. Have explosive ordnance disposal (EOD) and demilitarization provisions been considered?

f. Have all sneak circuits, single-point failure modes, human engineering oversights, and other safety-related hazards been eliminated?

7. Inspection and Test:

a. Are inspection and test requirements excessive?

b. Are quality assurance provisions applied at the highest level of assembly practicable?

c. Has destructive testing been minimized?

d. Are the selected acceptable quality level (AQL) provisions adequate to ensure the desired level of safety and reliability?

e. Have preproduction and periodic production tests been defined to ensure fuze performance characteristics?

f. Can the design be inspected economically?

g. Are the classifications of defects consistent with the quality assurance requirements?

13-5 MATERIALS

The variety of materials available today provides the design engineer with a wide choice. Although the primary concern is selection of a material with properties that meet the required performance and safety characteristics, the designer must keep in mind that the material selected influences the cost and producibility of his design. Ideally, the material selection process should be a series of decisions to achieve optimum performance with the optimum cost and producibility characteristics.

During selection of a material to satisfy the design requirements, the chemical, physical, and mechanical properties are of prime importance. These characteristics are available in a number of excellent reference books (Refs. 12, 13, and 14) and will not be repeated here.

Fig. 13-4 illustrates the decision-making flow and shows the interrelationships of the design, the materials selection, and the manufacturing selection processes. Each of these elements imposes constraining criteria on the subsequent element in the loop. In Step I the designer reviews the performance requirements of the proposed design and determines the specific characteristics required of the materials to be used. When these characteristics, e.g., tensile strength, modulus of elasticity, hardness, corrosion resistance, electrical properties, and density, have been identified as requirements, materials are reviewed (Step II) to determine which can satisfy the design performance and safety characteristics. The resultant list of materials is reviewed (Step III) to determine what manufacturing processes are compatible with each material. This list of processes is then checked against the design requirements (Step IV), e.g., tolerance, finish, configuration, quantity, and cost, to determine which of the manufacturing processes can meet the requirements. The result of this process (Step V) is a list of acceptable materials and manufacturing processes that can provide a firm base for a tradeoff analysis among optimum and alternative materials and manufacturing processes.

13-5.1 POTTING MATERIALS

Potting compounds are used in fuzes to encapsulate electronic parts to protect them against shock, vibration, and the ingress of moisture. Electronic components used in fuzes are more reliable and have a longer life when properly encapsulated. The potting material not only provides protection from adverse natural environments but also provides

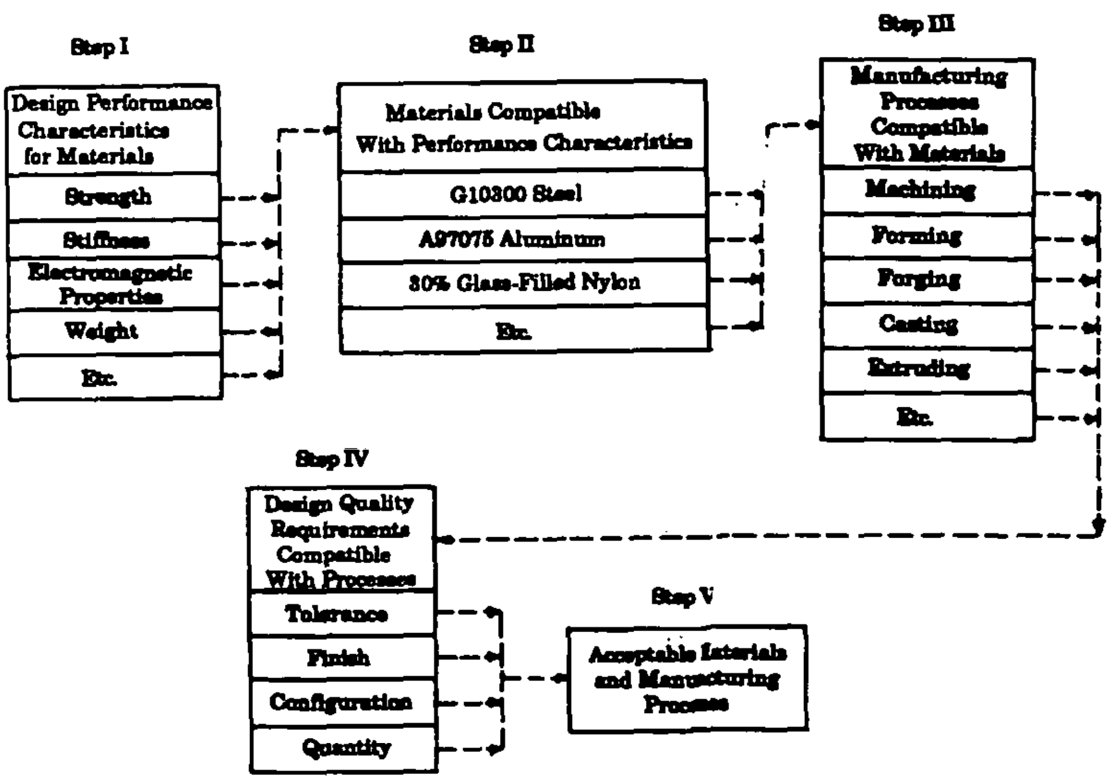


Figure 13-4. Interrelationship of Design, Material Selection, and Manufacturing Processes

structural integrity to withstand adverse induced environments.

Table 13-2 lists some commercially available potting compounds that have been successfully used in fuzes. Each material has specific properties, and no one material can be used for all applications. Therefore, each fuze must be analyzed and a potting resin selected that has the most important properties for the specific application.

TABLE 13-2. POTTING COMPOUNDS USED SUCCESSFULLY IN FUZES

FUZE	POTTING COMPOUND	TYPE	COMMERCIAL SOURCE*
ARMY			
M445 Multiple Launch Rocket System Fuze	ISO FOAM PE-10S	Polyurethane	Witco Chemical Corporation ISO Foam Systems Wilmington, DE 19720 (302) 328-5661
M587 Fuze	Hysol C9-R246/ H-R248**	Epoxy	Hysol Div., Dexter Corp. Olean, NY 14760 (716) 372-6300
M724 Electronic Artillery Time Fuze	Epic R1017/ H4003**	Epoxy	Epic Resins 1900 East North Street Waukesha, WI 53186 (414) 549-1101
M732 Proximity Artillery Fuze and M734 Multioption Mortar Fuze	ISO FOAM PE-18S	Polyurethane	Witco Chemical Corp. ISO Foam Systems Wilmington, DE 19720 (302) 328-5661
M735 Fuze for 8-in. Nuclear Projectile and XM749 Fuze for 155-mm Nuclear Projectile	Polymercast V356-HE80	Polyurethane	N. S. Polymerics Division of Hitco Box 2187 Santa Ana, CA 92707 (714) 549-1101
M817 TDD for CHAPARRAL Missile	Sylgard 184	Silicone	Dow Corning Corp. Midland, MI 48640-0994 (517) 496-4000
M818 Fuze for PATRIOT Missile	RTV90-224	Silicone Foam Pellets	General Electric Co. Silicone Products Div.
NAVY			
MK 43 Fuze FMU-117/B Electric Bomb Fuze XM750 Rocket Fuze	Epic R1016/H5008	Epoxy	Epic Resins 1900 East North Street Waukesha, WI 53186 (414) 549-1101
MK 344 Electric Bomb Fuze	Hysol C9-F700/ H3741†	Epoxy	Hysol Div., Dexter Corp. Olean, NY 14760 (716) 372-6300
MK 376 Rocket Fuze	Epic 51-791403/ 52-801-102	Epoxy	Epic Resins 1900 East North Street Waukesha, WI 53186 (414) 549-1101
MK 404 VT-IR Fuze	75% Mobilewax Cerese 25% Flexo-wax-C	Wax	Mobile Oil Co. Glyco, Inc. 488 Main Avenue Norwalk, CT 06856-5100 (203) 847-1191

*Identification of companies does not constitute an endorsement by any DoD component.
**Meets Honeywell Specification MH 20278P
†Meets NSWC Specification WS 8687B

Some disadvantages of potting electronic components are

1. Replacing wires and components of a potted assembly is almost impossible.
2. Because the potting material occupies all the free space in an assembly, it adds weight to the assembly.
3. The circuits must be specifically designed for potting.
4. Extra time and labor are required to clean the circuit and to protect the components prior to embedment.
5. Component heat is trapped and retained by the insulating character of the potting compound.
6. Potting compounds may affect the electrical characteristics of a circuit.

Typically, a potting compound used for fuzing should have the following characteristics (Ref. 15):

1. Capable of being mixed, poured, and cured at room temperature
2. An exothermic polymerization temperature below 77°C (170°F)
3. Provide support and cushion from shock up to 50,000 g
4. Capable of withstanding thermal shock between -54° and 71°C (-65 and 160°F)
5. Low viscosity
6. High electrical insulation properties and low absorption especially at high frequencies
7. Compatible with the embedded components and adjacent materials
8. Dissipate the internal heat generated
9. Have a shelf life that equals or exceeds the expected life of the fuze
10. Hermetically seal the fuze from its environment.

Some potting formulations may be incompatible with explosives. If the potting resin and explosive are not in close proximity, incompatibility is of little concern. The curing of some resins directly in contact with explosives is the most risky condition. Intimate mixtures of precured resins with certain explosives may be dangerous. It is the amine curing agent, not the resin itself, that is incompatible with an explosive. Frequently, acid anhydride curing agents can be used near explosives if temperatures are not too high. In any event, the fuze designer should always specify that materials used near explosives must be compatible with them (Ref. 16).

13-5.2 SEALING MATERIALS

In designing a fuze, all passageways for potential ingress of moisture, dust, or gases should be sealed in some manner. The selection of sealing methods for fuzes requires careful consideration by the designer. Sealing may be accomplished in fuzes by various methods, such as welding, soldering, eutectic metal injection, epoxy, varnish, various commercial sealants, or by the use of a softer material, e.g., rubber, cork, or gasket materials, between two mating surfaces. O-rings have been used extensively to seal fuzes because they offer a dependable and reasonably economical approach for protection of the internal components of fuzes from a wide range of environments over their expected lives. To achieve a good seal with an O-ring, the designer must adhere to industry standards for groove size, material selection, and surface finish. If a hermetic seal is required in a fuze design, the designer must use methods, such as soldering or brazing, in which a nonferrous filler material with a melting point less than that of the base material is placed between the mating surfaces. Ultrasonic welding has also been used to seal some explosive components. It produces no fusion because the weld temperature approaches only 35% of the melting point of the base metal. Ultrasonic welding is used principally with aluminum.

13-5.3 SOLDERS

Solder usually is used in electromechanical and electronic fuzes to complete electrical circuits between components. The two general classes of solder are soft solder and hard solder. Soft solders, which are used extensively in electric and proximity fuzes, have a number of desirable properties:

1. They can be used to join metals at relatively low temperatures.
2. They can withstand considerable bending without fracture.
3. They can usually be applied by simple means and can be used with metals having relatively low melting points.

Printed circuit boards (PCB) or hard-wired electronic components may be soldered with a hand soldering iron or by production-oriented wave soldering and cascade soldering. Failure rates for soldering connections from MIL-HDBK-217, *Reliability Prediction of Electronic Equipment* (Ref. 16), are listed in Table 13-3.

The wave soldering process involves passing the PCB over a liquid solder wave that is generated by a pumping machine. The wave provides heat to the areas to be soldered as well as solder to the parts to be joined. In cascade soldering a solder waterfall is constructed by pumping the molten solder to the top of a steplike structure and letting it flow to the lowest level. Due to the nature of the cascade, the PCB passes over the steps of the molten solder at a slight angle, which permits the escape of trapped air and eliminates the

TABLE 13-3. FAILURE RATES FOR SOLDERING (Ref. 16)

CONNECTION	FAILURES/10^6 h
Hand solder	0.00440
Wave solder	0.00044
Cascade solder	0.00012

probability of blowholes. Fig. 13-5 shows the operation of the cascade process in a simplified diagram.

Flux is used in soldering operations to remove metal oxides, prevent reoxidation, and lift other impurities from the area to be soldered. In general, only nonactivated or mildly activated fluxes are permitted to be used in fuzes. These types of fluxes are covered in MIL-F-14256 (Ref. 17) and Federal Specification QQ-S-571 (Ref. 18).

13-5.4 PLASTIC PARTS

The use of plastics is more and more prevalent in fuzing applications. The properties and moldability of many of the new plastic materials have enabled the designer to produce complex component configurations with close tolerances at relatively low cost. Consideration, however, must be given to such characteristics as strength and stiffness, creep, impact resistance, and compatibility with explosives when the designer contemplates the use of plastic for a fuze component. Some parts may be simple structures for which the choice of a plastic may depend upon low material cost and/or ease of manufacture. For other parts, performance may depend on strength, rigidity, impact resistance, or other properties. As a result, the screening process and the selection of optimum materials are complicated procedures, and the peculiarities of the behavior of plastic materials must be considered.

In general, the types of plastics used for fuzing applications are either filled or unfilled thermoplastic and thermosetting resins. Thermoplastics are more versatile in processing and more processes are applicable to them, whereas thermosets are more rigid as a rule but are able to withstand higher temperatures. Fillers are sometimes added to thermoplastics and thermosets to improve mechanical, chemical, or electrical properties or to reduce brittleness. Table 13-4 lists the mechanical properties of a number of plastics used in fuzes. Further references on plastics and their use with explosive ordnance are Refs. 6 and 19.

Plastics can be used in fuze rotors, sliders, shutters, or other devices that contain explosive components, such as primers or detonators. It is generally necessary, however, to enclose the explosive component in a steel sleeve, which is either molded or ultrasonically staked in place in the plastic

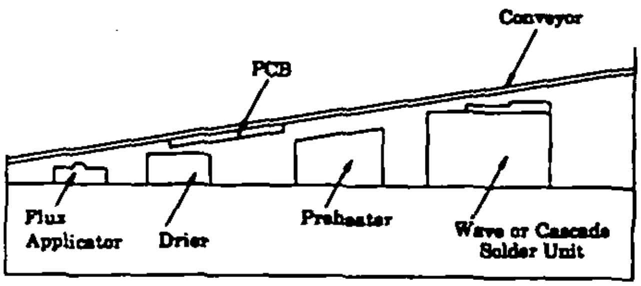


Figure 13-5. Cascade Soldering (Ref. 9)

carrier. Failure to confine the explosive component properly could lead to reduced detonator safety because breakup of the carrier could permit hot gases or fragments to cause initiation, burning, or charring of the explosive lead if the detonator is inadvertently initiated in the safe position. Explosive train reliability could also be degraded by lack of confinement. As cited in Chapter 4, a confined explosive is much more reliable in initiating another explosive than an unconfined explosive.

13-5.5 DIE-CAST PARTS

For many fuzing applications, die casting offers an economical, high-speed production method. Development of new alloys, high-capacity machines, and better finishes and tolerance control have all combined to extend the use of die castings for fuze components. Before choosing an alloy for a die-casting application, factors that must be considered include mechanical and physical properties, casting complexity, and metal cost. Table 13-5 presents a selection guide for zinc and aluminum, the two most common alloys used in fuzing applications. Aluminum is the preferred alloy because of better corrosion resistance, higher strength-to-weight ratio, and permanence of dimensions. Also aluminum die castings have better thermal and electrical conductivities. Zinc die castings have good mechanical properties and are the lowest in cost. Zinc has been used successfully in a fuze detonator carrier (rotor). The higher acoustical impedance of zinc makes it a better confining medium than aluminum; however, under constant load zinc will creep. Compensation must be made in the design if this condition is to be avoided. Aging also changes the dimensions and reduces the mechanical strength of zinc die-casting alloys. If rigid dimensional tolerances must be maintained, the dimensional changes can be accelerated by annealing at 100°C (212°F) for 3 to 5 h or at 39°C (102°F) for 10 to 20 h. Table 13-6 lists some of the properties of typical die-casting aluminum and zinc alloys.

Die-cast gears and pinions have been successfully used in untuned escapements to achieve safe separation in some fuzing systems. In general, this use is limited to gun-fired or air-launched ammunition with acceleration limits of less than 20,000 g. For higher acceleration launched ammunition, stamped gears and hobbed pinions of brass or steel are preferred.

13-6 CONSTRUCTION TECHNIQUES

During design of a fuze, an organized and systematic pattern of events must take place if the design is to meet fully all of its requirements and objectives. First, the individual components must be designed and arranged in the fuze so they ensure reliability of functioning. An equally important factor is to ensure that the components retain their integrity and reliability under the extremes of the induced and natural environments they will encounter during their service lives.

TABLE 13-4. MECHANICAL PROPERTIES OF SELECTED PLASTICS (Ref. 9)

MATERIAL	TENSILE PROPERTIES					FLEXURAL STRENGTH		COMPRESSIVE STRENGTH		SPECIFIC GRAVITY	MAXIMUM CONTINUOUS SERVICE TEMPERATURE	
	YIELD STRENGTH		MODULUS OF ELASTICITY		ELONGATION AT YIELD							
THERMOPLASTICS	MPa	(ksi)	GPa	(ksi × 10^3)	%	MPa	(ksi)	MPa	(ksi)		°C	(°F)
Polystyrene												
unfilled	37-54	(5.3-7.9)	2.4-3.4	(3.5-5)	1-2	55-97	(8-14)	79-110	(11.5-16)	1.04-1.05	65	(150)
20% glass	76	(11)	7.6	(11)	1-2	107	(15.5)	103	(15)	1.20	65	(150)
Polysulfone												
unfilled	70	(10.2)	2.6	(3.8)	50-100	106	(15.4)	96	(13.9)	1.24	—	—
20% glass	121	(17.5)	7.6	(11)	20	162	(23.5)	145	(21)	1.38	150	(300)
Polyvinyl chloride (PVC)												
unfilled	41-52	(6-7.5)	2.4-4.1	(3.5-6)	40-80	69-110	(10-16)	55-90	(8-13)	1.31-1.45	55-70	(130-160)
15% glass	90	(13)	6.6	(9.5)	2-3	117-138	(17-20)	—	—	1.52	—	—
THERMOSETS												
Alkyd												
mineral-filled	41	(6)	13.1	(19)	0.5-1	62	(9)	172	(25)	1.98		
Diallyl phthalate (DAP)												
glass-filled	55-69	(8-10)	9.7-15.2	(14-22)	2-4	76-207	(11-30)	172-241	(25-35)	1.5-1.9		
mineral-filled	34-60	(5-8.7)	8.3-15.2	(12-22)	2-4	59-76	(8.5-11)	138-221	(20-32)	1.6-1.9		
Epoxy												
glass-filled	34-138	(5-20)	20.7	(30)	4	55-207	(8-30)	124-276	(18-40)	1.86-1.92	95-205	(200-400)
mineral-filled	28-69	(4-10)	3.4-13.8	(5-20)	2-3	41-124	(6-18)	124-207	(18-30)	1.6-2.1	95-205	(200-400)
Melamine												
cellulose-filled	34-90	(5-13)	7.6-9.7	(11-14)	0.6-1.0	62-110	(9-16)	228-310	(33-45)	1.47-1.52		
glass-filled	34-72	(5-10.5)	11.0-16.5	(16-24)	0.6	97-159	(14-23)	138-241	(20-35)	1.5-2.0		
Phenolic												
wood-flour-filled	34-62	(5-9)	5.5-11.7	(8-17)	0.4-0.8	48-97	(7-14)	172-214	(25-31)	1.135-1.46		
glass-filled	48-124	(7-18)	13.1-22.8	(19-33)	0.2	103-414	(15-60)	179-483	(26-70)	1.7-2.0		
Polyester sheet molding compound	55-172	(8-25)	9.7-17.2	(14-25)	3	69-248	(10-36)	103-207	(15-30)	1.65-2.6		

(cont'd on next page)

TABLE 13-4. (cont'd)

MATERIAL	TENSILE PROPERTIES: YIELD STRENGTH		TENSILE PROPERTIES: MODULUS OF ELASTICITY		TENSILE PROPERTIES: ELONGATION AT YIELD	FLEXURAL STRENGTH		COMPRESSIVE STRENGTH		SPECIFIC GRAVITY	MAXIMUM CONTINUOUS SERVICE TEMPERATURE	
THERMOPLASTICS	MPa	(ksi)	GPa	(ksi × 10^3)	%	MPa	(ksi)	MPa	(ksi)		°C	(°F)
Acrylonitrile-butadiene-styrene (ABS)												
unfilled	34-55	(5-8)	1.7-2.6	(2.5-3.8)	2.5-3.5	59-100	(8.5-14.5)	—	—	1.04-1.06	—	—
20% glass	83-90	(12-13)	5.5-6.2	(8-9)	1.5-2.0	117-138	(17-20)	97	(14)	1.23	70-80	(155-180)
Acetal												
unfilled	61-69	(8.8-10)	2.8-3.1	(4.1-4.5)	3-45	90-97	(13-14)	34-90	(5-13)	1.41	—	—
20% glass	62-83	(9-12)	6.2-6.9	(9-10)	2-7	69-103	(10-15)	34-124	(5-18)	1.55	90-110	(195--230)
Acrylic												
unfilled	50-76	(7.3-11)	2.1-3.1	(3-4.5)	3.6-3.0	79-110	(11.5-16)	72-124	(10.5-18)	1.15-1.19	60-80	(140-180)
15% glass	69-72	(10-10.5)	3.1	(4.5)	4.9-5.0	103-110	(15-16)	117-124	(17-18)	1.19	80-95	(180-200)
Nylon 6/6												
unfilled	55-83	(8.0-12)	2.1-4.1	(3.0-5.9)	30-70	83-124	(12-18)	76-138	(11-20)	1.13-1.16	65-120	(150-250)
30% glass	179	(26)	8.3	(12)	3-4	262	(38)	165	(24)	1.37	95-120	(200-250)
Nylon 6												
unfilled	59-83	(8.5-12)	1.7-3.1	(2.5-4.5)	25-110	83-117	(12-17)	55-110	(8-16)	1.12-1.14	80-105	(180-225)
30% glass	165	(24)	6.9	(10)	2.0	193	(28)	165	(24)	1.40	95-100	(200-215)
Polycarbonate												
unfilled	59-66	(8.5-9.5)	2.1-2.4	(3.0-3.5)	6-9	76-93	(11-13.5)	69-86	(10-12.5)	1.18-1.21	105-120	(220-250)
20% glass	110	(16)	6.9	(10)	4-6	172	(25)	138	(20)	1.34	115-125	(240-260)
Polyester												
unfilled	55	(8)	2.3-2.6	(3.3-3.7)	50-300	83-90	(12-13)	59-62	(8.5-9)	1.31-138	—	—
20 % filled	121	(17.5)	7.2	(10.5)	4-5	165	(24)	117	(17)	1.43	140	(280)
Polyethylene												
low-density, unfilled	8-16	(1.2-2.3)	0.1-0.3	(0.14-0.38)	90-600	—	—	—	—	0.91-0.93	55-90	(130-195)
high-density, unfilled	21-28	(3-4)	0.4-1.2	(0.6-1.8)	20-130	—	—	19-25	(2.7-3.6)	0.94-0.97	55-90	(130-195)
Polypropylene												
unfilled	31-37	(4.5-5.4)	1.2-1.6	(1.7-2.3)	6-20	41-55	(6-8)	38-55	(5.5-8)	0.90-0.91	95	(200)
40% glass	72	(10.5)	6.9	(10)	4-5	152	(22)	68	(9.8)	1.22	80-120	(180-250)

TABLE 13-5. SELECTION GUIDE FOR ZINC AND ALUMINUM DIE-CASTING ALLOYS

SELECTION FACTOR*	ZINC ALLOYS	ALUMINUM ALLOYS
MECHANICAL PROPERTIES		
Tensile Strength	2	3
Impact Strength	2	3
Elongation	2	4
Dimensional Stability	3	2
Creep Resistance	2	2
Brinell Hardness	2	3
PHYSICAL PROPERTIES		
Electrical Conductivity	2	1
Thermal Conductivity	3	1
Melting Point	1	2
Density	3	2
Corrosion Resistance	3	2
CASTING CHARACTERISTICS		
Ease, Speed of Casting	1	2
Complexity	1	2
Dimensional Accuracy	1	2
Minimum Section Thickness	1	2
COST		
Dies	1	2
Metal	1	2
Production	1	2
Machining	1	2
Finishing	1	3

*Relative values in number codes: 1 = highest rating
4 = lowest rating

Finally, concern for the producibility of each component must be exercised. Regardless of the degree of complexity, the objective of the design is to create a fuze that will satisfy all the specified performance and physical objectives and concurrently to maximize producibility. This pattern of events is a highly iterative process filled with decision points, each of which permits a potential tradeoff for the creation of alternatives to the established design.

13-6.1 MECHANICAL AND ELECTRICAL CONSIDERATIONS

The permissible volume and weight as well as location of the fuze are generally specified at the start of a program. The anticipated fuze environments during operational use and during storage, handling, and transportation are also specified. These environments, particularly any unusual ones, must be kept in mind from the start of a fuze program.

When designing housings, packages, and other mechanical parts of a fuze, it is not sufficient to consider only the mechanical requirements for strength, volume, and weight. In many instances, their effects on the performance of the fuze must be considered. The dimensions of some parts and the tolerances on the dimensions may have a direct relation to performance. For other parts the degree of stiffness or positional variation under conditions of shock or vibration may affect the performance of a fuze.

Many mechanical design problems can be eliminated by following a logical design approach. A suggested approach is

1. Determine the mechanical requirements of shape, dimension, rigidity, material, and finish imposed by the functions of the fuze.
2. Determine the mechanical requirements of shape, dimension, strength, materials, and finish imposed by operational use, transportation, handling, and storage.
3. Locate or orient functional components so they experience the least detrimental effect from interior and exterior ballistic environments.
4. Make a preliminary design and check critical elements for stress, resonant frequency, and static and dynamic balance.
5. Examine the design for producibility with respect to materials, fabrication processes, and inspection and tests.
6. Check the preliminary design by observing the performance of fuze models subjected to tests pertinent to the verification of the design.
7. Build several lots of fuzes and revise the design between lots as indicated by the model tests and then repeat the tests to verify the design iteration.
8. Review the drawings and specifications to ensure that the design is adequately defined for manufacturing and that the production testing methods, procedures, and inspection sample sizes ensure the desired level of safety and reliability.

The elements that should be considered to minimize or eliminate problems associated with electronic fuze designs are

1. Whenever possible, select standard components that have historically demonstrated their capability to function reliably at specific electrical, mechanical, and environmental levels and are covered by a military specification.
2. Use redundancy, more resistant components, more rugged packaging, and methods of derating to assist in fulfilling safety and reliability requirements.
3. Use packaging and assembly techniques that are consistent with cost, size, environmental stress, and production volume.
4. Conduct tradeoff analyses on the use of discrete components versus custom integrated circuits (ICs), manual versus automatic insertion of components, drilled versus

TABLE 13-6. PROPERTIES OF ALUMINUM AND ZINC DIE-CASTING ALLOYS

ALLOY DESIGNATION	ALUMINUM		ZINC	
	360.0	380.0	AG40A	AG41A
TYPICAL MECHANICAL PROPERTIES				
Tensile Strength, MPa (ksi)	305 (44)	315 (46)	285 (41)	330 (47.9)
Yield Strength,* MPa (ksi)	170 (25)	160 (23)	—††	—††
Elongation, %**	3.5	3.5	10	7
Shear Strength, MPa (ksi)	190 (28)	195 (28)	215 (31)	260 (38)
TYPICAL PHYSICAL PROPERTIES				
Melting Point °C (°F)	650 to 760 (1200 to 1400)	650 to 760 (1200 to 1400)	380 (716)	380 (716)
Electrical Conductivity, %IACS †	28	27	27.5	26.5
Thermal Conductivity, W/m·k(Btu/ft·h·°F)	113 (65.3)	96.2 (55.6)	113 (65.3)	109 (62.9)
Density, Mg/m^3 ($lb/in.^3$)	2.63 (0.095)	2.74 (0.099)	6.6 (0.238)	6.7 (0.242)

*0.2% offset
**With 50-mm (2-in.) bar (as cast)
†IASC = International Annealed Copper Standard (of electrical conductivity)
††Zinc alloys do not possess recognized elastic moduli.

punched holes for PCBs, encapsulation versus conformal coating, and military grade versus commercial grade components.

5. Segregate heat-producing elements from heat-sensitive components.

6. Provide shielding or filtering from the deleterious effects of electromagnetic radiation.

13-6.2 ENCAPSULATION

One of the most commonly used methods of maintaining the functional relationships and preserving the integrity of electronic components is encapsulation. The materials used for encapsulation are described in par. 13-5.1, and the use of encapsulation as a construction technique is discussed in the paragraphs that follow.

The basic encapsulating methods are potting, dipping, and spraying. Potting materials may be relatively soft, e.g., wax, polyethylene, and polysulfone, or rigid, e.g., the commercial resins listed in par. 13-5.1.

Two different approaches are used to encapsulate electronic assemblies or parts. One method is to embed the entire circuit in a single mold or housing. The advantages of this technique are that the components are provided maximum support, and therefore, thinner PCBs and fewer supporting structures are required. One disadvantage of this method, particularly if a rigid encapsulation material is used, is that it is not possible or cost-effective to rework defective assemblies if one component fails. Another disadvantage of rigid and semirigid potting materials is that the electronic components are subject to stresses as the compound expands and contracts during temperature changes. At low temperatures these stresses may be great enough to affect adversely the performance of certain electronic components.

The second method of encapsulation is dipping, or conformal coating, of the electronic assemblies. This technique has been used successfully in a number of electronic fuzes, particularly those subjected to low-acceleration launch environments. Conformal coating is more economical than complete embedment, and it provides some structural support while it inhibits the entry of moisture and contaminants. Conformal coatings also can be used when there is a mismatch between the coefficients of thermal expansion (CTE) of the electronic component and the rigid potting compound. When this method is used for stress relief, several requirements should be met. First, the conformal coating should have a CTE higher than that of the encapsulating compound, second, the conformal coating should have a low elastic modulus, and third, in certain situations the conformal coating should not bond to the encapsulating compound or to the component.

13-6.3 SUPPORTING STRUCTURE

Because of the extreme environments of shock and vibration in which fuzes must operate, a great deal of design effort is devoted to the main structure of the fuze. In electronic fuzing systems size, weight, reliability, and structural integrity are prime considerations, and the choice of supporting methods must reflect the priority of these factors. Fig. 13-6 shows the basic construction of an electronic module of a missile fuze. The printed circuit boards are mounted between "napkin ring" supports in a catacomb structure. Interboard electrical connections are made through a flexible printed circuit strip, which interfaces with each board. The assembly may be encapsulated with a rigid, semirigid, or conformal coating to provide additional support and structural integrity. Fig. 13-7 illustrates an artillery electronic time fuze using an A-frame construction of five PCBs supported at the top and bottom and encapsulated with a foam potting (Isofoam, PF18). Both the catacomb and A-frame constructions have been used successfully in a number of fuze designs. Finite element modeling of these configurations can be accomplished with a general-purpose NASTRAN computer program used to perform a numerical evaluation of the survivability of the design under dynamic loading.

In mechanical timers and escapements used in artillery fuzes, the supporting structures (posts) and the thicknesses of the plates that encase the gear and pinion sets and the escape wheel must be sufficiently rugged to prevent an "oil canning" effect during setback. The designer must make sure the assembly above the timer is properly supported to prevent transfer of inertial forces onto the timer plates. Lack of attention to proper supporting structures can lead to wedged pinions and, consequently, inoperable fuzes.

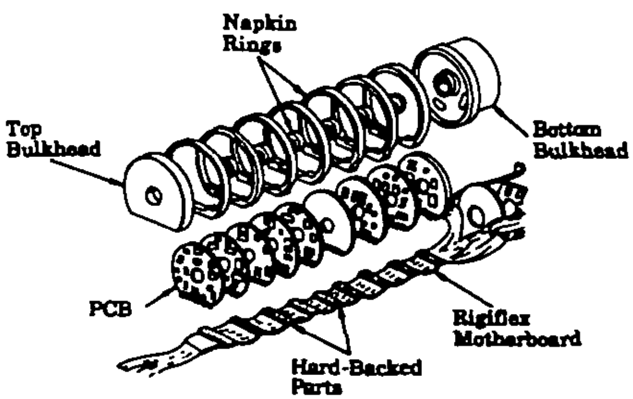


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Figure 13-6. Electronic Module for a Missile Fuze (Ref. 20)

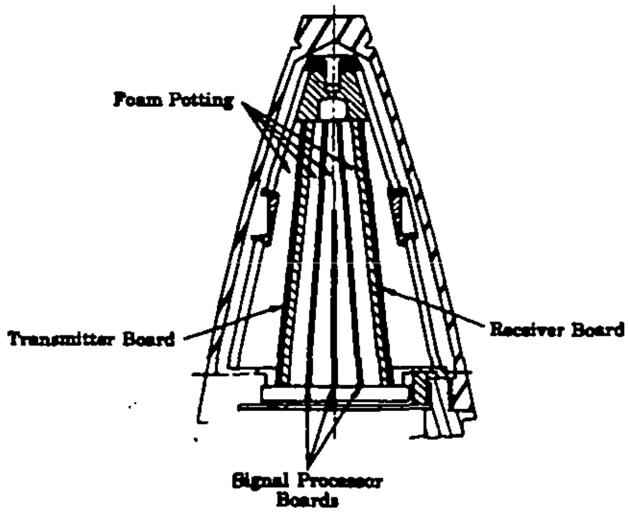

Figure 13-7. A-Frame Supporting Structure for an Electronic Artillery Fuze

13-7 LUBRICATION

A lubricant is expected to minimize friction, wear, and galling between sliding or rolling parts. It must do this under two conditions:

1. Those that are inherent in the component element itself, i.e., load, speed, geometry, and frictional heat.
2. Those that are imposed from external sources, i.e., temperature and composition of the surrounding atmosphere, nuclear radiation, inactive storage, vibration, and mechanical shock. The imposed conditions are usually more restrictive for lubricant selection.

Mechanical fuze components contain elements that undergo a variety of sliding and rolling motions and combinations of these. For example, a mass translating on guide rods involves only linear sliding, the balls in a ball bearing involve only rolling motion, and meshing gear teeth surfaces experience both rolling and sliding motions. The lubricant satisfactory for any given type of motion will not necessarily be suitable for another if loads and speeds are not similar.

Selection of the proper lubricant requires not only knowledge of the specific function that the lubricant is to perform in the device but also consideration of interactions including chemical processes, such as corrosion of the metal parts by components of the lubricant, e.g., corrosion due to oxidation of molybdenum disulfide (MoS_2) in the absence of suitable inhibitors or solution of copper alloys during lubricant oxidation processes, and physical interactions, e.g., attack by active organic materials on synthetic elastomers and plastic structural members. In addition, the inherent stability of the lubricant must be considered. Stability is of particular importance if storage for long periods of time, with or without elevated temperatures (which speed up oxidation rates), is involved. In general, lubricants are inhibited against oxidation by appropriate additives, but because temperature is an important parameter, the oxidation stability characteristics of the lubricant should be considered in connection with the expected storage life and pertinent temperatures of the mechanism being lubricated. Oxidation of fluid or semifluid lubricants may lead to thickening of the lubricant and the consequences of increased forces being required for operation or corrosive attack on the materials of construction.

A wide variety of fluid and semifluid lubricants are available with a wide temperature range of applicability, a range of compatibility with organic and inorganic structural materials, and a range of other properties that may be pertinent, e.g., nonspreading and lubricity. In addition, both dry powdered and bonded solid film lubricants are available. The choice of a lubricant depends on the totality of functions it must perform and the structural and functional features of the mechanism being lubricated. For example, a very severe nonspreading and low vapor-pressure requirement in connection with long-term storage may lead to the choice of a solid lubricant, whereas adhesion problems with bonded lubricants at high loads, or with thin films associated with low mechanical tolerances, may complicate the use of dry film lubricants. In fuzes subject to high rates of spin (above 25,000 rpm), fluid and semifluid lubricants tend to be displaced by centrifugal force; this displacement causes loss of lubricant and possible contamination of other fuze parts. Requirements for corrosion protection may require additives that cannot be used with dry lubricants.

In simpler fuzes choice of proper materials, plating, and finishes can obviate the necessity for a separate lubricant.

Solid film lubricants now are used more often than oils for timers and escapements because they have better storage characteristics. Oils tend to migrate over long periods of storage and therefore may not provide the necessary lubricity in desired areas.

A large variety of lubricants with proven military properties are available. The lubricants most commonly used for escapements, gears, bearings, and linkages are listed in Table 13-7.

13-8 TOLERANCING

Tolerances on dimensions and surface finishes play a very important role in determining item reliability and producibility. Specification of unnecessarily tight tolerances can have a detrimental effect on producibility and cost. As tolerances and surface finishes become tighter, manufacturing operations that are more specialized and expensive are required. Extremely tight tolerances, however, do not necessarily imply poor producibility. Tight tolerances for certain parts may be imperative for the item to function properly. If, on the other hand, the tolerances can be loosened without detracting from the functional or performance characteristics of the item, producibility may be enhanced. Details of the design of all parts should be surveyed carefully to assure both inexpensive processing and ease of assembly. It must be remembered that each production method has a well-established level of precision that can be maintained in continuous production. The production tolerances for various machining operations and the cost curves for tolerances and surface finishes show that it is important to analyze the tolerance structure requirements to produce a functional, economical design.

Tolerancing affects the interchangeability of components, and complete interchangeability of components is desirable whenever feasible. However, in complex mechanisms, such as timers, for which components are small and tolerances

TABLE 13-7. COMMON TIMER LUBRICANTS (Ref. 22)

TYPE	MIL SPEC*	COMPOSITION	COMMENTS
Oil	MIL-L-3918 (Ref. 23)	Specified synthetic ester mixture and additives	Low temperature −40 °C (−40°F), nonspreading lubricating oil
Oil	MIL-L-11734 (Ref. 24)	Specified mixture of C9-C10 dibasic acid esters and additives	Standard fuze oil: used in many mechanical time fuzes over military temperature range
Solid Film	MIL-L-46010 (Ref. 25)	MoS_2, graphite, etc, in resin binder	Bonded solid film lubricant; resin cures at 149°C (300°F) for 1 h
Solid Film	MIL-L-46010 (Ref. 25)	Same as above	Same as above except resin cures at 204°C (400°F)
Solid Film	MIL-M-7866 (Ref. 26)	Powdered MoS_2 minimum purity 98.5%	Unbonded; applied by tumbling or burnishing
Solid Film		Polytetrafluoroethylene	Applied by dipping or immersing in ultrasonic cleaner.

**MIL SPEC* = military specification*

are critical, complete interchangeability is often impractical. In these instances conformance with the tolerance specifications may be achieved by selective assembly of parts.

ANSI Y14.5M, *Dimensioning and Tolerancing* (Ref. 21), is used throughout the military services and also is widely used in industry as the standard system for geometric tolerancing and dimensioning. Par. 9-3.5 discusses the advantages and illustrates the concept of geometric tolerancing and dimensioning. Ref. 27 is an excellent treatise on this subject and provides tolerance limits for numerous manufacturing processes.

13-9 COMPONENTS

The selection of components for a fuze design comprises a large segment of the total design process. This effort encompasses tasks for standardization, approval, qualification, and specification of parts that meet the performance, reliability, safety, and other requirements of the evolving design. The use of standard or proven components can reduce the development time and cost as well as the unit production cost. The selection of a material for a component affects manufacturing processes, cost, safety, reliability, and many other aspects of the design. The fuze designer must therefore be judicious in his selection of components to ensure a cost-effective and safe design that will meet all the performance requirements after long-term storage and exposure to the rigorous military environment.

13-9.1 SELECTION OF COMPONENTS

Often failure of a fuze component is a greater calamity than failure of a component in another system. Early activation can cause a hazard to personnel. Improper fuze activation results in failure of the weapon even when other systems have done their jobs.

A wide selection of commercially supplied, off-the-shelf components, particularly electronic components, are available to structure fuzing systems and constitute the building blocks from which fuzes are designed. The tasks of selecting, specifying, assuring proper design application, and controlling the parts used in a complex fuzing system constitute a major engineering effort. Numerous controls, guidelines, and requirements must be formulated, reviewed, and implemented during the development effort. Preferred parts lists, which tabulate specific parts already in use and existing fuze designs, can help to select proven components in the supply system or inventory.

The problems of fuze component reliability vary with the type of fuze in which the components are used. The requirements for long, inactive shelf life, extreme environmental conditions while in operation, and the inability to pretest for complete function before use add to the difficulties in the selection of components.

For these reasons the designer should use standard components whenever possible, be well acquainted with the environmental conditions under which the fuze is to operate, and recognize the effects of the combination of different conditions. Of particular importance is the relationship between temperature and the rate of chemical action because this relationship is a critical factor that affects the storage life of equipment. Explosive components, discussed in Chapter 4, present special problems to the fuze designer.

13-9.2 ELECTRICAL COMPONENTS

Electrical components are necessary in electronic fuzes. Capacitors, resistors, microcircuits, diodes, transistors, and switches present special problems as a result of the military environments that put stringent requirements on their ruggedness, aging, and temperature characteristics. In addition, these components must meet other specifications, i.e., tolerances, reliability, size, and rating, depending upon the fuze in which they are used.

Components must be rugged enough to operate after withstanding setback forces, high rotational forces, and occasionally severe deceleration forces imposed by target impact. To ameliorate these requirements, components can be mounted in a preferred orientation. For example, a fuze that is subjected to high rotational forces can have its components mounted so that the rotational forces operate on their strongest dimensions. Another solution is to encapsulate or put a conformal coating on all of the components to add strength to the entire configuration and to give added support to the wire leads.

To relieve the effects of aging, moisture, and thermal and temperature effects, the designer can select military grade components with inherent resistance to identified environmental stresses, hermetically or hydraulically seal the fuze, provide heat sinks or select packaging approaches and placement of components that will fulfill the thermal resistance requirements, and select components such that the variation in one is opposed by that in another. For example, in a simple resistor capacitor (RC) circuit, a resistor whose value increases with increasing temperature can be coupled with a capacitor whose value decreases with increasing temperature.

A general rule for electronic part selection is that whenever practical, standard components should be used. The following list of military standards provides valuable information and data on the selection and testing of electronic components (Refs. 28-30):

1. MIL-STD-202, *Test Methods for Electronic and Electrical Component Parts*
2. MIL-STD-750, *Test Methods for Semiconductor Devices*
3. MIL-STD-883, *Test Methods and Procedures for Microelectronics*.

In addition, military standards exist that list by military designation those parts or devices preferred for use in military equipment (Refs. 31-40):

1. MIL-STD-198, *Selection and Use of Capacitors*
2. MIL-STD-199, *Selection and Use of Resistors*
3. MIL-STD-200, *Selection of Electron Tube*
4. MIL-STD-454, *Standard General Requirements for Electronic Equipment*
5. MIL-STD-701, *Lists of Standard Semiconductor Devices*
6. MIL-STD-1132, *Selection and Use of Switches and Associated Hardware*
7. MIL-STD-1277, *Electrical Splices, Terminals, Terminal Boards, Binding Posts, Terminal Junction Systems, Wire Caps*
8. MIL-STD-1286, *Selection and Use of Transformers, Inductors, and Coils*
9. MIL-STD-1346, *Selection and Application of Relays*
10. MIL-STD-1353, *Selection and Use of Electrical Connectors, Plug-In Sockets, and Associated Hardware.*

13-9.3 MECHANICAL COMPONENTS

Examples of mechanical components used in fuzes are safety and arming devices (SAD), timers, detents, g-sensors, switches, gear trains, and mechanical structures.

These components differ from electronic components in that they are not usually available as standard items. Quite often the fuze designer can save development time and reduce risk by selecting components or design concepts from fuzes that are presently in use. In this way, the reliability, safety, and environmental resistance of these designs can be incorporated into the new design.

The mechanical components must be rugged enough to perform reliably and to withstand the setback, rotational, and target impact forces that are imposed. In addition, the fuze components must withstand the natural and induced environments associated with transportation, handling, and long-term storage. One of the major problems encountered in the design of mechanical components is that of maintaining the proper frictional characteristics after long periods of inactive storage. Lubricants, if used, must be carefully chosen. All metal should be either corrosion resistant or protected against corrosion by appropriate application of plating or coatings (Ref. 41). Corrosion due to galvanic action resulting from dissimilar metals must be considered.

Frequently, there is an opportunity to combine several parts so that the total number of parts is smaller, but all too frequently, this opportunity is overlooked. The fuze designer should examine every component design to determine the potential for combination with an adjacent component in the next assembly. Fig. 13-8 illustrates an example of product simplification that was effected in the Navy's MK 1 Bomblet Fuze.

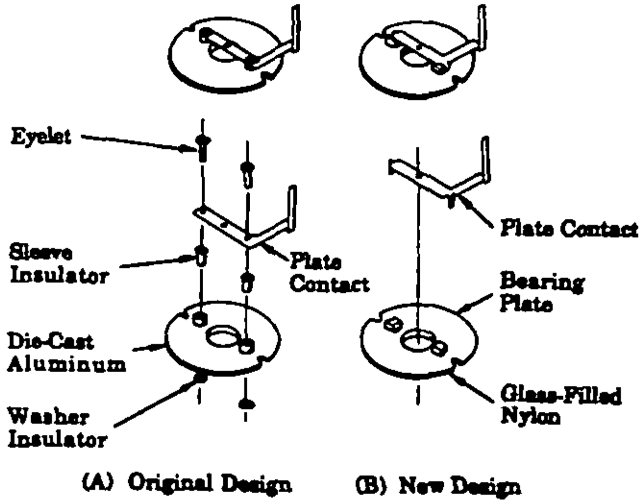

Figure 13-8. MK 1 Fuzing System, Bearing, and Contact Plate Assembly (Ref. 9)

13-10 COMPUTER-AIDED DESIGN AND COMPUTER-AIDED ENGINEERING

In addition to creating a broader and more powerful range of design capabilities, computer-aided design (CAD) and computer-aided engineering (CAE) have provided a more directed and economical testing program as well as an improved means to design fuzes. CAD allows an engineer to change any dimension, component, or mass and examine instantly the updated blueprint. CAE then considers these new values and calculates how the new physical characteristics will affect the functional performance of the fuze.

Although dimensions differ greatly, fuze design typically relies on a common library of components. This library includes rotors, dashpots, gear trains, rolling balls, sliders, clockwork mechanisms, and various types of springs. CAD maintains a schematic library, from which the schematic of a component may be called into a blueprint being developed by the computer. For example, if a fuze design calls for a spring, the draftsman need only input its dimensions, Wahl factor, and placement. The spring is then drawn and becomes an integral part of the blueprint. A rotor or gear train can be included with the same ease.

A valuable feature of CAD is that it can instantaneously show the fuze from any angle or perspective, complete with dimensions. CAD also allows the user to view cutaway sections, exploded views, and separate components. This gives the design engineer a picture of exactly how the fuze and its components will look and work.

The instrumentation for monitoring the performance of various fuze components at the proving grounds is cumbersome, costly, and complex. Furthermore, the typical test result determines only whether the fuze as a whole functions or not. CAE allows tests to be performed without a prototype and thereby saves time and money. Present-day computers allow an engineer to observe components of the fuze throughout delivery with time frames in the millisecond range. This is useful in determining clearances, tolerances, and potential trouble areas.

The equations describing fuze behavior are extremely complex and time-consuming to solve; CAE can play a vital, simplifying role in the design of fuzes. A CAE program will consider all of the dimensions, components, and masses of a fuze and immediately calculate vital statistics such as the center of gravity. For example, an increase in the outside nose angle will move the center of gravity slightly forward, possibly to the detriment of the flight characteristics. CAE enables the computer to perform the laborious task of calculating the new center of gravity.

13-11 FAULT TREE ANALYSIS (FTA)

The fault tree is a symbolic logic diagram showing the cause and effect relationship between a top undesired event, e.g., fuze arms or fires at an incorrect time, and the contributing causes. The top event is typically identified as a safety failure at a system or subsystem level, and a top-down approach is pursued to identify the causal events leading to the top event. It is a deductive analytical means used to identify all failure modes that may contribute to the potential occurrence of the undesired event or a reliability failure. The fault tree displays all the necessary failure modes and the specific conditions that cause such an event.

A fault tree analysis (FTA) can be performed either qualitatively or quantitatively. Every FTA begins as a qualitative analysis, and most of the value of the analysis is realized in this form. The quantitative analysis is a numerical estimate of the risk associated with the event that helps to determine how serious the problem is. The quantitative fault tree provides the foundation for applying safety or reliability engineering effort to control or eliminate those contributing failure paths having the greatest probability of occurrence. Such paths are generally described as critical paths, and they indicate the single failure or combination of failures (independent failure modes) that are most likely to result in the top event. Although numerical techniques are useful for relative comparison, their use in determining absolute values is inappropriate. Reliance on numbers alone ignores the fact that unpredictable interactions and human elements can also be expected to occur.

Fig. 13-9 illustrates a simplified fault tree for a hypothetical weapon system. In the example in Fig. 13-9, the undesired event is inadvertent initiation or activation of the weapon (Event A). This event requires that the fuze be in the armed position (Event B) and that electrical or mechanical energy be applied to the first component in the explosive train (Event C). Obviously, to complete this FTA, other events leading to Events A and B must be constructed as illustrated. The fault tree continues until all input events are identified. Ref. 42 provides a complete description of the FTA as well as the common symbols for fault tree elements and their logical meanings.

13-12 FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS

The failure mode, effects, and criticality analysis (FMECA) is another tool that can be used by the fuze designer to identify the effects of hardware failure modes on operation or safety. The FMECA is an expansion of the failure mode and effects analysis (FMEA). The basic difference is that the FMECA identifies the criticality of failure modes to the safety of the system, whereas the FMEA identifies only reliability-related failure modes.

The FMEA shows the immediate or direct effects of a failure. The effects of the failure in each mode, e.g., resistor open, shorted, or grounded or safety detent lock-tension or shear failure, omission, or malassembly, and the failure rate for that mode are then presented, together with a statement of direct effects, e.g., loss of power or signal or loss of lock on the safety and arming (S&A) out-of-line mechanism.

The objective of the FMECA is to trace, throughout the system, the ultimate effects that influence safety and to determine the probability of undesirable effects if the failure occurs and thus the overall probability of occurrence of these undesirable effects. Based on these results, corrective action and redesign may be accomplished. Evidence of a catastrophic fuze failure rate greater than 10^{-6} indicates noncompliance of a design with MIL-STD-1316. Fig. 13-10 represents a worksheet and format that can be used for the FMECA. The data required to perform the FMECA are

1. Fuze design specifications and drawings
2. FMEA logic block diagrams and component failure data
3. System description and specifications
4. Test and evaluation plans
5. Tradeoff study results
6. Test results and safety studies and reports
7. Hardware inspection reports.

Additional guidance on the preparation of the FMECA is in Ref. 44.

13-13 MAINTENANCE AND STORAGE

Ideally, fuzes should be completely maintenance free. They should be designed so that they can be placed on the shelf and then perform safely and reliably when withdrawn for use as much as 20 years later. Every effort should be made to produce ammunition and fuzes that have optimum properties of handling, storage, shelf life, and serviceability.

Ensuring high reliability and safety after extended storage requires that special effort be applied during design and development, test and evaluation, production, training, and storage. Lack of effort in any of these areas can result in a fuze that may be declared unserviceable after only a short life span.

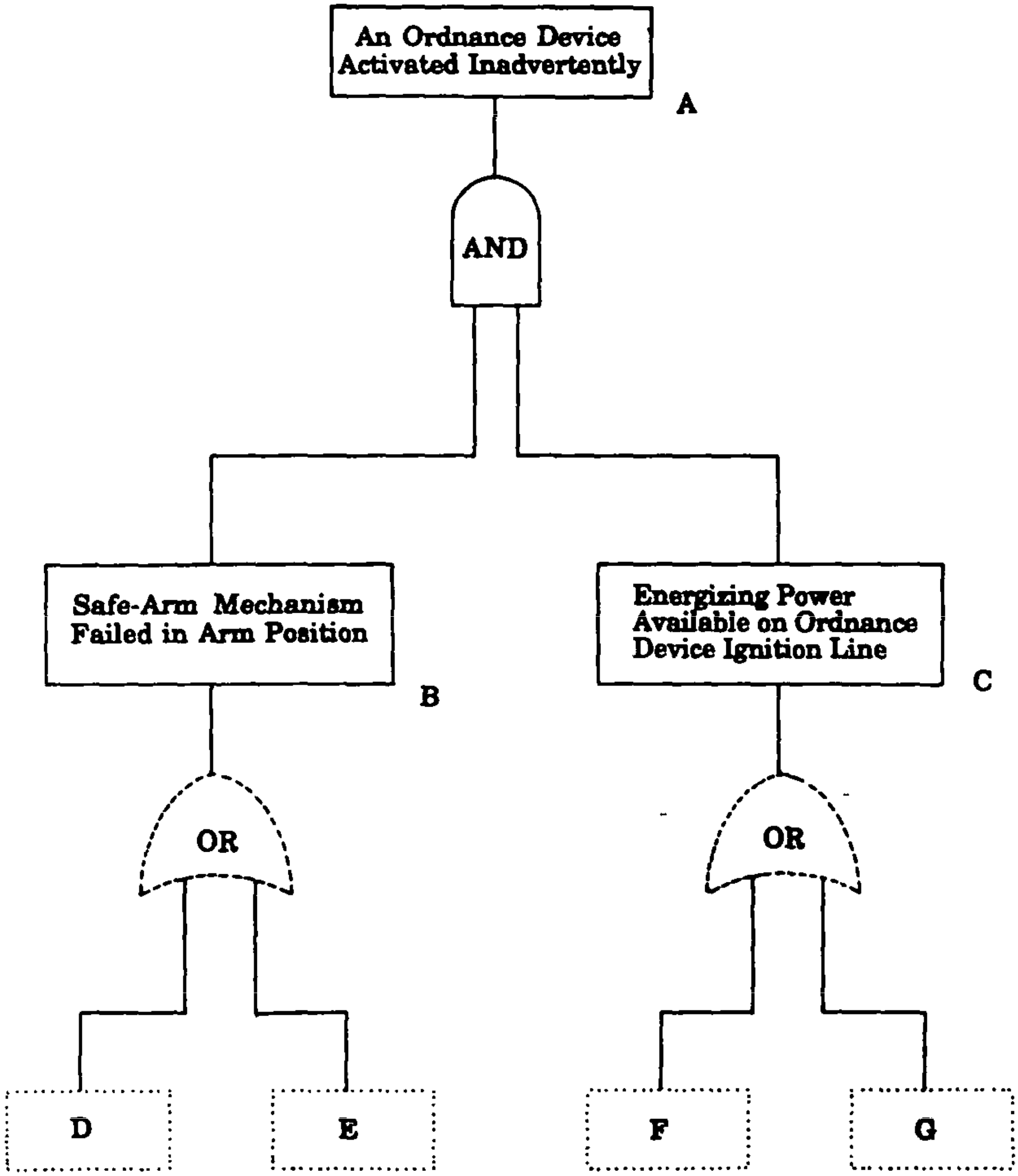

Figure 13-9. Simplified Fault Tree Analysis for Hypothetical Weapon System

One key to maximizing and controlling reliability and safety throughout the life of a fuze is to conduct a comprehensive test program that addresses all of the known and anticipated environments and stresses in which the design must survive. A number of fuze designs have failed after being introduced into service because they had not been properly tested at extreme shock, vibration, or temperature levels during the evaluation. Although a number of standards have been developed for the testing of fuzes, it is the designer's responsibility to devise and apply additional appropriate tests to evaluate the nonstandard conditions of the natural and induced environments of military operations.

A second key to assuring the long-term reliability and safety of a fuze is quality assurance documentation. It is necessary not only to state the dimensions and tolerances to

Program ______ System ______ Subsystem ______ Revision ______ Rev. Date ______				Failure Mode Effects and Criticality Analysis (FMECA)						Engineer ______ Date Started ______ Date Completed ______ Page ______ of ______ Pages			
Item Identification				Failure Mode / Cause			Failure Mode Effects			Criticality Evaluation			Remarks or Recommended Actions
Name	Drawing / Part No.	Generic Failure Rate (λ_G) (Per 10^6 h)	Function	Failure Mode and Cause	Prob. of Occur (λ_m) (Per 10^6 h)	Mission Phase	Component or Functional Assembly	Sub-system	Mission or System	Hazard Cat.	Prob. of Failure Mode Effects	Probability of Critical Effects (Col 6 x Col 12)	
1	2	3	4	5	6	7	8	9	10	11	12	13	14

Figure 13-10. Example of a Failure Mode, Effects, and Criticality Analysis Worksheet (Ref. 43)

which the fuze must be produced and the nature and properties of the materials of which the fuze must be made but also to state methods used to determine whether these requirements have been met by the manufacturer to a satisfactory extent.

The term "quality assurance" embraces the techniques used in the determination of the acceptability of the fuze. These techniques include

1. Establishment of criteria for homogeneity (lot definition)
2. Establishment of acceptance criteria (inspection plans, sampling acceptable quality levels (AQLs))
3. Determination of methods of inspection (gaging, testing, and visual inspection)
4. Classification of defects
5. Material handling controls
6. Process controls.

Incorrect classification of defects, unrealistic or ambiguous acceptance criteria, incomplete analysis of desired quality, and inadequate methods and levels of inspection may result in unreliable, costly, or hazardous fuzes.

MIL-STD-490 (Ref. 43) provides guidelines for the preparation of a fuze specification.

13-14 MILITARY HANDBOOKS

The following list includes military handbooks appropriate to this chapter on design guidance along with a brief synopsis of the contents of each:

1. MIL-HDBK-727, *Design Guidance for Producibility*, April 1984. This document provides the design engineer with information to assist him in reducing or eliminating design features that would make producibility difficult to achieve.

2. AMCP 706-205, Engineering Design Handbook, *Timing Systems and Components*, December 1975. This document provides design considerations for electronic, mechanical, pyrotechnic, flueric, electrochemical, and nuclear delay timers. Production techniques and processes are also addressed for each type of timer.

3. AMCP 706-110 through -114, Engineering Design Handbooks, *Experimental Statistics*, Sections 1 through 5, December 1969. These handbooks are a collection of statistical procedures and tables useful in the planning and interpretation of experiments and tests. Section 1 provides an elementary introduction to basic statistical concepts, Section 2 provides detailed procedures for the analysis and interpretation of enumerative and classificatory data, Section 3 has to do with the planning and analysis of experiments, Section 4 addresses nonstandard statistical techniques, and Section 5 contains mathematical tables needed for the application of procedures given in Sections 1 through 4.

4. AMCP 706-179, Engineering Design Handbook, *Explosive Trains*, January 1974. This handbook includes development of the complete explosive train from elements suitable to initiate the explosive reaction to the promotion of effective functioning of the final output element. Design principles and data pertaining to primers, detonators, delay elements, leads, boosters, main charges, and specialized explosive elements are covered.

5. MIL-HDBK-777, *Fuze Catalog Procurement Standard and Development Fuze Explosive Components*, 1 October 1985. This handbook provides technical information and data on primers, squibs, detonators, delays, relays, leads, and boosters used in the production of standard and development fuzes. Drawings, specifications, illustrations, input and output characteristics, specific applications, materials, weights, and loading pressures are included.

6. MIL-HDBK-145A, *Active Fuze Catalog*, 1 January 1987. This handbook provides technical information and data on the production of procurement-standard, development, and stockpiled inventory fuzes of the Army, Navy, Air Force, and Marine Corps. Drawings, specifications, cognizant activity, and brief descriptions and arming, ballistic, functioning, physical, and explosive train data are included.

7. DARCOM-P 706-103, Engineering Design Handbook, *Selected Topics in Experimental Statistics With Army Applications*, December 1983. This handbook presents

many new and useful techniques in experimental statistics not found in the *Experimental Statistics* Handbooks. Errors in measurements, precision, and accuracy of measurements, determination of sample size, and testing strategies are covered.

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30. MIL-STD-883C, *Test Methods and Procedures for Microelectronics*, 27 July 1990.
31. MIL-STD-198E, *Selection and Use of Capacitors*, 16 September 1988.
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33. MIL-STD-200K, *Selection of Electron Tube*, 7 November 1977.
34. MIL-STD-454M, *Standard General Requirements for Electronic Equipment*, 15 August 1990.
35. MIL-STD-701N, *Lists of Standard Semiconductor Devices*, 31 January 1990.
36. MIL-STD-1132A, *Selection and Use of Switches and Associated Hardware*, 19 July 1990.
37. MIL-STD-1277B, *Electrical Splices, Chips, Terminals, Terminal Boards, Binding Posts, Junction Systems, Wire Caps*, 28 December 1983.
38. MIL-STD-1286D, *Selection and Use of Transformers, Inductors, and Coils*, 30 June 1987.
39. MIL-STD-1346B, *Selection and Application of Relays*, 29 April 1985.
40. MIL-STD-1353B, *Selection and Use of Electrical Connectors, Plug-In Sockets, and Associated Hardware*, 12 May 1989.

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CHAPTER 14
FUZE TESTING

The importance of test and evaluation (T&E) as a major control mechanism of the system acquisition process is explained. The two categories of T&E, technical and user, are described, and the objectives of each phase of the two categories are discussed. The functions of the US Army Test and Evaluation Command (TECOM) and the US Army Operational Test and Evaluation Agency (OTEA) are explained. Also discussed are laboratory and field testing; destructive, aggravated, and nondestructive testing; and the use of standard testing specifications.

The specialized facilities and techniques used to study fuze functioning attributes under dynamic environments are described. Included are centrifuges, high-speed spin machines, air guns, launchers, recovery methods, wind tunnels, rocket sleds, telemetry, and on-board recorders.

Environmental testing programs for fuzes and their components are discussed. The effects and tests for electromagnetic environments and rain are explained, and the tests and governing specifications for the vulnerability environments of bullet impact and cook-off are described. Also explained are surveillance testing and the associated topics of the factors affecting shelf life and accelerated environmental testing.

The testing considerations following development, which include product acceptance, first article sampling, and lot acceptance, are described, and the role of the acceptance quality level (AQL) is explained.

The concluding topic, analysis of data, discusses the use of statistical techniques applicable to fuze testing.

14-1 INTRODUCTION

Test and evaluation (T&E) is the major control mechanism of the acquisition process. Programs advance from one phase of the acquisition process to the next by actual achievement of preset performance thresholds verified by T&E. There are two principal categories of T&E, technical and user.

The technical evaluation is performed by the technical agency and addresses the technical characteristics of the fuze, the acquisition process, and the fielding of an effective, supportable, and safe fuze. It verifies the attainment of technical performance specifications, producibility, and adequacy of the Technical Data Package (TDP) and determines safety and human factors. Technical evaluation encompasses the use of prototype, simulations, and tests as well as full-scale development models of the fuze.

The operational evaluation is performed by the user. It addresses the effectiveness and suitability of the fuze and weapon system for use in combat by typical military users. It provides information to estimate organizational structure, personnel requirements, doctrine, and tactics; identifies any operational deficiencies; and assesses manpower and personnel integration (MANPRINT) aspects (system safety, health hazards, human factors engineering, training, manpower, and personnel) of the system in a realistic operational environment.

Technical evaluation is concerned with technical aspects and is usually conducted by or under the control of the developing activity. User evaluation is concerned with military user aspects and is usually conducted by the designated user. Technical and user evaluations are conducted throughout the system acquisition process to provide information that will help to assess acquisition risk and service worth. Technical evaluation conducted during the Demonstration and Validation and Engineering and Manufacturing Development phases is performed using advanced development prototype, engineering development prototype, and production prototype or initial production hardware and is designated as Development Test (DT), Production Proveout Test (PPT) and Qualification Test (QT). The corresponding user evaluation is designated as Early User Test and Evaluation (EUTE), Initial Operational Test (IOT) and Follow-On Operational Test and Evaluation (FOTE). The Test and Evaluation Master Plan (TEMP) is the controlling document for T&E; it combines in one document the development tests and the user tests to be accomplished, the performance thresholds to be achieved, and the assets required. For a typical fuze program, schedules are established for the conduct of key tests prior to program milestones. The test results and their evaluation are important inputs used by decision makers to assess the programmatic risks of proceeding to the next phase of development. Thus testing plays a major role in shaping the course of a fuze development program.

14-2 TECHNICAL EVALUATION

Technical evaluation is conducted to demonstrate that the engineering design and development process is complete, design risks have been minimized, the system will meet specifications, and safety objectives have been met and to estimate the military utility of the system. The US Army Materiel Command (AMC) has responsibility for the development of fuzes and their technical evaluation program. AMC assigns the majority of its development testing to the

US Army Test and Evaluation Command (TECOM). The emphasis in TECOM's mission is on independent evaluation; therefore, TECOM makes maximum use of valid test data, regardless of whether they are generated at laboratories, arsenals, proving grounds, or contractor plants. Government development testing is conducted to supplement valid contractor test results and to provide data that cannot be provided through normal contractor effort. TECOM provides test facilities and expertise to contractors and materiel developers and monitors contractor-conducted tests to ensure validity of data. Test planning must be coordinated to minimize the number of tests and to preclude duplication. Implicit in the requirement for coordination is the need to maximize the exchange of data between the development and user T&E organizations.

The principal objectives of the technical evaluation are

1. To produce information relative to technical performance, compatibility, interoperability, vulnerability, transportability, survivability, reliability, MANPRINT, safety, correction of deficiencies, and integrated logistic support

2. To provide information to the decision-making authority at each decision point regarding the technical performance and readiness of a fuze to proceed to the next phase of acquisition

3. To determine the operability of a fuze in the required climatic and realistic battlefield environments.

It is desirable to combine portions of technical and user tests when testing large expensive systems or systems of which only a small number will be produced or fielded. Combined testing is encouraged because it can save significant amounts of time, test items, and money. Care must be taken, however, in the planning and conduct of these tests to ensure that both technical and user test purposes are served.

Development tests are conducted during the Demonstration and Validation Phase to support the Milestone II decision for entry into Engineering and Manufacturing Development. The development tests results are used to demonstrate that all technical risk areas have been identified and reduced to acceptable levels, the best technical approaches have been selected, and the needed technology is available. Components, subsystems, brass-board configurations, and advanced development prototypes are examined to evaluate the potential application of technology and related design approaches before entry into Engineering and Manufacturing Development. Depending on the technological and material status, development tests results may be adequate to determine component interface problems and fuze performance capabilities, and unless the requirements of the baseline design change, the development tests results should remain applicable throughout the program.

Production Proveout Tests (PPT) are conducted during the Engineering and Manufacturing Development phase using engineering development prototype models. The purpose of PPT is to provide the technical data needed to determine the readiness of the system to transition into either limited or full production. The technical performance (which includes reliability, environmental resistance, availability and maintainability, survivability, performance specifications, interoperability, safety, and logistic supportability) of the entire system is measured during this phase. PPT demonstrates whether engineering is reasonably complete and solutions to all significant design problems have been identified. For larger programs PPT is normally subdivided into discrete phases and testing is conducted on models of increasing maturity. The formal technical evaluation is conducted during the final phase of PPT using, insofar as is possible, production-representative hardware, validated software, and firm documentation that includes drawings, specifications, and operation and training manuals. The broad purpose is to identify technical deficiencies and determine whether the design meets the technical specifications and requirements. PPT also provides a major source of data for certification of readiness for user evaluation.

The principal objectives of the user evaluation are

1. To assist the developers by providing information relative to operational performance, doctrine, tactics, logistics, MANPRINT, technical publications, reliability, availability, and maintainability (RAM), and refinement of requirements

2. To ensure that only operationally effective fuzes and weapons systems are delivered to the Army operating forces

3. To assess, from the user's viewpoint, the desirability of a system considering systems already fielded and the benefits or burdens associated with the system.

14-2.1 LABORATORY AND FIELD TESTS

Both laboratory and field tests are conducted during development to measure the performance of a fuze and to determine the degree to which it meets the stated operational requirements. Normally, the relatively inexpensive laboratory tests are conducted prior to the field tests and thereby give the fuze designer an opportunity to find and correct faults before conducting the more expensive field tests. Each type of test, however, has its own attributes. Some laboratory test attributes are

1. These tests are generally less expensive to run.

2. These tests can be run on component and subsystems levels.

3. Environmental conditions can be controlled to a greater degree.

4. Recovery is easier.

5. More comprehensive instrumentation to measure both performance and environment can be used.

6. Aggravated conditions can be applied more easily to help determine the margin of design.

Some field tests attributes are

1. Conditions more accurately reflect the operational environments.

2. System tests are generally easier to perform.

3. Ancillary and test equipment are more easily integrated as part of the operation.

4. Operational forces are more easily integrated as part of the operation.

The long history of fuze development has led to the establishment of standardized tests, most notably the MIL-STD-331 (Ref. 1) series. Standardized tests are useful for promoting uniform evaluation and interchangeability of results. Over the years test results have shown that fuzes which passed all the applicable standardized tests proved safe and rugged for service use; however, these tests should be imposed only when they serve a definite purpose. Standardized tests are most useful in assessing safety and environmental ruggedness. However, the preparer of each test program should determine whether the standardized tests address all project requirements and, if they do not, should supplement the standardized tests with other tests that do address the needs. Some aspects of fuze operation, such as explosive energy transfer, can also be determined through use of standardized tests. For tests involving operational characteristics, there are good reasons to design tests peculiar to the fuze being developed because it is likely that this fuze will be sufficiently different from what was developed in the past.

Several military standards address tailoring environmental tests to the specific development program rather than imposing standardized tests. MIL-STD-810 (Ref. 2) and DOD-STD-2105 (Ref. 3) are notable in this regard. The objective of tailoring is to assure that military equipment is designed and tested for resistance to the environmental stresses it will encounter during its life. The information used must be based on the environmental definitions determined by the life environmental profile. Operational environmental tests, in which the ambient environment is to be duplicated, lend themselves to tailoring. Accelerated tests investigating storage or transportation attributes where the environmental effects are to be simulated are not readily tailored. Such accelerated tests by their very nature may use unrealistic parameters; these tests are discussed in par. 14-7.2.

Typical laboratory and field test flow diagrams for projectile fuzes are given in Figs. 14-1 and 14-2, respectively, to illustrate significant elements of these programs.

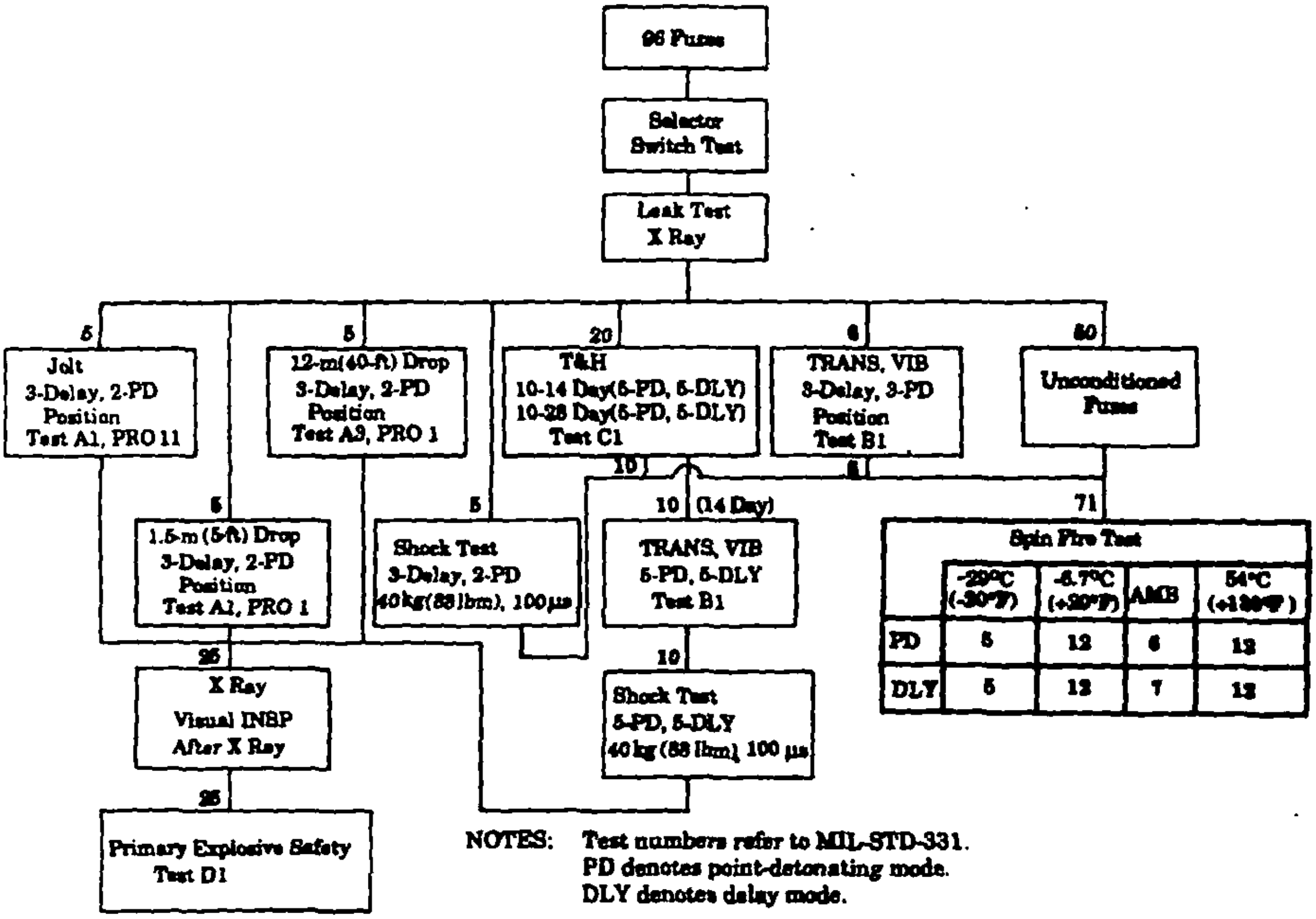
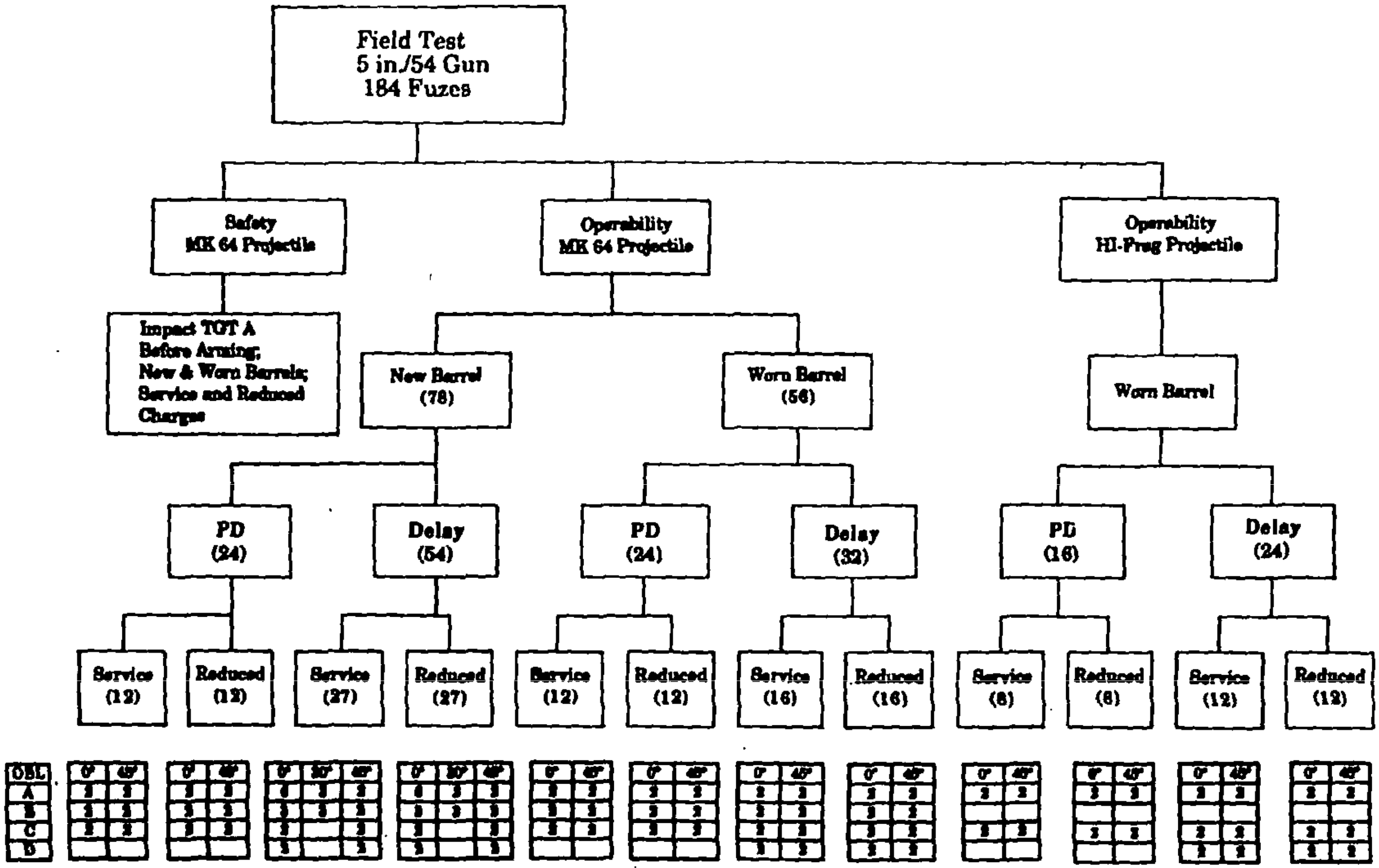


Figure 14-1. Typical Laboratory Test Plan for Projectile Fuze



NOTES: PD denotes point-detonating mode.
OBL denotes obliquity.
TGT denotes target; A-1/4 in. mild steel; B-3/8 in. mild steel; C-2 in. plywood; D-1/4 in. aluminum.
Service and Reduced refer to propellant charges.

Figure 14-2. Typical Field Test Program for Projectile Fuze

The *test plan* is an important document of the overall development plan. It specifies the tests to be performed; the procedures to be used; the assets (organization, people, money, facilities, and instrumentation) required, the assessment criteria, the schedules, the hardware sample size required and the associated baseline design disclosures, and the performance data to meet each of the program milestone requirements. The materiel developer plays an important and, in many respects, a leading role in generating the test plan. For this effort the materiel developer works closely with TECOM.

14-2.1.1 Component, Subsystem, and System Testing

Many operational attributes of fuzes can be determined by conducting tests on a less than full-system configuration. The advantages for performing these tests are the ease with which they can be accomplished, the comparatively low cost associated with the tests, and the ability to obtain valid data without the need for having the entire system available. Such tests are usually conducted in the laboratory during the Demonstration and Validation Phase and early in the Engineering and Manufacturing Development Phase when much data are needed to verify the design. An advantage to conducting these tests during the early stages of development is that if the design is found to be inadequate, hardware changes can be made inexpensively and the item retested. During performance of the tests, the component and/or subsystem under study is mounted in a fixture simulating tactical conditions and is instrumented to provide the operational parameters sought. The tests can be performed at ambient temperatures or at other temperatures deemed appropriate for the investigation being conducted. In addition to providing operational data, tests of this type are also useful in providing ruggedness and safety data on the component and/or subsystem level. For items that have to be purchased commercially, e.g., electronic components, these tests are useful in establishing the specification controls that will be used in screening the items.

Although some system and near-system configurations are tested during development testing, most of the system tests are conducted in PPT just prior to the Milestone III decision point. Testing of two subsystems is discussed in the paragraphs that follow.

14-2.1.1.1 Explosive Components

The explosive train is a key functional subsystem of the fuze. (See Chapter 4 for a detailed discussion of explosive trains.) On application of initiation energy (electric or percussion), the primer or initiator, detonator, and lead all actuate in sequence and transfer energy to initiate the booster, which in turn initiates the main charge. During development testing there is a need to determine the input parameters required to initiate an explosive component reliably and the output parameters resulting from actuation of the explosive component. For electroexplosive devices the initiation energy is computed from the appropriate combination of the applied electrical parameters. For percussion devices the initiation energy is equated to the drop height of a known mass striking the firing pin or anvil of the device. The output of these devices is measured by any of a number of well-established tests. Among these are the gap or barrier test, sand test, copper-block test, lead-disk test, steel-plate dent test, Hopkinson-bar test, and a pressure-time measurement test (Ref. 4). The test data are used to establish the firing sensitivity and output parameters for the intended application of the fuze.

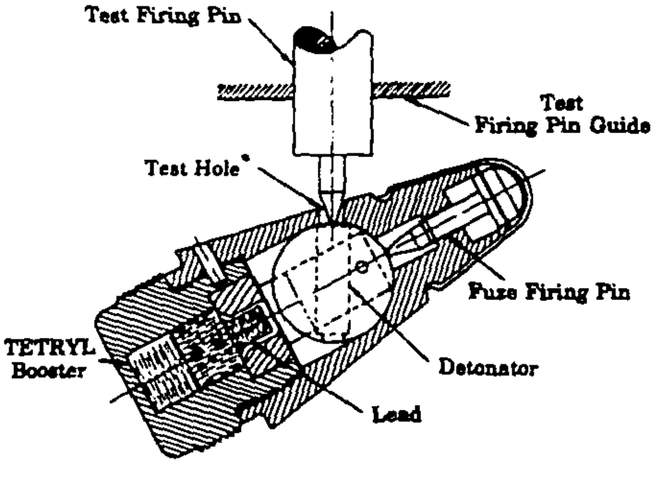
Explosive train subsystem tests are performed to determine whether each component in the train will be initiated reliably and the final component has sufficient output to initiate the booster reliably. To perform the tests, the explosive components are assembled in line (in the armed position) in either a fuze body or test fixture. The first element of the explosive train is actuated on application of the proper electrical or mechanical input, and the explosive train is allowed to function. After the test the system is inspected for complete firing train performance. For fuzes employing delay elements, it is necessary to measure the delay firing time of the train.

The explosive safety tests are performed to determine whether the rest of the explosive train will be safe when the first element is initiated in unarmed positions. In this test the effectiveness of the out-of-line safety feature, or interrupter, of the explosive train can be evaluated by firing the first explosive element in the fully unarmed position and at intermediate positions between the fully armed and the fully unarmed positions. It is not sufficient to rely on tests only in the fully unarmed position or only in intermediate positions. Both modes of testing must be accomplished. Fig. 14-3 presents an arrangement for the explosive safety test.

Fig. 14-4 presents an evaluation program for an electric detonator. The program consists of initial characterization tests, which include visual inspection, X ray, leak tests, electrical tests, single and serial environmental tests, safety tests, electrical sensitivity tests, and output tests. The leak and electrical tests are also performed before the output tests to ensure that the previously applied tests have not damaged the samples. X rays are performed at any point in the program that indicates degradation of performance; degradation is determined by study of the X rays and comparison with the initial X rays.

14-2.1.1.2 Arming and Firing Devices

The performance characteristics of fuze devices, which require the forces and energies associated with the dynamic deployment environment to accomplish the arming and firing functions, can be determined in the laboratory using simulation techniques. The following test equipment is used



*This hole is drilled in fuze body to initiate the detonator in the unarmed position.

Figure 14-3. Arrangement for Detonator Safety Test

for this purpose: centrifuges, high-speed spin machines, drop testers, air guns and launchers. This test equipment normally simulates only one aspect of the dynamic environment, but in most cases this is adequate for the investigation being conducted. Test equipment does exist, however, that can, in one test, program accelerations to simulate the launch, vibration, and target-impact phases of rocket-launched weapons and the setback, spin, and drag phases of gun-fired weapons. These combined environment tests are normally performed on a systems basis. As with explosive components, the arming and fuzing devices are environmentally conditioned at selected levels of temperature, humidity, and vibration prior to or while undergoing the simulation tests. The various test equipment is described in par. 14-2.1.5.

14-2.1.2 Destructive, Aggravated, and Nondestructive Testing

The tests conducted during development can generally be characterized as destructive, aggravated, or nondestructive. A discussion of each type, with examples, follows:

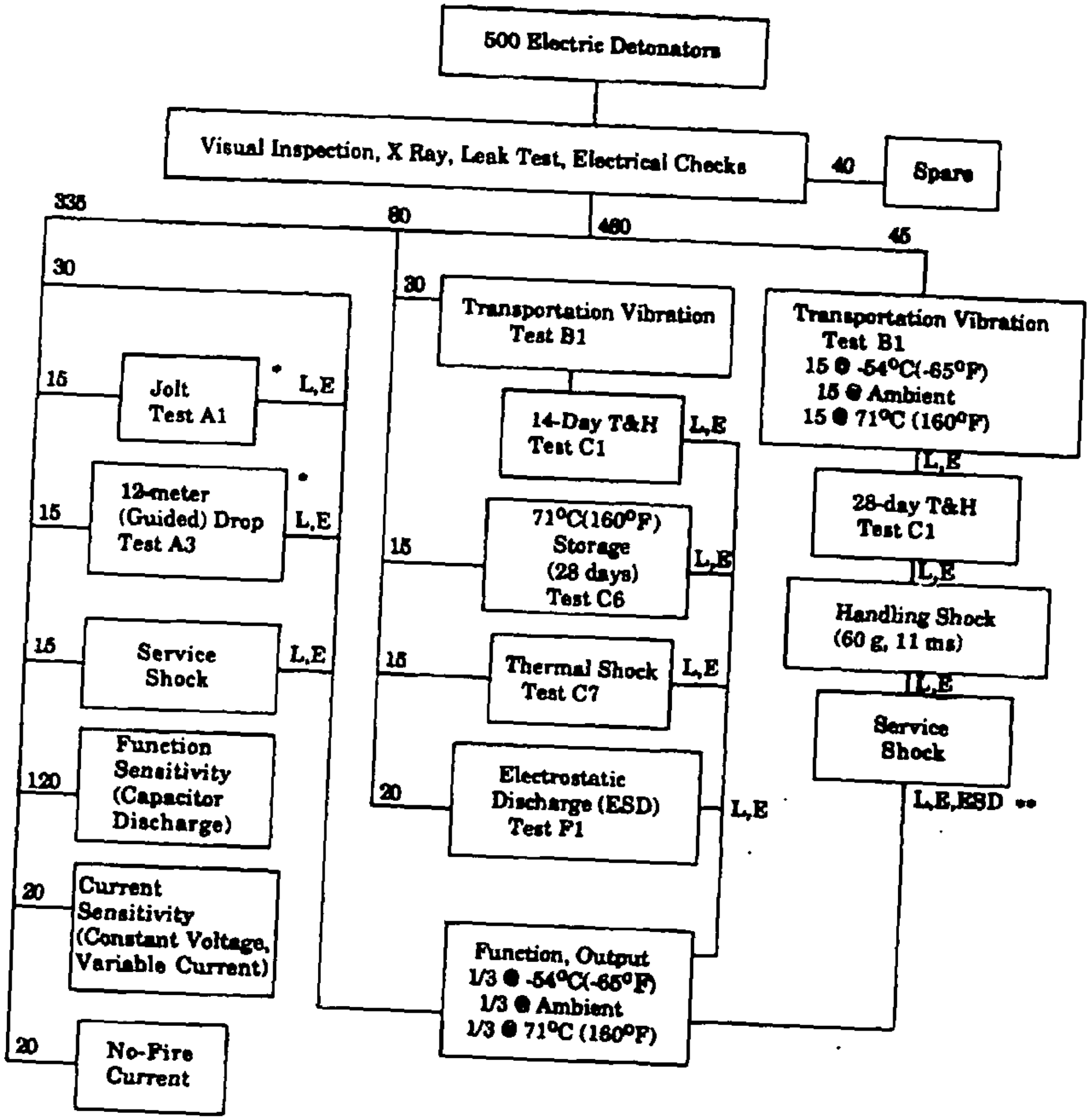
1. *Destructive Tests*. Destructive tests usually fall into two categories: (1) those tests, such as field firings, during which selected fuze characteristics are determined by instrumentation, but the fuze is destroyed by the terminal conditions and (2) those tests, such as Jolt, Jumble, and 12-Meter (40-Foot) Drop (MIL-STD-331 Test Nos. A1, A2, and A3, respectively) in which the fuze is not required to be operable but must be safe to handle and dispose of.

2. *Aggravated Tests*. Aggravated tests are those tests in which the imposed conditions are judged to be more severe than the conditions expected in normal service use yet are not as severe as the destructive test conditions. The tests are performed to determine the design margin or to induce failure purposely in order to determine "weak" elements. There are two general ways in which these tests are performed. In one, repeated cycles of a nondestructive test are applied and the test item is monitored for performance. For example, two complete cycles of the MIL-STD-331, Test No. C1, Temperature and Humidity, are sometimes performed to gain added confidence that the fuze will be satisfactory in unlimited service use. In the other, the severity of the test is increased in steps until the fuze fails or degrades significantly. For example, if the simulation of gun-launched shock were the environmental test of interest and 1000 g were the normal service condition, the tests might be run in 250-g increments starting with 1000 g. A different type of aggravated test would be one in which a redundant safety or reliability item were intentionally removed to determine whether the remaining item would still provide adequate performance. An example of this type of testing would be subjection of the fuze to rough handling shock tests with one of two independent locks of the out-of-line device intentionally removed. (This test is sometimes referred to as a subverted safety test.) If the one lock were found adequate to maintain the out-of-line integrity, considerable confidence would be gained that the fuze would remain safe during the rough handling that might occur during service use. Some aggravated test programs can result in reduced test time and/or reduced sample size over programs conducted at normal levels.

3. *Nondestructive Tests*. Nondestructive tests are those tests in which the imposed conditions are judged to be no more severe than the conditions expected in normal service use. The fuzes are required to survive the imposed conditions with essentially no degradation in performance or safety. Examples of these tests are Transportation Shock and Vibration and Tactical Vibration (MIL-STD-331 Test Nos. A5, B1, B2, and B3). Nondestructive tests are often programmed serially to simulate the cumulative effects of the manufacture-to-target environments. Even under these conditions the fuzes are required to have no degradation in performance or safety.

14-2.1.3 MIL-STD-331 Tests

MIL-STD-331 (Ref. 1) is the primary test standard for fuzes and fuze components. It establishes uniform environmental and performance tests for use during development and production. The purpose of the tests is to provide information on the ruggedness and operation of the fuze during and after subjection to natural and induced environmental conditions of military application. In a broad sense this standard applies to all fuzes; however, not all tests are applicable to all fuzes. It is the responsibility of the test planner to choose the individual tests of this standard that are applicable to the fuze being tested. The tests of MIL-STD-331 cover only those conditions that are recurrent and suffi-



*Output tests are conducted for information only. Proper function is not required.

**Test five from each of the three vibration temperature groups.

NOTES: Test numbers refer to MIL-STD-331.
L denotes leak test. E denotes bridge wire and insulation resistance measurements.
ESD denotes electrostatic discharge.
Detonator output is measured by the dent made in a steel block, a pressure bomb test, work done in a fixture, or the ability to reliably initiate another explosive component under penalty conditions. Function time data can be recorded if necessary.

Figure 14-4. Electric Detonator Evaluation Test Program

Communication with and monitoring of the specimen during a test is possible through slip ring assemblies. Some centrifuges provide compressed air through the vertical shaft to power pneumatically operated devices while under test.

Centrifuges can be designed to impose a number of forces in a programmed manner. For example, the Naval Surface Warfare Center (NSWC) 10-Foot Centrifuge (Ref. 5) has provisions for combining certain accelerations with the standard centripetal acceleration. Fixtures have been made to produce other effects experienced by a component of a particular missile. For example, a pneumatic hammer device introduces vibration to the specimen, an air-powered crank mechanism produces cyclic yawing motion transverse to the axis of the arm, and a special hinged arm and turntable assembly permits the specimen to change its orientation quickly from the insensitive to the sensitive axis with respect to acceleration. (Turntables can be used with other centrifuges to effect a relatively fast buildup time.) Other combinations of environments can also be accommodated.

A number of special purpose centrifuges exist in various fuze development laboratories; of particular interest to designers are the 10,000-g and 60,000-g centrifuges at Harry Diamond Laboratories (HDL), which are used for fuze performance measurements (Ref. 6).

14-2.1.5.2 High-Speed Spin Machines

The purpose of spin machines, or spinners as they are often called, is to evaluate spin-armed fuzes or components of these fuzes by subjecting them to spin rates encountered in service. This type of fuze is used in rifled-tube ammunition. Various versions of the spinners exist in the fuze community. In general, the basic spinner consists of a rotor to which the fuze or fuze component is mounted and a power system to drive the rotor. The test normally consists of spinning the rotors to a predetermined rotational velocity and determining whether arming occurred. Typical maximum spin rates are 15,000 to 30,000 revolutions per minute (rpm). During the fuze development, spinners are also used to corroborate design calculations by testing for the minimum spin-arming rate. The effects of eccentricities in the spin axes can also be determined on these machines. Spinner tests are essentially "static" tests because the rate of spin buildup is very slow compared to actual operational conditions. The tests, however, are useful in determining whether production quality is maintained.

The Fuze Arm Spin Test System (FASTS) (Ref. 7) not only spin arms the fuze but also has provisions for firing it. Firing of point-detonating fuzes is by the programmed release of an impactor designed to strike with sufficient energy to actuate the fuze. For those fuzes requiring electrical energy for firing, the brush-slip ring assembly of the FASTS is used to transmit power from the test console to the electrical leads of the primer.

14-2.1.5.3 Air Guns

Air guns are of interest to fuze designers to simulate shocks associated with projectile firing, target impact, and guided missile and rocket launching. Air guns are used in two modes: (1) closed muzzle gun (shock tester shown in Fig. 14-5(A)), in which the test item is accelerated to the desired shock value, and (2) open muzzle gun, in which the test item is propelled to a specified velocity and allowed to impact selected media external to the gun thereby producing the desired shock. Two variations of the open muzzle technique are used. The objective of the first variation, shown in Fig. 14-5(B), is to produce a shock having a prescribed magnitude; a calibrated stopping mechanism is used for this purpose. This variation is classified as a shock tester. The objective of the second variation, shown in Fig. 14-5(C), is to simulate field conditions; stopping materials having the dynamic properties of field materials are used. This variation is classified as a launcher. The guns are referred to by their bore size.

Regardless of bore size, all air guns used in the closed muzzle mode employ the same principle of operation, which is to accelerate a piston containing a test object down the length of a closed barrel by means of high-pressure air. A typical firing sequence begins with loading the piston with the test object installed into the gun barrel. The barrel is sealed and the piston seated into the release mechanism in front of the breech chamber. The release mechanism holds the piston securely in place until the air pressure to produce the desired acceleration is built up in the breech chamber. The release mechanism is then actuated and frees the piston and allows the air charge to accelerate the piston along the length of the barrel. As the piston moves ahead, the pressure in the muzzle increases while that of the breech diminishes. A point is reached at which the air pressure in front of the piston becomes great enough to slow, stop and accelerate the piston in the opposite direction. The process is repeated until the energy of the shot is expended in the form of friction. The deceleration peak is somewhat less than 10% of the maximum peak.

The use of compressed air as the acceleration medium allows air guns to produce greater velocity changes than are possible with drop testers, which operate using the acceleration due to gravity. This, in turn, produces a much better simulation for testing fuzes to launch and impact conditions that can be obtained with velocity-limited shock testers. For bores of 0.381 m (15 in.) or more, peak accelerations of 2000 g or more are possible for test specimens with a mass of 4.5 kg (10 lbm). Electrical measurements during the shock test are possible if electrical cables are used.

Of particular interest to fuze designers are the NSWC 2-in. and 5-in. air guns (Ref. 5), the HDL 2-in. and 3-in. artillery simulators and the 4-in. and 7-in. setback simulators (Ref. 6), and the US Army Armament Research, Development, and Engineering Center (ARDEC) 2-in. and 5-in. air

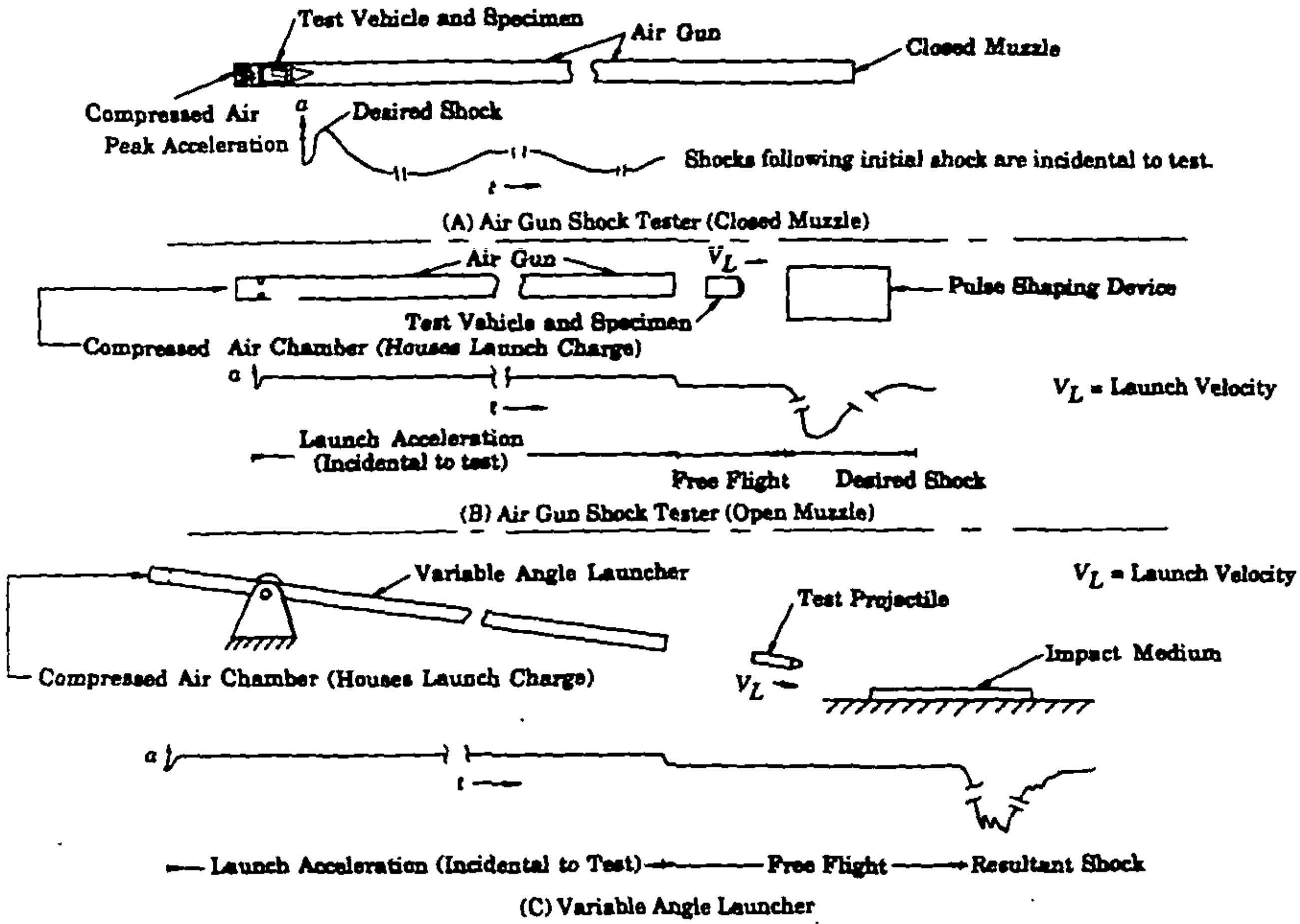


Figure 14-5. Air Guns and Launchers

guns and 155-mm gas gun. These facilities are used primarily to test ballistically fired fuzes for the effects of the setback environment. The NSWC guns act as closed muzzle, shock testers subjecting the test specimens to the desired acceleration on release of air pressure. Peak accelerations of 48,000 g and 28,000 g are attainable for 0.45-kg (1-lbm) and 2.27-kg (5-lbm) test specimens, respectively, in the 5-in. gun. The peak acceleration is reached in approximately 0.1 ms and decays to zero in 1.5 to 6.0 ms. When using a spin adapter, spin rates of up to 110 revolutions per second (rps) and angular accelerations to 480 krad/s^2 at 20,000-g setback are attainable for light payloads. (See Fig. 14-6.) The spin adapter for the NSWC 5-in. air gun is shown in Fig. 14-7.

The HDL guns act as open muzzle, shock testers accelerating the fixture containing the test specimen to a predetermined velocity; the shock is obtained when the fixture is allowed to impact a stopping device calibrated to produce the desired acceleration level. The HDL 2-in. and 3-in. guns also have provisions to impart spin on impact. Peak spin rates of 300 rps can be obtained, and associated peak accelerations are 500 to 10,000 g for the 3-in. gun. Most setback simulation tests in the 4-in. gun are performed at less than 35,000 g; however, peaks to 100,000 g are possible. The 7-in. gun is capable of producing peaks of 20,000 g with 13.6-kg (30-lbm) payloads.

The ARDEC guns operate by accelerating a piston containing the test object in a gun barrel by means of high-pressure gas. The 2-in. and 5-in. air guns use the "diaphragm" method of firing, whereas the 155-mm gas gun, which is rifled, uses the "metering sleeve" method, which provides a longer acceleration pulse. The 2-in. gun is capable of producing peak amplitudes of 200,000 g with a rise time of 0.20 ms, the 5-in. gun can produce a peak amplitude of 50,000 g with a rise time of 0.25 ms, and the 155-mm gas gun can produce a peak amplitude of 16,000 g with a rise time of 2.0 to 8.0 ms.

14-2.1.5.4 Launchers

A typical air-gun launcher consists of a barrel, compressed air source, release mechanism, and the medium to be impacted. The test specimen is mounted in an appropriate test vehicle and placed in the breech of the gun. When the air pressure is built up to the proper value, a release

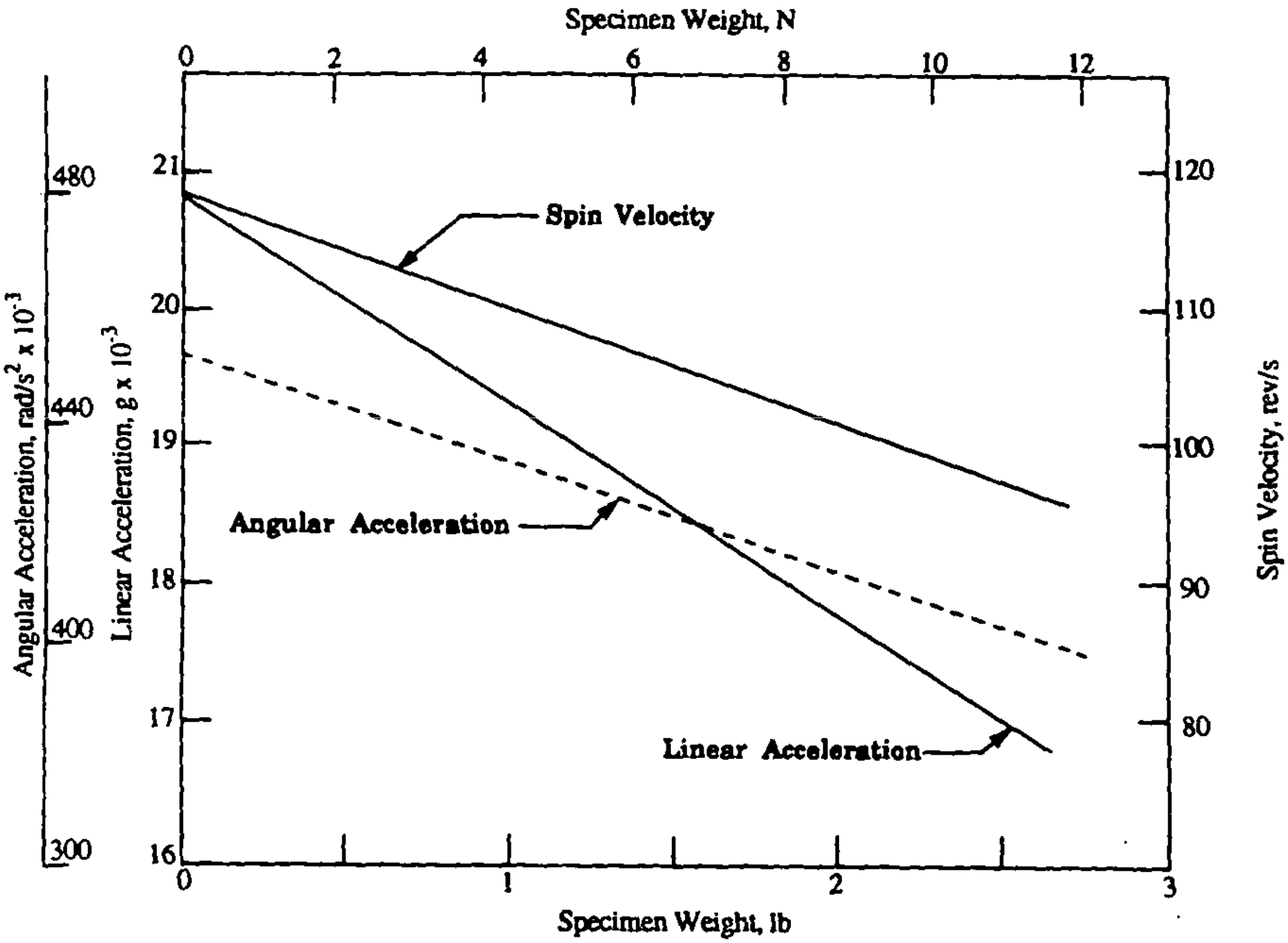


Figure 14-6. Naval Surface Warfare Center 5-in. Air Gun Setback-Spin Characteristics

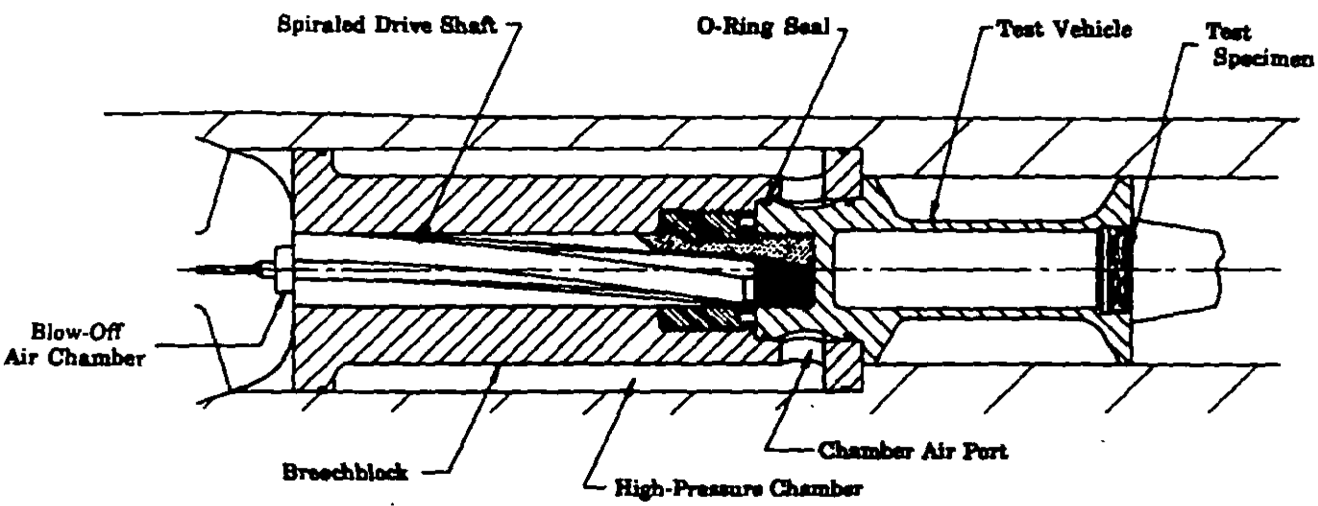


Figure 14-7. Setback-Spin Adapter for Naval Surface Warfare Center 5-in. Air Gun

mechanism is actuated and the test vehicle is released and allowed to accelerate down the length of the barrel. After exit from the barrel, the test vehicle is allowed to impact the selected medium. The free flight of the specimen and the impact can be studied by means of high-speed photography and video techniques. Except for high velocities, trailing cable instrumentation is possible. In tests of this type, it is necessary to keep the accelerating forces low in comparison with the terminal forces. Launchers have been designed (Ref. 5) to produce velocities up to 335 m/s (1100 ft/s) for a 2.3-kg (5-lbm) projectile.

14-2.1.5.5 Recovery Methods

During the course of a test and evaluation program, sometimes it is desired to recover a gun-fired fuze without any significant shock imparted to it beyond that of projectile launch. A number of techniques have been developed for this purpose. At NSWC, Dahlgren, VA, projectiles are fired into two armor-clad, tandem boxcars loaded with sawdust, which provides the stopping mechanism for the projectile. A second technique employed at NSWC is to fire a projectile from the launching gun across a small gap into a long tube made of a series of 5-in./38 gun barrels attached in tandem. The movement of the projectile in the tube compresses the air ahead of it, and eventually the compressed air brings the projectile to rest. Both of these techniques have been used with some success. A third technique used is called vertical recovery. For this, the projectile is launched vertically, reaches its peak, descends vertically (tail first), and impacts earth. The impact point is spotted, and the projectile recovered. For this technique the stopping shock is considerably smaller than the launch. A variation of this technique employs water or mud rather than earth as the stopping medium. Vertical recovery has been used with considerable success. A fourth technique developed by NSWC, White Oak, MD, employs a two-stage parachute recovery system, which was developed specifically for 5-in./54 caliber projectile fuzes so that they could be recovered and studied following actual gun firing. The recovery round may be fired at any gun elevation angle between 2.7 and 90 deg. Recovery may be initiated by the user at preset times between 5.5 and 45 s, at which time the fuze recovery package is initiated. The first-stage canopy of the recovery system retards the velocity of the projectile to approximately 113 m/s (370 ft/s). Following a 2.3-s delay, the main canopy deploys and further retards the impact velocity of the fuze to approximately 9.1 m/s (30 ft/s). Fig. 14-8 is a sketch of the round and Fig. 14-9 depicts the chain of events. Ref. 8 describes three distinct parachute systems used for gun firing and soft recovery of XM517 projectile hardware. The three are designed to provide soft recovery for (1) complete projectile body, (2) nose-fuze and telemetry section, and (3) a canister having selected electromechanical components.

14-2.1.5.6 Wind Tunnels

Air-actuated or air-induced fuze functions can be studied using wind tunnels. For these tests the fuze is mounted in the wind tunnel in a manner simulating service conditions, and the air velocity is slowly increased until the function is effected. By testing a number of fuzes, the threshold air velocity to effect the fuze function can be characterized on a statistical basis for the design being studied.

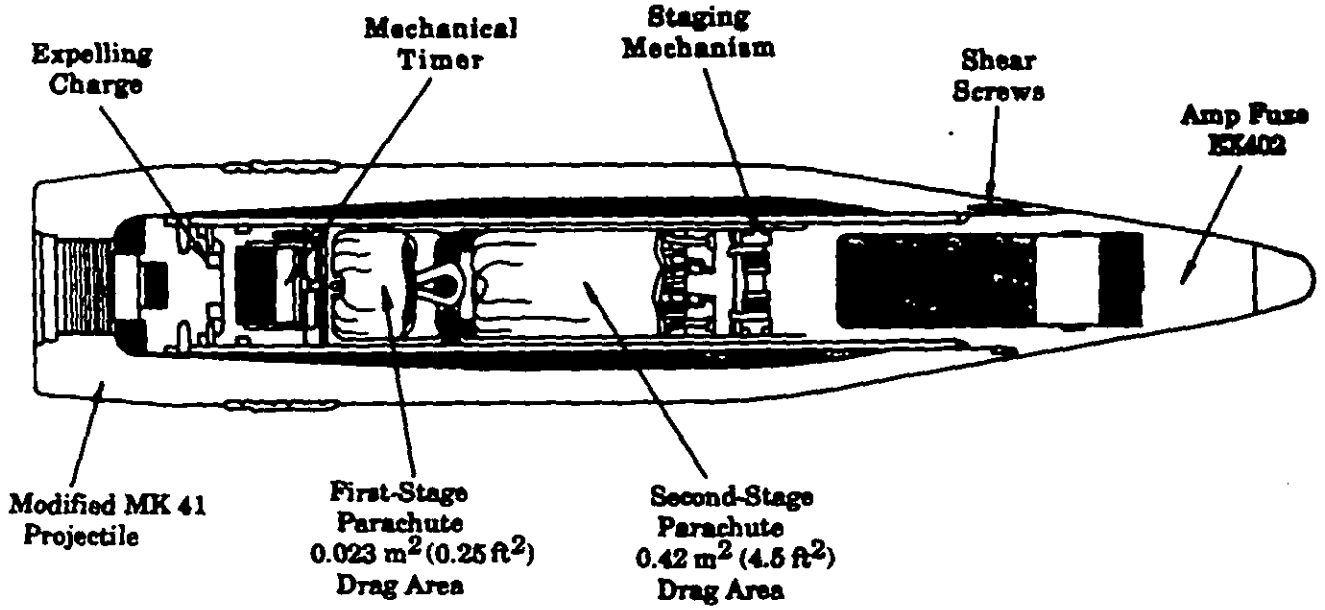


Figure 14-8. Parachute Recovery Round for 5-in./54 Guns

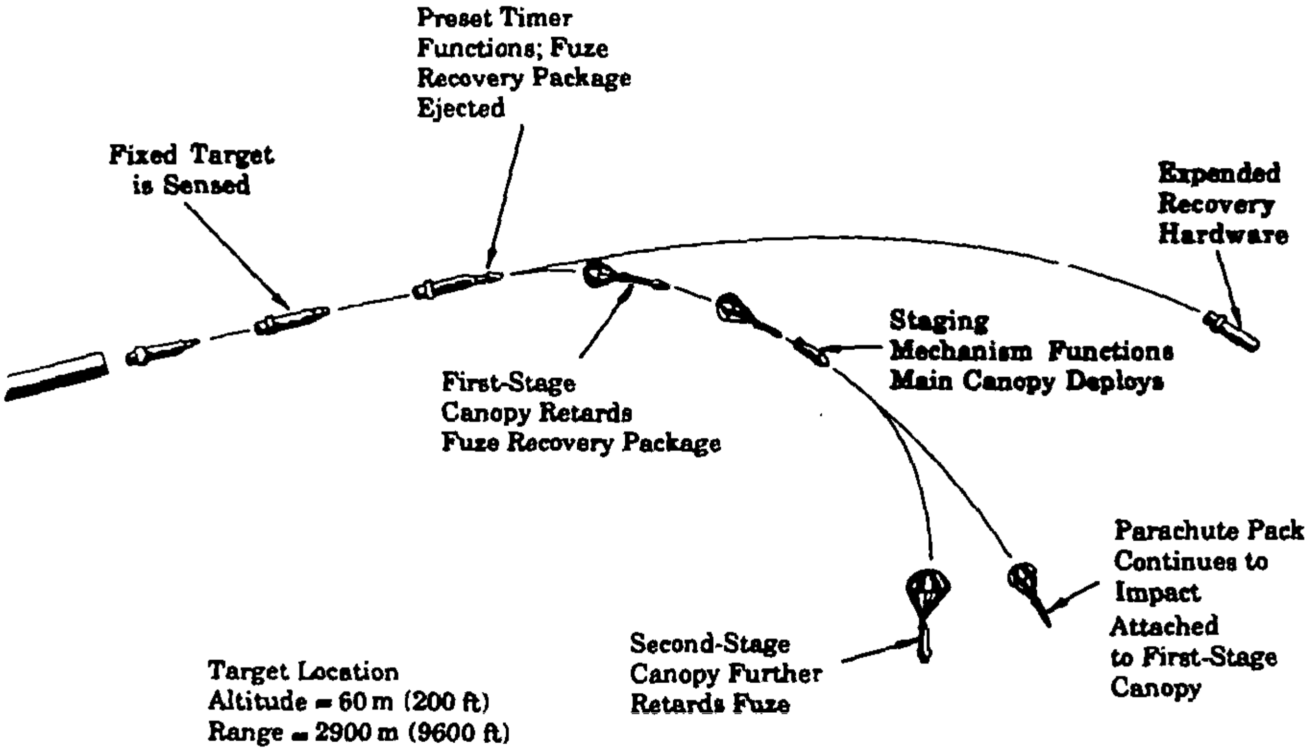


Figure 14-9. Parachute Recovery Sequence of Events

14-2.1.5.7 Rocket Sleds

Rocket sleds are used to accelerate fuzes to service velocities in order to study terminal impact phenomena. The fuze is mounted in its projectile, or another vehicle simulating tactical conditions, accelerated to the desired velocity by the sled, and then released from the sled and allowed to impact the preselected medium placed at the desired impact area. Fuze functions and impact conditions are measured using on-board recorders, telemetry, photography, or combinations of these. Because sled tests are expensive and difficult to run, they are performed only when there is no other way to obtain the required information.

14-2.1.5.8 Telemetry and On-Board Recorders

Telemetry and on-board recorders are used to measure fuze functions and environmental parameters. Although telemetry has been in use for many years and the techniques for accomplishing the measurements are well-established, they are still in the realm of the specialist. Fuze developers usually coordinate with range personnel to plan the measurements and rely on them to perform the telemetry. Recent developments by the Armament Test Laboratory at Eglin Air Force Base have resulted in solid-state technology on-board recorders that are shock hardened to gun-firing acceleration levels and have a 20-kHz frequency response with four analog and four digital event channels. Unlike the telemetered test vehicle, recovery of the test vehicle containing the on-board recorder is necessary in order to retrieve the data.

At Picatinny Arsenal, recoverable digital memories have been developed and used to instrument inert artillery projectiles. The modules are designed to withstand ground impact after full trajectory firings and to be recovered for data retrieval. They are small, lightweight, extremely rugged, easy to use, and require no modification to projectile bodies for antennae, access holes, etc.

14-2.1.5.9 Visual Indicators

For those gun-launched tests performed to determine whether the fuze did arm, visual indicators can be used effectively. The fuze is modified so that upon arming, a flash or smoke puff is emitted. Spotters and photographic coverage are used to detect the visual indication. Thus arming time can be derived.

14-2.1.6 Electromagnetic Effects (EME)

The electromagnetic (EM) environment is defined as the totality of all the EM energy (radiated and conducted) to which the fuze will be subjected during its life. If the fuze is unprotected, the EM environment has the potential to fire electroexplosive devices (EEDs), destroy transistors, and cause electronic circuits to malfunction. Since EEDs are used to initiate explosive, propellant, and pyrotechnic devices and electronic devices are used to perform a number of functions, some of which are concerned with safing, arming, and firing, spurious actuation of EEDs and/or changes in the performance characteristics of electronic circuits could result in serious degradation of safety and reliability. Depending on the degree of degradation, these undesired actions can range from injury to personnel or damage to material to degradation of fuze performance beyond acceptable tolerances. Because of the potential seriousness of the problem, some specifications concerned with EME carry the statement that EEDs shall not be used when the functional requirement can be met by other equally cost-effective means.

The Electromagnetic Evaluation Section of the ARDEC has a technical staff and facilities available to help fuze designers meet the EME requirements (Ref. 9). The recommended approach is to employ an EME specialist early in development to address the EME requirements and thereby avoid expensive and less-than-optimum retrofit protection that may be needed when it is found that the design does not meet the EME requirements. Ref. 9 also suggests that the EME specialist be called on to participate in developing requirements documents, test plan reviews, tests, and the various review stages of the development.

The seven EMEs discussed in Ref. 9 should be considered during development of each fuze. They are radio frequencies (RF) susceptibility, lightning susceptibility, electrostatic discharge, electromagnetic pulse (EMP), electromagnetic interference/electromagnetic compatibility (EMI/EMC), electronic countermeasures/electronic counter-countermeasures (ECM/ECCM), and electromagnetic fields inadvertently emanating from operating equipment (TEMPEST). The degree of attention each of these effects receives from the developer is normally determined by the criteria delineated in the requirement document for the item. The developer should be aware, however, that protection from EME can frequently be designed into the system at little or no cost by careful choice of components and configuration. The potential EME susceptibility of a fuze will increase as wires are attached or the fuze is mounted on a munition because these actions increase the receiving effectiveness of the fuze antenna; susceptibility evaluation tests should consider this phenomenon.

14-2.1.6.1 RF Susceptibility

Principal sources of RF energy are radars and communications equipment. To exacerbate the problem, the trend for this equipment is to generate even higher radiated power in the future. Information for Army applications on the maximum field intensities of concern and guidance for developing tests are provided in Ref. 10. Ref. 11 is a Navy handbook that provides electromagnetic environment considerations for the protection of military electronics from the adverse effects of the electromagnetic radiation environment. RF hazard tests are performed to evaluate the susceptibility to premature detonation of firing circuits containing EEDs during the various logistic and deployment phases of the fuze. The Army RF hazard field intensity certification levels, "TAG criteria", are presented in Table 14-3.

Both reliability and safety of EEDs are of concern. The accepted Army safety factor for hazardous conditions is 10 dB and for reliability it is 6 dB.

Ref. 9 cities the following paragraph as an example of how the safety factor is applied:

> "Consider an EED that has a no-fire current of 200 milliamperes. No-fire current is defined as that level of current that will not fire this EED 99.99% of the time, with a 90% confidence level. For example, if premature detonation of this EED would cause a safety hazard, applying the 10 dB safety factor defines a current ratio of 3.13. This means 200/3.13 or 63.90 milliamperes is the maximum safe current that may be induced in the EED when subjected to any of the field intensities shown...". (Applicable data are shown in Table 14-3.)

If the fuze is to be used in Navy applications, the requirements of MIL-STD-1385 (Ref. 12) must be met. Similarly, if the fuze is to be used in Air Force applications, the requirements of MIL-STD-1512 (Ref. 13) must be met.

14-2.1.6.2 Lightning Susceptibility

As part of their life exposure, fuzes may be subjected to lightning. MIL-STD-1757 (Ref. 14) presents test techniques for this environment. Fuzes are normally subjected to pulses of current having peak amplitudes of 200 kA and time durations of less than 500 μs. Assessment criteria are that the fuze should not create a safety hazard after undergoing a

TABLE 14-3. RF HAZARD SUSCEPTIBILITY CRITERIA ("TAG CRITERIA") (Ref. 9)

FREQUENCY	CW* FIELDS, V/m		PEAK FIELDS, V/m	
	Vertical	Horizontal	Vertical	Horizontal
100 kHz to 10 MHz	100	10	200	200
10 to 100 MHz	100	100	200	200
100 MHz to 18 GHz	100	200	20,000**	20,000**

*CW = Continuous wave

**Design goal, not a test requirement

direct strike and that the fuze should remain safe and reliable after undergoing a near strike—10 m (33 ft)—exposure.

14-2.1.6.3 Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC)

Interference may exist between electronic equipment in a system, vehicle, etc. For example, operation of the communication transmitter may interfere with a fire control system. Also either system may radiate excessively. Complete performance and test requirements are specified by MIL-STDs 461 and 462 (Refs. 15 and 16).

14-2.1.6.4 Electronic Countermeasures/Electronic Counter-Countermeasures

Munitions or weapon systems could be susceptible to jamming by enemy actions. Criteria to withstand jamming are specified by the Office of Missile Electronic Warfare (OMEW), White Sands Missile Range (WSMR), NM.

14-2.1.6.5 TEMPEST

Electromagnetic fields inadvertently emanating from operating equipment, such as electronic typewriters, computers, and computer terminals, could allow interception of classified information by unauthorized persons. Leakage other than electromagnetic is also of concern to the military. Standards are specified in accordance with Ref. 17.

14-2.1.6.6 Electrostatic Discharge (ESD)

Electrostatic discharge (ESD) background information and test procedures for fuzes are contained in MIL-STD-331, Test F1 (Ref. 1). Two sources of ESD are considered: energy stored on a human being and energy stored on hovering aircraft used in vertical replenishment. Test F1 presents test procedures for both conditions and the associated fuze configurations. The test series consists of discharging fully charged capacitors onto designated test points, and three procedures are used. Procedure I tests are conducted on bare fuzes to evaluate safety and operability. Procedure II tests are conducted on fuzes in their packaged configuration to evaluate safety and operability. Procedure III tests are conducted on bare fuzes to evaluate safety only. For Procedure I the discharge through a resistor (either 500 or 5000 ohms) of a 500-pF capacitor charged to 25 kV is used; this condition represents the upper-bound hazard posed by human beings. For Procedures II and III the discharge of a 1000-pF capacitor charged to 300 kV is used; this condition represents a typical upper-bound hazard posed by helicopters and other hovering aircraft.

14-2.1.6.7 Electromagnetic Pulse (EMP)

The pulse that occurs as a result of a nuclear burst is referred to as an electromagnetic pulse (EMP). It is characterized by a short duration and high intensity. Its effects on the disruption of communications are well-known; it can, however, also affect the safety and reliability of fuzes. Simulation tests are performed in accordance with Ref. 18.

14-2.1.7 Rain

Point-detonating (PD) projectile fuzes, unless protected, are susceptible to downrange prematures when fired during heavy rains. This mode of malfunction is due to the increased sensitivity of the PD fuze, which is caused by the erosive action of the high-velocity, fuze-raindrop impacts. This phenomenon has been reproduced at Holloman Air Force Base, Alamogordo, NM, by mounting PD fuzes on sleds and rocket propelling the sleds through simulated rain fields. The rain fields were created by placing water-spray nozzles parallel to the sled track at suitable heights and angles and pressurizing them to produce the desired number and size of water droplets. Because the rain-exposed section of the track facility is considerably shorter than the service flight of the PD-fuzed projectile, it was necessary to compensate for the shortened exposure by increasing the number of large raindrops (greater than 4 mm (0.16 in.) in diameter) in a linear manner, i.e., if the rain-exposed portion of the rocket test is one-fifth the service flight, then five times the number of large raindrops that would be experienced in service is needed for the test. Tests have been run at velocities of 457 to 823 m/s (1500 to 2700 ft/s) to correspond to projectile service conditions. Using similar rain-producing techniques, test firings have also been made with cannons instead of sleds at Holloman Air Force Base. The Supersonic Naval Ordnance Research Track (SNORT) at the Naval Weapons Center, China Lake, CA, is also equipped with a rain simulator (Ref. 19).

Changes have been introduced into PD fuze designs that significantly reduce the probability of downrange premature firings. The design changes are described in par. 1-5.1.

14-2.1.8 Bullet Impact and Cook-Off Tests

The governing specifications for bullet impact and cook-off tests are DOD-STD-2105 (Navy) (Ref. 3) and MIL-STD-1648(AS) (Ref. 20), respectively. These tests are performed on a systems basis, and although the investigations are concerned primarily with the performance of the explosive, the fuze, nevertheless, is an integral part of the test.

The bullet impact test is performed to evaluate the response of major explosive subsystems to the kinetic energy transfer associated with the impact and penetration by a given energy source. In this case the source selected is a 20-mm, M95 armor-piercing (AP) projectile fired at service muzzle velocity at a range of 30 to 70 m (98 to 230 ft) from the test item. Alternate rounds meeting certain criteria may be substituted for the M95 projectile. The impact point on the test item is selected so that the round penetrates the most shock-sensitive material contained within the test unit that is not separated from the main explosive charge by explosive train barriers or other safety devices. Two units are each subjected to this test. High-speed photographic and videotape recordings are used for visual coverage and documentation of the tests. A posttest examination of the recordings and the hardware is made to determine the degree of reaction. Pass-fail criteria are not given per se; however, the results of these and other tests are used by the Navy Weapon System Explosives Safety Review Board (WSESRB) to make a final recommendation for service use.

Two cook-off tests are performed: slow cook off (Ref. 3) and fast cook off (Ref. 20).

The slow cook-off test is performed to determine the minimum payload reaction temperature and to measure the overall safety response of major explosive subsystems to a gradually increasing thermal environment. Two test items are subjected to this test. They are normally preconditioned to a temperature that is 55.5 deg C (100 deg F) below the predicted reaction temperature. The air temperature is then increased at a rate of 3.3 deg C (6 deg F) per hour until a reaction occurs. The temperatures and elapsed time are measured continuously. Cratering and fragment size are measured and documented as an indication of the degree of reaction. As with bullet impact test, there are no pass-fail criteria; the data are used by the WSESRB to make a final recommendation for service use.

The fast cook-off test is applicable to all air-launched weapons used aboard aircraft carriers. The tests are performed to determine the type of reaction that occurs and the time to reaction when the weapon is subjected to an intense fuel fire. Two units are tested individually; the configuration used is that found on the aircraft on the flight deck. Prior to the cook-off test, the projectiles are subjected to environmental preconditioning tests simulating lifetime encounters. The fast cook-off test consists of engulfing the ordnance for at least 15 min in a JP-5 aircraft fuel fire and recording the reaction as a function of time. The flame temperature is to reach 538°C (1000°F) within 30 s after ignition and is to average at least 871°C (1600°F) during the period after the temperature has reached 538°C (1000°F) and all ordnance reactions are completed or until 15 min have elapsed. Closed circuit color TV coverage is used to record each test. The criteria for passing the test are

1. During the first 5 min of the test, the reaction severity should be no greater than that for a burning reaction. This reaction is characterized by the energetic material undergoing combustion with possible opening up and venting of the energetic material enclosure. Burning reactions are acceptable at any time during the test; however, propulsive burning sufficient to launch the test item is not acceptable at any time.

2. After the first 5 min and until the test item returns to ambient temperature, the severity of reaction should be no greater than that for a deflagration reaction. This reaction is one in which the energetic material undergoes rapid combustion and ruptures its enclosure. The item or major parts may be thrown up to 15.2 m (50 ft), but no damage is incurred by the blast effects or the fragmentation.

14-3 ARMY FUZE SAFETY REVIEW BOARD

Every new or product-improved fuze or any existing fuze with a new application must be reviewed and tested, and safety certification obtained before the fuze is permitted to be introduced into the operational forces. The Army Fuze Safety Review Board performs the certification function.

To assist the board in its evaluation, the fuze design organization submits a documentation package, which is reviewed by the board members, and then normally follows the package with a presentation before the board. The contents of the documentation package are related to the complexity of the item under review and the point in the life cycle of the item at which the review is conducted; generally, the later in the life cycle the review is held and the more complex the item, the more voluminous and comprehensive the documentation package will be.

General contents of the documentation package are

1. Drawings and sketches that describe the fuze and/or safety and arming device (SAD) under review (Emphasis should be placed on explosive components and hardware and circuitry affecting explosive safety.)

2. A description of the intended use of the system emphasizing storage areas, usage environment, handling equipment, launching platform, performance sequence, and disposal methods

3. A description of the item safety features, which includes a description of the safety program plan and its results. A list of all safety tests and analyses conducted, which provides test parameters and results, and type and scope of analyses. Information obtained during development, test, and evaluation that bears on explosive safety is presented. Also included is information on all safety devices that have been incorporated as well as the safety precautionary measures to be invoked. The extent to which the item meets the requirements of applicable standards (particularly MIL-STD-1316, *Safety Criteria for Fuzes*), specifications, and safety controls is discussed.

4. Verification that publications required for safe operation, training, packaging and handling, transportation, explosive ordnance disposal, storage, and stowage have been promulgated.

MIL-STD-882 (Ref. 21) provides for a formal safety program that stresses hazard identification and elimination or reduction of associated risk to an acceptable level. Two hazard analyses of primary importance to fuze designers and the review board are the preliminary hazard analysis (PHA) and the system hazard analysis (SHA). The purpose of the PHA (predesign analysis of potential hazards) is to identify the hazards of abnormal environments, conditions, and personnel actions that may occur in the phases before safe separation. This analysis is used as a guide for the preparation of design requirements. The purpose of the SHA (failure mode, effects, and criticality analysis, and fault tree analysis) is to evaluate the safety of the fuze design and, if quantified, the estimation of the safety system failure rates.

14-4 ROLE OF TECOM

TECOM's efforts are in support of technical testing and evaluation (TT&E), and as indicated in par. 14-2, the emphasis of TECOM's mission is independent evaluation. It employs valid data to evaluate test items regardless of where the data are generated. For most nonmajor or designated systems, TECOM provides independent evaluation plans (IEPs), test design plans (TDPs), and independent evaluation reports (IERs) to material developers. (For major and selected nonmajor systems, the US Army Materiel Systems Analysis Activity (AMSAA) provides these plans and reports.) The test and evaluation master plan (TEMP) formalizes all the test and support requirements and responsibilities for each phase of testing and includes the TECOM-generated IEPs and TDPs. TECOM participates throughout the material acquisition process and thereby maximizes the use of valid test data and reduces test time and cost. Representatives of TECOM participate on the developer-chaired Test Integration Working Group (TIWG). TECOM personnel also develop and coordinate threat scenarios with the US Army Training and Doctrine Command (TRADOC) to provide realistic tests. In support of its evaluation function, TECOM provides test facilities and expertise to contractors and materiel developers and monitors contractor-conducted tests to ensure validity of the data. There are nine test agencies subordinate to TECOM including five proving grounds, a missile range, an aircraft development test activity, a cold region test center, and a tropic test center.

14-5 OPERATIONAL TEST AND EVALUATION (OT&E)

Operational test and evaluation (OT&E) is that T&E conducted to determine the military utility, operational effectiveness, and suitability of a system as well as the adequacy of doctrine, operating techniques, and tactics for system employment. The US Army Operational Test and Evaluation Agency (OTEA) is responsible for the Army's OT&E. OTEA employs a continuous process extending from concept definition through deployment to evaluate the operational effectiveness and suitability of a system by analysis of all the available data. This technique is known as continuous, comprehensive evaluation (C^2E). Although OTEA is responsible for the Army's OT&E, it does not conduct the actual testing for all projects; the in-process review (IPR) Category 2 and 3 projects are conducted by a designated test organization.

An objective of OT&E is that it be accomplished in an environment as operationally realistic as possible using operational and support personnel. OT&E information is used to help decision makers at each milestone. Prior to the Milestone I decision, OT&E is conducted to assess the operational impact of candidate technical approaches and to assist in selecting preferred alternative system concepts. Prior to the Milestone II decision, OT&E is conducted to examine the operational aspects of selected alternative technical approaches and to estimate the potential operational effectiveness and suitability of candidate systems. Prior to the Milestone III decision, OT&E is conducted to provide a valid estimate of the operational effectiveness and suitability of the system. The items tested during this phase must be representative of the production items to ensure that a valid assessment can be made of the system expected to be produced. Following Milestone III, OTEA manages the Follow-On Operational Test and Evaluation (FOTE) to ensure that the initial production items meet the operational requirements.

OTEA interfaces with the organization performing TT&E by participating in the test planning, conducting joint tests when the objectives of OT&E and TT&E can be achieved, and reviewing the TT&E results for applicability to OT&E objectives.

14-6 PRODUCT ACCEPTANCE

The procurement of fuzes is accomplished using a detailed design disclosure package, i.e., drawings and specifications. The drawings describe the form and fit of the design, and the specifications cover the functioning of the device and the quality assurance provisions (QAPs) of the design. In short, the specifications define the essential requirements of the fuze and give the procedures by which it will be determined that the requirements have been met. From a test and evaluation standpoint, the QAPs are of greatest concern since they require that the hardware be tested for proof that the requirements have been met. Starting in DT and culminating in PPT, it is necessary that the hardware be checked against the QAPs and a determination be made that the hardware and QAPs are compatible, all essential requirements (reflecting the life of a fuze) and tests are included, all nonessential tests and requirements are eliminated, and requirements for specialized test equipment are reduced to an absolute minimum. With the QAPs so established, they are used to check the quality of production.

The ideal goal of procurement is to accept only perfect fuzes. This would require 100% testing, which, in turn, would be prohibitively expensive and consume an inordinate amount of time. Further, there are some fuze attributes that require destructive testing; consequently, no fuzes would be available for delivery if 100% testing were invoked. To maintain costs and schedules at a reasonable level, less than 100% assurance that fuzes are suitable must be accepted. This requires the establishment of sampling procedures for testing. The fuze designer must determine at what point the combined cost of manufacture and test would be reasonable and still assure the acceptance of good fuzes. MIL-STD-105 (Ref. 22) establishes the statistical techniques that permit the designer to select the optimum sampling. The acceptable quality level (AQL) parameter (the maximum number of defects acceptable) can be stipulated, and MIL-STD-105 can be used to help establish the size of the test sample and specify the number of failures for acceptance or rejection of the lot being sampled. Normally, every effort should be made to select a sample consisting of units of product selected at random from the lot.

In establishing an AQL the most important consideration is the seriousness of the defect. The degree of compromise made with respect to the quality considered acceptable is completely dependent upon this factor. Systems of classifying defects assist in permitting defects of similar natures to be treated alike. MIL-STD-105 lists three principal classifications of defects: critical, major, and minor. These defects are defined in par. 2-3.

With respect to critical defects, the contractor may, at the discretion of the contract authority, be required to inspect every unit of the lot being produced. The right is reserved to inspect every unit submitted by the contractor for critical defects and to reject the lot when a critical defect is found. The right is also reserved to sample the lot submitted by the contractor and to reject a lot if one or more critical defects are found.

14-6.1 FIRST ARTICLE TESTS

First article tests, or production qualification tests as they are sometimes referred to, are conducted on samples from the first lot fabricated by a contractor to demonstrate the adequacy and suitability of the contractor's processes and procedures in achieving the performance that is inherent in the design. Production qualification tests are particularly necessary when a contract is awarded to a new source that has not previously produced the item. The specifications for the item delineate the applicable requirements, tests, acceptance criteria, and AQL. In general, the tests specified are those suitable for production; however, development-type tests may be specified if they are likely to expose inadequate quality of manufacture. A typical production qualification test plan is presented in Fig. 14-10. The tests to be performed by the test activity designated by the contract are shown; not shown are the contractor's inspections that precede these tests. The acceptance/rejection criteria are included in Fig. 14-10. For example, AC-0 means the production lot is acceptable if no failures are witnessed in the designated attribute, and RE-X means that the lot is rejected if x or more failures are witnessed. During inspections the AQL level is set at 1.5% for minor defects and 0.065% for major defects. Any critical defects noted are grounds for rejection of the lot.

14-6.2 LOT ACCEPTANCE TESTS

After it has been determined that the contractor's processes and procedures are adequate and suitable, the emphasis in testing shifts to lot-by-lot sampling inspections. These inspections are conducted in two parts: quality conformance sampling and periodic quality conformance.

Quality conformance sampling tests are performed on the fuzes being submitted for acceptance. Each production lot is sampled in accordance with the designated provisions of MIL-STD-105. Normally, testing is conducted at the contractor's plant or at a testing activity designated by the procurement activity. Selection of the units from each lot should be made in a manner such that the quality of the units will represent as accurately as possible the quality of the lot, and the selections should be made in a random fashion. Of concern in sampling plans is the risk of making a wrong decision, i.e., accepting a bad lot or rejecting a good lot. In general, this risk can be reduced by increasing the sample size. The designer's detailed knowledge of the fuze is necessary to set the AQL that minimizes risk within cost and schedule constraints and yet provides confidence that the required technical information has been obtained. The types of tests specified can vary over a broad spectrum. Included are dimensional checks, operational tests, environmental tests, and field tests. The objective is to select tests that are sensitive to detecting whether manufacturing has degraded the quality of the design. Also the tests selected must have been proven during development.

Periodic quality conformance tests are performed on fuzes from designated lots. The fuzes are normally selected by a Government representative, and the tests are conducted at a Government-designated testing activity.

Examples of a quality conformance sampling test plan and a periodic quality conformance test plan are shown in Figs. 14-11 and 14-12, respectively.

14-7 SURVEILLANCE TESTS

Because fuzes are required to have a long life, it is necessary to check the state of their serviceability periodically. The tests used to accomplish this check are called surveillance tests. Normally included in this category are specification tests at the fuze level, operational tests at the weapon level (including field firings), and inspections and tests on the parts level. The information obtained is used to determine whether changes have occurred in operational characteristics and to detect whether the fuzes are undergoing physical or chemical changes, which could result in reduced capabilities, safety hazards, or failures in the future. The surveillance tests are usually conducted at ordnance depots where the fuzes are in storage; however, if capability does not exist there, the fuzes are transported to appropriate test facilities. Surveillance tests are generally performed at six-month or one-year intervals.

The surveillance test program is a source of reliability data on fuzes and their components after various storage

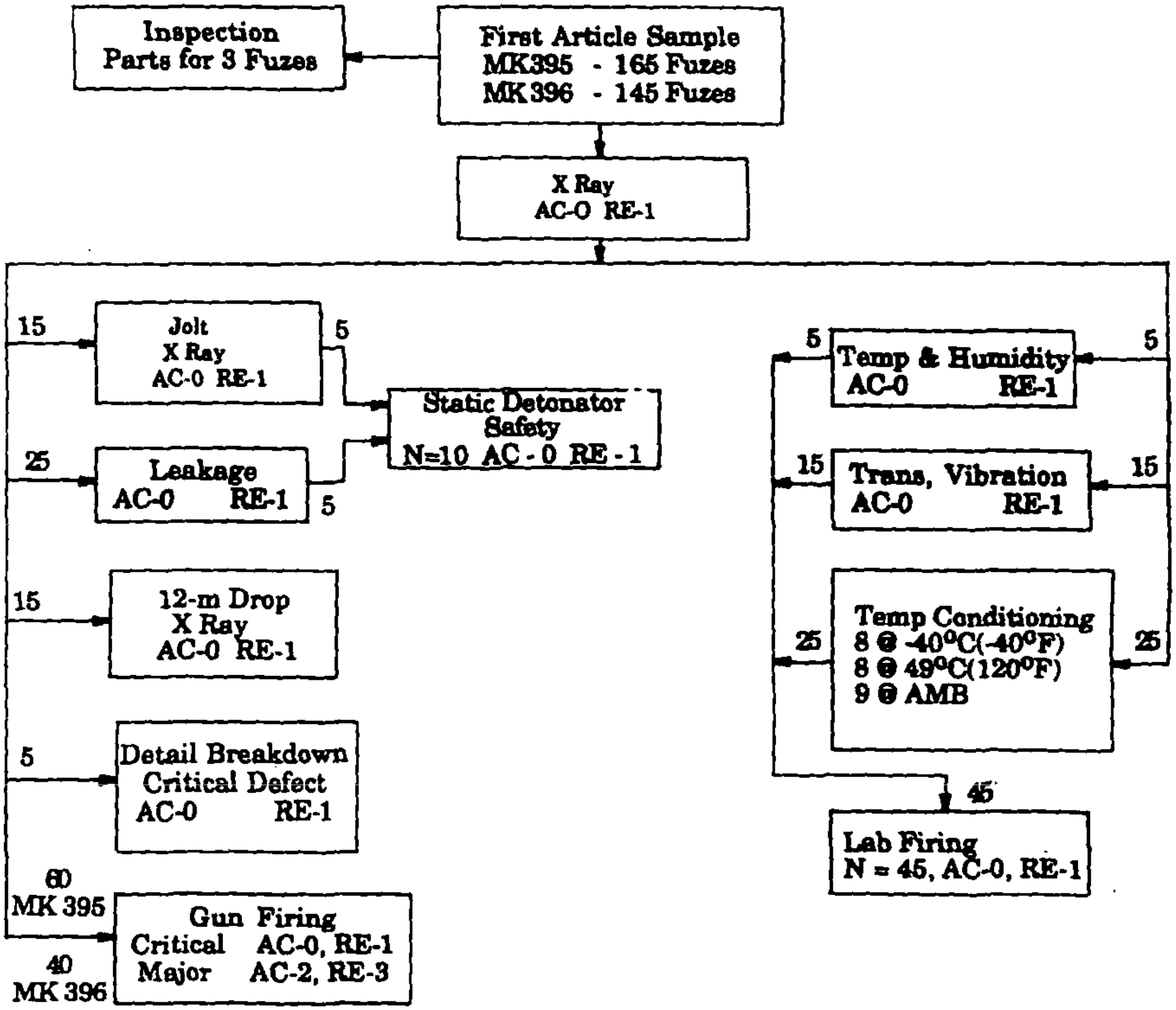


Figure 14-10. First Article Tests for MK 395 MODS 0 and 1 and MK 396 Mode Auxiliary Detonating Fuzes (Ref. 23)

periods. This information can be used by designers for product improvements and future designs and by logisticians to establish acceptance criteria and packaging and storage requirements. Designers can contribute to the effectiveness of the surveillance program by incorporating features in the fuze that facilitate the determination of serviceability, hazards, and rate of deterioration. Inclusion of these features reduces the number of costly field firing tests.

14-7.1 FACTORS AFFECTING SHELF LIFE

The principal factors adversely affecting shelf life are moisture, incompatibility of materials, corrosive atmospheres, and temperature extremes. These factors lead to chemical changes in fuzes, which in time lead to degraded performance. The results of development and surveillance tests on ordnance items have shown a number of recurring failures (Ref. 25); most of these have the common cause of moisture susceptibility. Moisture promotes corrosion and embrittlement of metals and also causes bonded joint failures. Quite frequently moisture is the major contributor to propellant or pyrotechnic material breakdown. Sealing against moisture is a highly effective design technique, and among the proven sealing techniques are O-rings, solder, fusion, epoxies, and adhesives. Many fuzes are stored in hermetically sealed cans; however, care must be taken not to rely entirely on sealed cans to protect against moisture because fuzes spend part of their logistic life outside of the storage can. Whichever method of sealing is selected, leak tests should be performed to check the quality of the seal. Leak tests are a sensitive way of determining the effective-

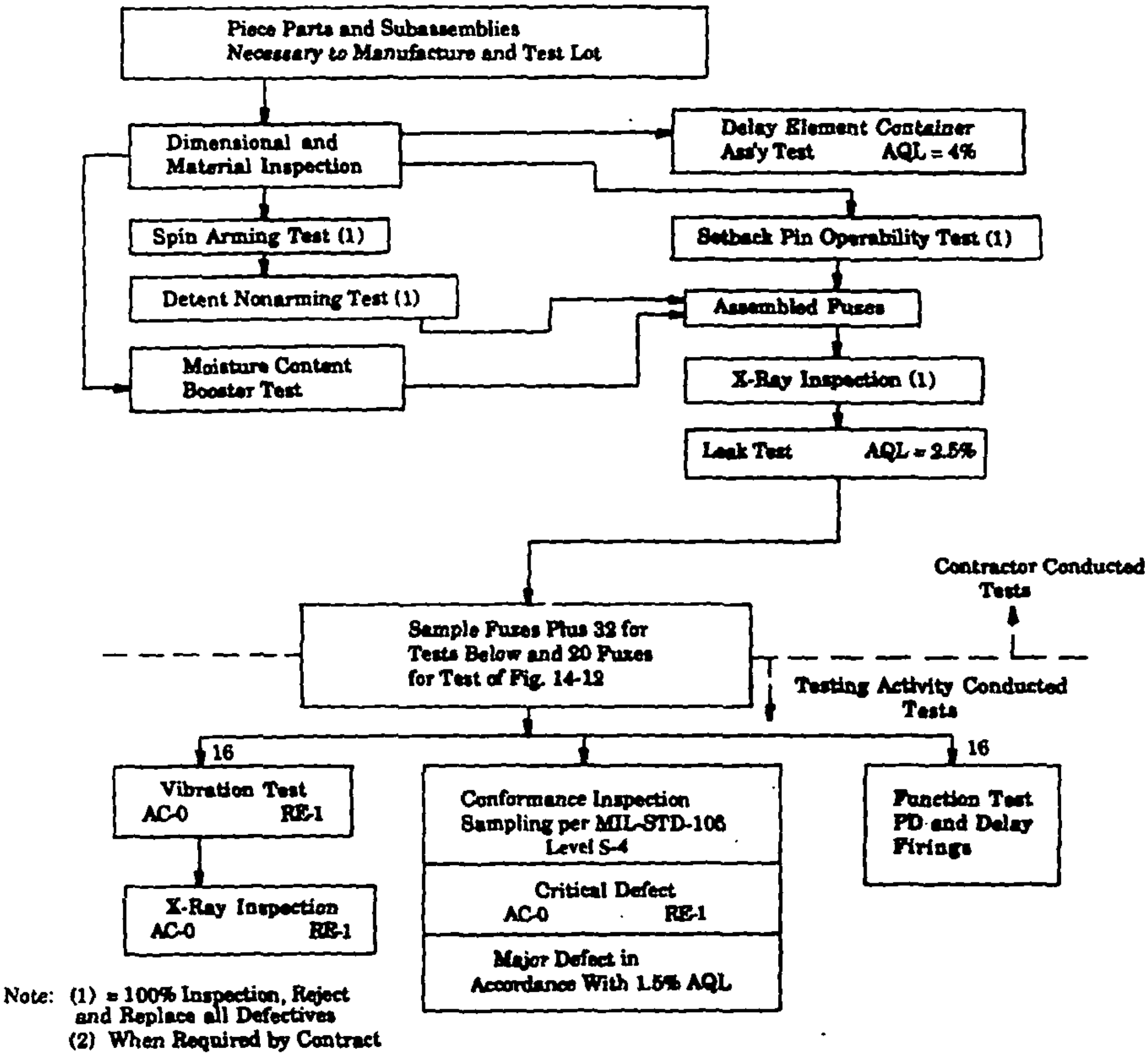
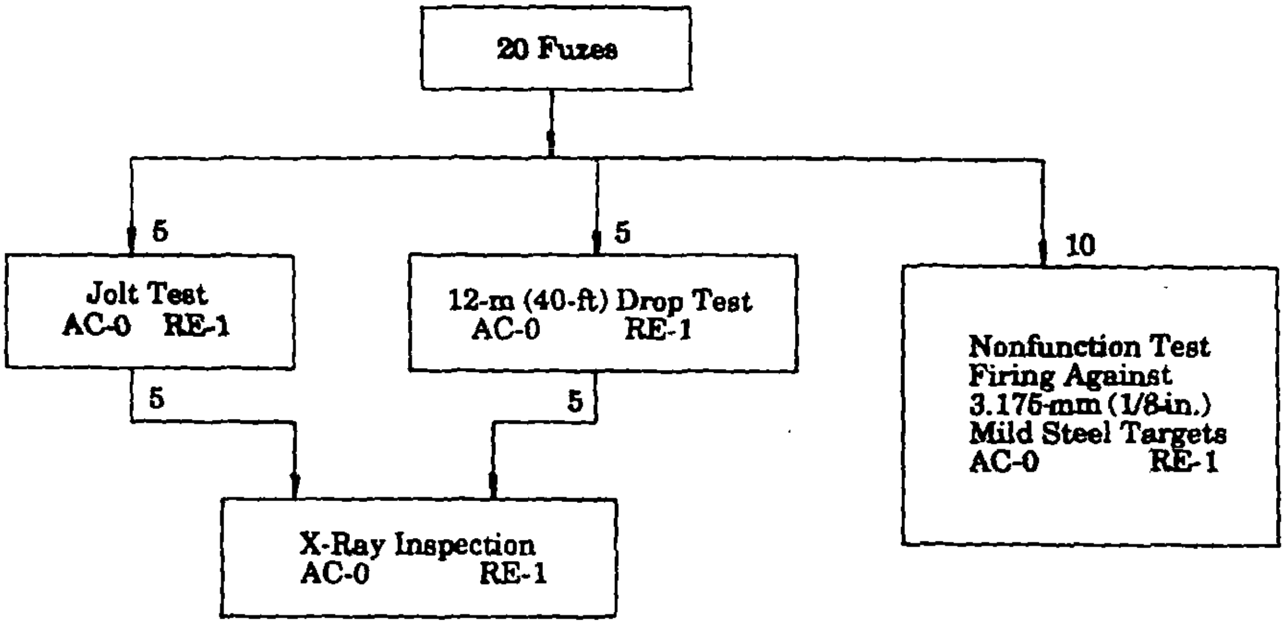


Figure 14-11. Quality Conformance Test for MK 407 Mode Point-Detonating Fuze (Ref. 24)

ness of the seals during both development and production. By quantifying the leakage that can be tolerated over the projected length of the life of the fuze, the appropriate leak tests can be specified.

A popular misconception is that conformal coating as used on printed circuit boards (PCBs) protects components from moisture. In fact, conformal coating does not keep moisture from the boards. The specifications on most conformal coatings show they will transmit 0.02 to 0.04 g (0.0007 to 0.0014 oz) of moisture per day through 0.0645 m^2 (100 $in.^2$) under conditions of 32°C (90°F) and 90% relative humidity on one side and dry conditions on the other side. On a 0.127- × 0.254-m (5- × 10-in.) PCB, this action can yield over 1 g (0.035 oz) of water in two months. This is nearly representative of many jungle conditions. Conformal coating does play an important role in protection, however, because it keeps dirt and contaminants off the PCB. If the PCB is clean to begin with and the permeated water is nearly pure, the circuits will not be adversely affected. On the other hand, if there is dirt and/or contaminant under the conformal coating, the water will mix with them and could produce a damaging reaction.

For mechanisms that require lubricants in order to operate effectively, consideration must be given to the deleterious effects of temperature extremes and the long shelf time required of fuzes. Generally, liquid lubricants tend to break down and become contaminated. The preference, therefore, is for dry film lubricants, which have superior characteris-



Note: Periodic sample is tested at rate of one lot in every 10 lots. A qualifying periodic sample is required from first lot to pass the tests of Fig. 14-11. After a lot is rejected, a qualifying periodic sample is required from the next lot to pass tests of Fig. 14-11.

Figure 14-12. Periodic Quality Conformance Tests for MK 407 MOD 0 Point-Detonating Fuze (Ref. 24)

tics under these conditions. Compatibility studies should be performed on the candidate fuze materials and lubricants.

Because of the long shelf-life requirement imposed on fuzes, it is important that the explosive compounds be compatible with the metal parts. The design objective is to avoid use of those items that can react chemically even though the reaction may be slow. Table 4-2 has been prepared to assist the designer in this effort; it contains a listing of the compatibilities of explosives and metals commonly used in fuzes. Chapter 4 discusses the compatibility problem in considerable detail. It is important to note that incompatibilities can produce either more sensitive or less sensitive compounds, which could result in safety and/or reliability problems.

14-7.2 ACCELERATED ENVIRONMENTAL TESTS

Accelerated tests are designed to shorten the test time by increasing the frequency, duration, and/or amplitude of the environmental stress that would be expected to occur in field use. The effectiveness of an accelerated test depends on the reaction of the test item to the increased stresses. If the reaction of the test item produces a realistic failure mode, i.e., one that typically occurs in service, then the test is useful. Such failure modes as rusting of steels, oxidizing of other metals, leaching of nitrogen compounds from explosives, reversion of polyurethanes, or other chemical deterioration of plastics can all be accelerated by certain environmental stresses. Thus the key to effectiveness is the failure mode. Is it realistic or not? A good test shows whether a realistic failure mode is resident in the design being tested. If the failure mode is present, redesign may be called for. If the failure mode does not show up, then it is probably not resident in the design and reasonable assurance is gained that such a failure mode will not cause problems in service usage. Accelerated tests are best used to explore storage characteristics. By ruling out classical failure modes in a particular design, survival during real world storage is enhanced.

Most accelerated tests use environmental parameters designed to increase chemical effects. These tests use steady-state and cyclic temperatures, humidity (including condensation), salt fog, and solar radiation. Cycling temperature with humidity causes moisture condensation on the test item with the possibility of surface deterioration. Elevating the temperature increases the rate of chemical reactions, whereas decreasing the temperature creates ice in small crevices and promotes some deterioration modes in plastics. Proven-effective accelerated tests are extreme temperature storage (28-day hot and cold storage tests at −54°C (−65°F) or 71°C (160°F), 28-day temperature and humidity tests using similar temperature limits with 95% relative humidity at the elevated temperature, thermal shock tests using 3 to 10 cycles of exposure to the same temperature limits with rapid changes from one temperature to the other, and salt fog tests of various durations and concentrations of salt. The solar radiation tests of MIL-STD-810, particularly Procedure II, can produce accelerated results of actinic effects, such as fading of paints and photochemical reactions of polymers. The effects of transportation vibration can be accelerated by compressing months of low-frequency truck, ship, or aircraft vibration accelerations into a twelve-hour sinusoidal test with or without accompanying temperature extremes. Except for the solar radiation tests, these tests are in MIL-STD-331.

As discussed, the effectiveness of these tests is based on the realism of the results, not on the matching of the test parameters to the service environment. Since the failure modes start on a microstructural scale, the deterioration must be accelerated to the level at which functional failures occur to make posttest examinations easier. Corrosion on an integrated circuit lead is hardly ever found by inspection after an environmental test. It is usually found only after the corrosion has progressed to the point at which the lead breaks and function is affected. Diagnostic microscopic inspection is an important failure analysis technique. Inspection and failure analysis must be thorough because other realistic failure modes may be produced simultaneously with the unrealistic failure mode. Sound technical judgment must be used rather than precise pass-fail criteria.

14-8 PRODUCT IMPROVEMENT TESTS

Product Improvement Programs (PIPs) are initiated when it is desired to increase safety, reliability, performance envelope, or useful life of fuzes in production or in the operational inventory. Initiation of Product Improvement Programs for major end items is in response to the Operational Requirements Document (ORD). The program is research, development, test, and evaluation (RDTE) funded and follows normal development processes. This requires formal development testing and operational testing programs, which can be significantly truncated if it can be determined that previous test results are still applicable. Improvement programs for lesser items are Operations and Maintenance, Army (OMA), or Army Procurement Appropriation (APA). Testing programs for these items are not as formal as the RDTE-funded items, and the scope of the test program will depend on the extent of the design changes and how the design changes affect the operational, safety, or logistic characteristics.

14-9 ANALYSIS OF DATA

Even if it were economically feasible and sufficient time were available, it would not be possible to characterize completely the entire production lot of a fuze by testing each fuze because the ultimate fuze operation is destructive; therefore, the procedure would leave no useful fuzes. Thus the fuze designers and test engineers resort to testing small numbers of fuzes from each lot and supplementing the test data with statistical techniques and analytical studies. Most detailed characterization studies are done using data obtained during component testing because these tests are relatively inexpensive and performance data can be obtained readily. The component data are then combined to characterize the fuze. Although they serve a useful purpose, these studies must be supplemented with proof tests in which the fuze is assembled in the munition for which it was designed and deployed under simulated combat conditions. Proof tests are used to demonstrate that there are no systems problems; indirectly they also show that nothing major has been overlooked in the characterization studies. These tests produce little quantified data since the firings yield only go/no-go information; however, the observed go/no-go performance is often used to establish reliability statistically, especially in the later stages of a program.

The topic of experimental statistics aimed specifically toward military applications is the subject of six handbooks (Refs. 26 through 31). These handbooks have considerable relevance to fuze applications and are recommended to designers and test engineers. These personnel should be versed in such topics as random sampling, frequency distributions, measures of reliability, statistical significance, and practical significance so that, at the very minimum, they would recognize those situations for which a professional statistician is required. As a word of caution, the services of a professional statistician should be used not only during the analysis phase of a program but also during the planning phase. If a program is not planned properly, it may not be possible to interpret the results meaningfully.

In designing an experiment one of the first questions encountered is, "What sample size should be used?". Unfortunately, there is no simple answer. The objective of the experiment is to have high confidence that the conclusions from the experiment will be valid and that they could be used for predictive purposes in similar situations. One factor affecting sample size is the spread of the data. If considerable spread is expected, then more samples would be needed than if there were little spread. Another factor is the confidence one would like to have that the results are sufficiently close to the true value. Obviously, the higher the required confidence, the greater the sample size will need to be. Table 14-4 (reproduced from Ref. 31) is presented to show the number of tests required for a particular reliability at the lower 95% confidence bound. If in a test series one attains 300 successes and no failures, it can be stated that the lower 95% confidence bound on the reliability of the item tested is 99.0%. For 3000 successes and no failures, the comparable reliability is 99.9%, an increase of only 0.9% for 2700 additional successes. The problem of selecting the proper sample size is simpler if the performance distribution

TABLE 14-4. LOWER 95% CONFIDENCE BOUNDS ON RELIABILITY BASED ON ZERO FAILURES IN N TRIALS (Ref. 31)

NUMBER OF TESTS, N	LOWER 95% CONFIDENCE BOUND ON RELIABILITY
50	0.940
100	0.970
200	0.985
300	0.990
400	0.993
500	0.994
1000	0.997
2000	0.9985
3000	0.9990
4000	0.9993
5000	0.9994
29957	0.9999

is known. The statistical properties of the distribution can be used to reduce the sample size below that which would be prescribed if the distribution were not known. Because of cost and schedule considerations, however, it may be necessary to restrict the sample size to what is reasonable and practical and to live with the associated risks.

To apply statistical techniques to experimental data, it is important that unrestricted random samples be selected from the population of fuzes being investigated. Experience has shown that it is not safe to assume that a sample selected haphazardly can be regarded as if it had been obtained by simple random sampling nor does it seem to be possible to draw a sample at random consciously. To help make unbiased selections, tables of random numbers (Ref. 30) and procedures for using the tables (Ref. 26) are available for finite populations.

Fuze data are of two types, continuous variable and quantal. The continuous variable category encompasses such fuze functions as arming times, signal processing, and sensor performance; the quantal category encompasses go/no-go functions exhibited primarily by explosive components. Statistical techniques exist for treating both types of test data to obtain lot characterizations with a prescribed degree of confidence. Inherent in obtaining this confidence is a prior knowledge of how an item is going to perform generally. This knowledge is obtained from past experience with similar devices and modeling studies. If the performance deviates significantly from that generally expected, the causes for the deviate performance should be investigated.

Knowledge of the distribution plays an all-important role in the interpretation of continuously variable data. Without this knowledge, there would be considerable risk associated with making conclusions and predictions. Because most of the programs are conducted on small sample sizes, it is not possible to determine accurately the distribution from the data itself. Fortunately, however, much information exists from past fuzing tasks that can help the design and test engineers determine the distribution within reasonable bounds. Statistical techniques are available (Ref. 26 through 31) for treating the commonly occurring distributions. The normal, or Gaussian, distribution is one that often occurs in fuze applications. This familiar bell-shaped curve is completely characterized by the mean and standard deviation statistics, which can be readily calculated. Through the use of these statistics, judgments can be made on answering such questions as does the sampled lot have characteristics sufficiently similar to those of the stockpile that equivalent performance can be reasonably expected, does the data from sampling successive lots indicate that the required level of production quality is being maintained, and does the data obtained from sampling a lot made by "improved" techniques show that the instituted changes do, in fact, produce improved products. To make these judgments, certain risks have to be taken. This is done by specifying the risk levels at which the data will be analyzed. It would be desirable to set these levels very low; however, it has been pointed out earlier that setting the levels very low has the associated requirement of a large sample size and considerable test cost.

For some applications it may be possible to obtain only go/no-go data. Explosive component firing tests are an example. For this situation, controlled variable levels of test are applied and the response of the components to each level is determined. An assumption is made that each component has an associated critical or threshold value at which it will respond. For any particular component the exact critical value cannot be determined. Other components from the sample, however, can be tested at higher and lower stimuli and statistical inferences made about the distribution of critical levels for the sampled population.

The probit method of analysis is a procedure used to analyze explosive data generated in this manner. The assumption is made that the distribution of critical values is normal; thus the critical level is the level at which half the samples would be expected to respond. The assumption of normality is not too restrictive because the procedure is not very sensitive to moderate deviations from the normal distribution; however, care must be taken in interpreting the data not to make any extrapolations beyond the range of the data. The test levels should be selected with a sufficiently wide range so that the proportion of components responding varies from near 0 to near 1. This assures that the critical value and standard deviation are well bracketed and can be determined with available statistical techniques. In analyzing the data the operations are performed using the base-10 logarithm of the stimulus because this transformed value, when coupled with the performance data, more closely follows a normal distribution than if the value of the stimulus itself were used. The performance ratio undergoes a transformation of sorts also; the cumulative normal distribution associated with the performance ratio is used rather than the ratio itself. The two transformed values are plotted with the stimulus as the abscissa and the response as the ordinate, and a regression line is drawn. From this the performance ratio can be predicted for any stimulus level within the range of the data. Alternately, an "exact" solution can be obtained from calculations (Ref. 27).

Another go/no-go data collection procedure is the Bruceton, or staircase, procedure. The test samples are tested at equally spaced stimulus intensity levels chosen before the start of testing. Starting at a level at which about 50% responses are expected, the test level is moved up one level after each "no-go" and lowered one level after each "go". This procedure is continued until the sample size has been expended. The nature of the Bruceton procedure is to concentrate testing at the 50% "go" point in order to obtain a good estimate of the mean. This method requires initial estimates of the mean and standard deviation of the distribution of critical levels. The requirements for estimating the values accurately, however, are not stringent. The usual test design places the test levels symmetrically about the 50% point and makes the step size equal to a factor associated with the assumed distribution. Testing is started at the presumed 50% point. As a caveat, the further the starting point is from the true mean, the less efficiently the samples will be expended. Also if the step size is too large or too small by a factor of four or more, there could be difficulties in obtaining meaningful analyses or even in performing the test (Ref. 32). Procedures for calculating the mean and standard deviation of critical levels are contained in Ref. 27 for normal distributions. Other, more sophisticated techniques for handling such data are the Langlie and the One Shot Transformed Response (OSTR) procedures. These are discussed in detail in Test D2 of MIL-STD-331.

As indicated previously, it is prohibitively expensive to demonstrate high reliabilities at high confidence levels by testing. An alternate approach is to use penalty testing, e.g., overtests. A procedure called variation of explosive composition (VARICOMP) has been developed using this concept (Ref. 33). VARICOMP is a method used to determine the detonation transfer probabilities of an explosive train by substituting explosive(s) of varied sensitivities or energies for the design explosive. For this procedure, construction, materials, and spatial configuration of the item under study are kept as nearly identical as possible to the intended design. By knowing the pertinent properties of the substituted explosives relative to the design explosive, statistically meaningful predictions of reliability or safety can be made at high confidence levels using results from a relatively small number of tests.

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GLOSSARY

A

Acceleration-Integrating Device. A mechanism response to an acceleration that integrates this acceleration into distance for arming.

Accelerometer. A device that senses inertial reaction in order to measure linear or angular acceleration.

Acceptable Quality Level (AQL). Maximum percent defective (or the maximum number of defects per hundred units) that, for the purpose of sampling inspection, can be considered satisfactory as a process average.

Adiabatic Compression. Compression of air to raise its temperature with sufficient rapidity to avert loss of heat.

Aerial Delivery. Delivery by projectile, rocket, or aircraft.

Air Bleed or Porous Restrictor. A porous metal restrictor to impede air movement to produce a delay action of a component.

Air-Bleed Orifice. A porous sintered metal filter that meters the passage of air.

Airspeed Discrimination. The ability of a fuze arming mechanism to respond solely to those airspeeds above a predetermined threshold value.

Algorithm. A pattern or set of procedures that defines a general method of solution that can be used to obtain a given result.

All-Fire. The firing energy required to guarantee firing of an electroexplosive device (EED).

All-Way Switch. A firing switch able to actuate in response to impact forces coming from any direction.

Alnico. An alloy of high magnetic permeability consisting of aluminum, nickel, and cobalt.

AND Function. The logic operation in which ALL inputs must be "high" (1) to produce a "high" (1) output.

Arming. A process by which a fuze explosive train is functionally aligned.

Arming Delay. A time from launch to arming of the fuze designed to allow safe separation of the munition from the launch platform.

Arming Mechanism. A device to align the fuze explosive train after measuring an elapsed time interval or distance traveled by the munition.

Asperities. Roughened parts of surfaces.

Asynchronous Clear. A clear signal that is independent or not synchronized with a reference signal.

B

Baffle. A component of a delay element that allows ignition of the delay pellet but prevents direct impingement of hot gases and particles from the primer. It provides a circuitous pathway for the igniting blast.

Ball Rotor. A sperical rotor used as a safety and arming device which usually carries a detonator in the out-of-line position and aligns the explosive train through the effects of centrifugal force. Attributes are its simplicity and its somewhat inherent degree of delayed arming. Its greatest use is in fuzes for small caliber rounds.

Belleville Spring. Conical-shaped spring-tempered washer that, when flattened to a dead center condition, can reverse direction by snapping over dead center; useful in propelling a firing pin in the initiation of a mine or other munition.

Bellows Motor. An electrically initiated, self-contained explosive unit that exerts a force over a large distance linearly or around a curve.

Bimetallic. An actuating device consisting of two strips of metal with different coefficients of thermal expansion bonded together so that the internal strains caused by temperature changes bend the compound strip.

Binary Coded Decimal (BCD). A binary numbering system in which any decimal digit 0 through 9 is represented by a group of 4 bits; each digit in a multidigit number continues to be identified by its 4-bit group.

Binary Counter. A frequency divider that continues to divide each dividend.

Bit. A binary digit whose value can be either 1 or 0.

Black Box. An electronic device whose internal mechanism is unknown to the user.

Blast Effect. Damage to the target from expanding gaseous products of an explosion as contrasted to damage from fragment penetration.

Bleeder Resistor. A resistor that draws a continuous load current from a power supply; used to improve the regulation of the power supply and safety.

Booster. Terminal explosive element in some fuzes.

Bore Rider. Sensing pin or lever in a fuze that locks against arming until freed by disengagement from the bore or tube of the weapon at muzzle exit.

Bore Safe. An unarmed condition of a fuze while traversing in the gun bore.

Bouchon. A mechanism containing a spring-loaded firing pin, a primer, a delay and detonator, and a safety release, e.g., as in a hand grenade.

Brassboard Configuration. Secondary stage of fabrication, as contrasted to preliminary stage or breadboard.

Brinelling. Denting of a softer surface by a harder surface from impact loadings.

Buffer. A circuit or component placed between other components to isolate each from the other.

C

Canister. Sheet metal, bomb-like container holding nested submunitions used to deliver and disperse the contents over a target area.

Cargo Round. A munition that disperses smaller munitions or submunitions over the target area.

Cathode. The negative electrode of a semiconductor diode or silicon-controlled rectifier (SCR).

Centrifuge. Arm or plate that rotates about an axis and is used to simulate axial, lateral, and/or rolling acceleration forces in fuzes.

Ceramic Resonator Oscillator. A stable oscillator that uses a ceramic resonator to produce the resonant frequency.

CH-6. Service-approved lead and booster explosive consisting primarily of RDX (98%) and calcium stearate (1.5%).

Chaff. A thin, flat piece of metal foil specifically designed to act as a countermeasure against radar when released into the atmosphere.

Chopper. A device used to interrupt a current at regular intervals.

Clearing Charges. Small charges initiated prior to the main charge to clear away overburden, which would interfere with the directed energy capability.

Closing Plug. A closure in the end of a cartridge case to retain propellant in separated ammunition.

Coanda Effect. Attachment of a dynamic stream of gas to a wall or surface of a channel.

Coined Cup. A solid end detonator cup, the end of which is thinned down by 50% or more by a coining process. The purpose is to retain a seal and not affect stab sensitivity.

Combustible Cartridge Case. A consumable cartridge case made of propellant.

Commit Point. A point in time or along a trajectory beyond which the fuze is committed to arm.

Complementary Metal Oxide Semiconductor (CMOS) Circuit. An integrated circuit fabrication technique using both P-channel and N-channel MOS transistors; used where low-power and high-noise immunities are desired.

Conductive Mixture. An electrically conducting primer mix that ignites when electrical energy is passed through it.

Conformal Coating. A process by which electronic components are coated by dipping in or spraying with a thermoplastic material to provide protection against moisture and to supply structural integrity.

Coriolis Force. An apparent force that, as a result of the rotation of the earth, deflects moving objects, such as projectiles, to the right in the northern hemisphere and to the left in the southern hemisphere.

Coulombmeter. A device for measuring the quantity of electric charge flowing through a circuit.

Creep. Forward motion of the internal parts of the fuze relative to the projectile that is caused by decelaration of the projectile during flight.

Creep Deceleration. Decreasing velocity because of air drag.

Crown-Barium Glass. Glass capable of accepting and retaining a high surface polish.

Crush Switch. An electric switch that operates only once by a crushing action which closes the contacts.

Crystal-Based System Clock. A clock that uses a crystal to produce a stable oscillating frequency.

D

Dead Coils. Inactive coils at one end or both ends of a spring for stability.

Dead Pressed. A loading pressure above which some explosives, such as lead styphnate, burn rather than detonate.

Decade Counter. Any counter that has 10 distinct states regardless of the sequence.

Demonstration and Validation Phase. Phase I of the System Acquisition Process, the objectives of which are to (1) better define the critical characteristics and expected capabilities of the system concept(s), (2) demonstrate that the technologies critical to the most promising concept(s) can be incorporated into system design(s) with confidence, (3) prove that the processes critical to the most promising system concept(s) are understood and attainable, (4) develop the analyses and/or information needed to support Milestone II decision, and (5) establish a proposed development baseline containing refined program cost, schedule, and performance objectives for the most promising design approach.

Design Margin. An extra margin of reliability, i.e., a safety factor.

Detached Lever Escapement. A three-center, tuned escapement capable of highly accurate timing (0.1% of set time).

Detents. Locks holding safety and arming mechanisms in the safe and/or armed position that are actuated by spin, setback, or bias spring.

Detonating Fuse. A metal-sheathed, flexible tube loaded with detonating explosive to give a detonating output; no delay exists as such.

Detonation Wave. The shock that precedes the advancing reaction zone in a high-order detonation.

Detonator. An explosive train component that can be activated by either a nonexplosive impulse or the action of a primer and is capable of reliably initiating high-order detonation in a subsequent high-explosive component of the train.

Die. A single square or rectangular piece of silicon into which a specific semiconductor circuit has been diffused. (Plural is dice.)

Differential Amplifier. An amplifier whose output signal is proportional to the algebraic difference between two input signals.

Digital. Term representing information in discrete or quantized form or in the form of pieces, such as bits and digits.

Digital Fluid Amplifier. A part of a flueric timing system, which, when coupled to a proportional fluid amplifier, performs as a timer.

Dimple Motor. An electrically initiated, self-contained explosive unit that exerts force by turning a dimpled cap inside out.

Directed Energy. Used with explosive detonations where part of the energy is channeled in a specific direction, e.g., as with a shaped charge.

Directed Energy Warhead. Warhead, in which, by design, the major part of the blast energy is directed in a desired direction(s) to maximize damage to the target.

Directed Fragmentation Warhead. Warhead, in which, by design, the majority of fragments is directed in a desired direction(s) to maximize damage to the target.

Disable. A command or condition that prohibits specific events from proceeding.

Discrete. Having definite and separate values rather than being continuous or smooth.

Doppler Rectifier. A full wave rectifier used in a doppler communication system that rectifies a reflected wave for further signal processing.

Doppler Signal. Reflected radio frequency signal from target.

Drag. Air resistance on a munition or missile that tends to cause deceleration linearly as well as rotationally.

Drag Sensor. A mechanism that responds to deceleration from air drag.

Drogue. A small parachute used to stabilize or decelerate a munition.

Dual In-Line Package (DIP). Standard packaging arrangement for integrated circuits, which has connecting pins in line along each long side of a rectangular plastic or ceramic package.

Dual Purpose Grenade. A type of submunition that contains a shaped charge to attack armor and a fragmentation effect to attack personnel.

Dud. An explosive munition that failed to explode although explosion was intended.

E

E-Cell. Electrochemical timer that functions by plating or deplating actions with an electrical output.

Electric Percussion Primer. A dual-purpose primer usually found in a cartridge case or breechblock that can be fired electrically or by percussion.

Electrically Erasable Read-Only Memory (EEROM). Read-only memory programmed by applying external electrical signals of specified value at specified times.

Electroexplosive Device. An explosive device fired by an electric charge and used to lock or unlock parts of a fuze or to detonate a fuze.

Electrolytic Capacitor. Capacitor whose electrodes are immersed in a wet electrolyte or dry paste.

Electromagnetic Pulse. High-intensity electromagnetic radiation generated by a nuclear detonation high above the surface of the earth to disrupt electronic and electrical systems.

Electronic Noise (General). Unwanted electrical energy other than cross talk present in a transmission system.

Electro-Optical. Detecting system with electrical output from an optical input.

Electrostatic Discharge. Dissipation of electrical energy between bodies with different potentials.

Emitter Coupled Logic (ECL). Logic family that operates on the principle of current switching.

Enable. Control input whose active state permits a circuit to operate.

Enabling. Act of removing or activating one or more safety features that prevent arming, thus permitting arming to occur.

Enabled Condition. A condition wherein one or more safety features, which prevent arming, are removed thus permitting arming to occur subsequently.

Energizer. Any device that applies a voltage.

Engineering and Manufacturing Development. Phase II of the System Acquisition Process, the objectives of which are to (1) translate the most promising design approach developed in Phase I, Demonstration and Validation, into a stable, producible, and cost-effective system design, (2) validate the manufacturing or production process, and (3) demonstrate through testing that the system capabilities meet contract specification requirements, satisfy the mission need, and meet minimum acceptable operational requirements.

Entrainment. A situation in which a stream of fluid flowing close to a surface tends to deflect toward that surface and can touch and attach to the surface.

Environment. The total set of physical conditions to which a fuze may be exposed.

Environmental Force. A specific stimulus obtained from the environment.

Exothermic. Characterized by or formed with evolution of heat.

Exploding Bridgewire. Small bridgewire that is electrically exploded by passage of very high current to cause detonation of a secondary explosive.

Explosive Logic System. A network of explosive trails as logic elements to perform a specified function.

Explosive Motors. Electrically initiated, self-contained explosive unit that exerts force by expanding a metal bellows.

Explosive Train Interrupter or Slider. A fuze component that interrupts the explosive train when the device is in the unarmed condition and that moves during arming to render the explosive train operative.

Expulsion. The act of expelling submunitions from their carrier.

Expulsion Charge. A pyrotechnic charge in a cargo round used to expel the payload of submunitions at the desired time.

Exterior Ballistics. Subdivision of ballistics that addresses the phenomena associated with the performance of missiles or projectiles during flight.

External Bleed Dashpot. An air dashpot that bleeds air from or to an internal volume within the fuze from or to the outside atmosphere.

F

Factory-to-Function Sequence. Phraseology used to cover the life of ammunition or a fuze from the time it leaves the factory until it functions over the target.

Fail-Safe. A design feature of a fuze that prevents the fuze from functioning if a safety feature(s) malfunctions.

Fairchild Advanced Schottky Transistor Transistor Logic (TTL) (FAST). An integrated circuit branch of the Schottky family that has a 15 to 80% power reduction over standard Schottky TTL.

Falling Leaf Mechanism. A safety mechanism responsive to an acceleration environment and consisting of several interlocking leaf-type weights that must release in a certain sequence.

Fast Clock Monitor. A device that senses and protects against a so-called runaway arming clock.

Fault Tree Analysis. Systematic method for tracing possible accident paths and evaluating their importance. The undesired event is the top event, and this event is linked to more basic events by statements and logic gates.

Film Bridge. Foil and mylar bridge exploded by electrical charge to cause detonation of HNS explosive.

Flash Detonator. Detonator designed to be receptive to flame initiation rather than stab initiation; it generally does not contain a priming mix.

Flash Hole. Blind hole intended to capture burning particles.

Flechettes. (French— a small arrow) A small, fin-stabilized missile, a large number of which can be loaded in an artillery canister.

Flettner Rotor. An aerodynamic shape in the form of an S, which causes rotation about the midpoint axis when subjected to fluid flow.

Flip-Flop. A circuit with two stable states that stays in each stable state until switched to the opposite state by an input signal.

Flueric Systems. The area within the field of fluidics that operates without the use of any moving parts other than interacting jet streams of gases.

Fluidic Generator. An electrical generator operated by turbulent ram air.

Fluidic Systems. The general field of fluid devices with their associated equipment (pistons, valves, seals, etc.) used to perform sensing, logic, amplification, and control functions.

Flutter Arming Mechanism. Ram-air-driven oscillating plate with restoring spring that is used to arm a submunition.

Flutter Plate. A spring-biased oscillating plate activated by aerodynamic (ram air) flow along the trajectory of a munition.

Folded Lever Escapement. A tuned timing escapement of the detached lever, three center type folded back upon itself to suit spatial and dynamic considerations in a mechanical time fuze.

Frangible. Property that characterizes a shatterable material, such as brittle plastic or glass.

Free Height. Overall length of a spring in the unloaded position.

Freon. A volatile refrigerant.

Frequency. The number of complete cycles of a periodic waveform during 1 s.

Fretting. Pulverization of a metal surface from repeated impacts by another metal surface, such as under vibrating conditions.

Fundamental Frequency. The lowest frequency component of a wave.

Fuse Cord. A flexible, hollow cord containing pyrotechnics to provide a delayed firing train.

Fusible Link. A low-melting-point metal or alloy that performs as a switch under thermal activation.

Fuze Component. A constituent part of a fuze. Normally fuze components can not be disassembled without destroying their designed use. The term includes both specially designed items and commercially procured items.

Fuze Subsystem. An assembly performing one or more subfunctions of fuzing. Examples include safety and arming device, target-detecting device, and arming-firing device.

Fuze Systems. A number of systems joined together to perform the total fuzing function.

G

Galvanic Cells. A pair of dissimilar metals capable of acting together as an electric source when brought in contact with an electrolyte.

Gap Decibang. A method of expressing explosive sensitivity based on a function that transforms sensitivity data into a normal distribution in which the explosive response increases with increased initiation intensity. Analogous to the decibel in that it expresses not an absolute energy or stimulus but rather a comparison with an arbitrarily established reference level.

Gap or Barrier Test. Test for sensitivity of an explosive by firing a donor explosive across an air gap or through a Lucite barrier to an acceptor explosive.

Gate. A digital circuit with several inputs and one output that performs a logical function, such as AND, OR, NAND, or NOR.

Graze Action. Passing close to the surface and/or following a path closely parallel to the surface.

Graze Impacts. A glancing angle with the target or ground, 80 to 90 deg from the normal.

Gun-Boosted Rockets. Rockets whose initial launch phase is propelled by a gun system launcher.

GUNN Oscillator. A microwave oscillator in which the frequency is controlled by current flowing through a solid, such as gallium arsenide (GaAs).

H

Hardwire Setter. Electrically operated device that requires physical contact to effect settings of a fuze.

Hazard Analysis. Analysis techniques used to identify hazards qualitatively or quantitatively, their causes and effects, hazard elimination, or a risk reduction requirement.

Heat Paper. A paper impregnated with glass, asbestos, or other refractory and pyrotechnic for use in thermal batteries.

Hermetic Seal. Barrier to protect the internal components of a fuze against contaminants.

High-Speed Complementary Metal Oxide Semiconductor (HCMOS). A higher speed complementary metal oxide semiconductor (CMOS) chip with retained low CMOS power consumption.

High-Speed Flyer Plate. Mylar disk accelerated to high speed by a heavy electrical charge.

Hopkinson Bar Test. A test that consists of firing a detonator in direct end-on contact with a long steel bar. A smaller steel block in wringing fit contact with the opposite end of the bar is thus projected outward by the shock wave. The velocity of the small block is a measure of the output.

Hot Wire Bridge. Bridge wire that is electrically heated by low current to cause ignition of the explosive.

Hybrid Circuitry. Integrated circuits connected to other components to accomplish a function.

I

Ignition Fuzes. Fuzes that emit a flame from a pyrotechnic charge rather than a detonation from HE; used in expelling payloads from munitions.

Impact Sensitivity. Susceptibility of a fuze to initiate on impact with a light target of a given hardness or thickness.

IMPATT Amplifier. Impact avalanche and transit time amplifier.

Impedance. Opposition in a circuit that will produce the same heating effect in a load resistor as the corresponding value of dc current.

Implosion System. An explosive system designed to have a sudden inward burst of particles or gases that brings pressure upon the center of something.

Inductive Coupling. Electrical or magnetic contact across a gap by magnetic induction.

Inertia Plunger. A fuze component that moves relative to the fuze body at impact and is used to close a switch or initiate an explosive charge.

Inertia Switch. An electrical switch that depends on its mass in motion for actuation.

Influence Sensing. Sensing of a target by reflected energy or heat emanations from the target; there is no contact between munition and target.

In-Line. Condition in which the explosive components are armed or in a line with no barriers.

Integrated Circuit (IC). A complex semiconductor structure that contains all the circuit components for a high-functional-density analog or digital circuit interconnected on a single chip of silicon.

Integrated Injection Logic (I²L). An integrated circuit family with greater density than transistor transistor logic and sometimes complementary metal oxide semiconductor that presents a variety of speed and power tradeoffs.

Internal Bleed Dashpot. An air dashpot that bleeds air from one internal volume in a fuze to another that is also internal to the fuze.

Interrupter. Device that physically separates the primary explosives in an explosive train from the output lead and booster explosives.

Inverter. A binary logic element that transforms a binary signal (1 or 0) to its opposite value (0 or 1).

Iterative Process. Repetitive process of modifying and refining a fuze design to meet requirements and/or improve performance.

J

Jet Momentum Interaction. One stream of gas is deflected by another.

Jettisonable Pod. A canister of submunitions with the capability of being released in its entirety in a safe mode.

Junghans Escapement. A clockwork escapement for projectile mechanical time fuzes characterized by bar-type springs and a deadbeat action; a tuned, two-center escapement.

K

Kinetic Energy Round. A high-velocity projectile (solid shot) that uses kinetic energy instead of HE to defeat a target; contains no fuze.

L

Latched. To hold onto, or maintain, such as a voltage or current.

Launch Environment. Forces present during launch of a munition useful in the arming process.

Lead. An explosive component of secondary explosive and a receptor to the initiating detonator.

Lead Disk Test. A test that consists of firing a detonator in direct end-on contact with a lead disk. The size of the hole produced is a measure of the output.

Level Shifter. A circuit that produces a different output level relative to an input level, such as a dc-to-dc converter.

Life Environmental Profile. Life history of events with associated environmental conditions for an item from release from manufacturing to its retirement.

Liquid Annular-Orifice Dashpot (LAOD). A timing mechanism that operates by moving a liquid from one chamber to another through an annular space between a cylinder and a fitted piston.

Logic. Result of planning a data processing system or of synthesizing a network of logic elements to perform a specified function.

Logic Function. A definition of the relationship that holds among a set of input and output logic devices.

Low-Acceleration Munitions. Those munitions (missiles and rockets) that experience a low-acceleration environment of much longer duration than that experienced by projectiles.

Low-Power Schottky Transistor Transistor Logic (LSTTL). Lower power dissipation form of the Schottky transistor transistor logic series with only slightly reduced speed.

M

Magnetic Signature. Distortion of the magnetic field of the earth by a vehicle which is characteristic of that vehicle.

Mechanical Baffling. A circuitous pathway through holes and channels in a delay element component to protect the delay pyrotechnics from unwanted damage by direct impingement of the primer gases.

Metal Oxide Semiconductor (MOS). A field-effect transistor (MOSFET) that has a metal gate insulated by an oxide layer from the semiconductor channel; a MOSFET is either an enhancement type (normally turned off) or depletion type (normally turned on).

Metal Oxide Semiconductor (MOS) Scales. Field-effect transistor made from a sandwich of metals for a gate, on top of oxide, on top of the semiconductor substrate that contains the source and drain.

Metastable. Marginally stable.

Metastable Compounds. Marginally stable compounds such as explosives.

Microcircuit. A compact electronic circuit (integrated circuit).

Microcomputer. A small computer that uses a microprocessor for its central processing unit (CPU).

Microcontroller. Microcircuitry used for control; a special type of microprocessor.

Microdet. Electrically initiated miniaturized detonator.

Micromechanical Device. A micromechanical silicon chip that uses chemical etching techniques for switching and sensing.

Microprocessor. The central processor of a computer fabricated as a large-scale integrated circuit.

Microstoning. Fine polishing technique.

Millimeter Wave. A wavelength of one thousandth of a meter.

Miniature Piston Actuator. An electrically initiated, self-contained explosive unit that exerts force by extending a piston; a short stroke device.

Misznay-Schardin Effect. Acceleration of a solid end plate (usually metal) from the face of an explosive charge under detonation so that the end plate remains a solid fragment and functions as a missile.

Monitor. To sense the condition or state of a switch of safety and arming device; similar to interrogate.

Multioption. A munition or fuze that can serve more than one purpose, usually selectable as time, proximity, or impact.

Multivibrator. A free-running relaxation oscillator in which the circuit resistor capacitor (RC) time constant determines the oscillating frequency.

Munition Canister. A sheet metal container housing submunitions and dispersing them at the desired time and place. Usually applied to an airborne munition.

N

Negator Spring. A constant force spring of a spiral strip material with inherent curvature wound in closed turns.

Near-Surface Burst. Proximity function that causes a fuze to function slightly above (0.3 to 1.5 m) ground.

Nonpreferred Wall. Wall opposite the preferred wall.

NOR Function. A binary logic element that requires no input be "high" (1) for the output to be "high" (1).

NPN Transistor. A semiconductor device composed of a P-type material sandwiched between N-type material in which the majority carriers are electrons; useful where a transistor is needed to activate when conventional current is applied to the base junction.

N-Type or N-Channel MOS. A MOS transistor whose source and drain are N-type diffusions in a P-substrate; applying a voltage of the proper polarity between gate and source produces a conducting channel of N-material between source and drain.

Nulled. Absorbed; rendered ineffective.

O

Off-Loading. Removal of ordnance from an aircraft, ship, truck, or launch vehicle.

Ogive. The curved or tapered front of a projectile.

Omnidirectional Switch. See All-Way Switch.

1 AMP, 1 WATT, NO-FIRE DEVICE. An electro-explosive device requiring more than 1 A, 1 W to fire.

OR Function. The logic operation by which any "high" (1) input will produce a "high" (1) output.

Overkill. Energy from an explosion in excess of that required to defeat the target; wasted energy.

Overtone Frequency. A frequency that is an integral multiple of the fundamental frequency.

P

Parasitic Element (Circuit and System). An unwanted circuit element that is an unavoidable adjunct of a wanted circuit element.

Percussion Initiation. Initiation of a primer whereby the primer case is not breached.

Peripheral Circuit. Any auxiliary input/output unit of a computer.

Phase Lock Loop (PLL). A circuit for synchronizing a variable local oscillator with the phase of a transmitted signal: widely used for tracking the carrier frequency of a signal.

Photoelectric Cell. A photoconductive cell used to convert changes in light intensity into electrical signals.

Piezo Crystal Power Source. A source of electricity when a crystal (quartz) is impacted (squeezed).

Piezoelectric. Electricity or electric polarity due to pressure, especially in a crystalline substance such as quartz.

Piezoelectric Transducer. A crystalline substance, such as quartz, that produces electricity when under pressure.

Piston Actuator. Self-contained electroexplosive device that, when ignited, locks or unlocks fuze mechanisms by the movement of a piston pin.

Plastic Deformation. Shearing a malleable material, such as a tin and lead alloy, or deforming it so that it flows plastically.

Pneumatic Annular-Orifice Dashpot (PAOD). A timing mechanism that operates by moving a gas from one chamber to another through an annular space between a cylinder and a fitted piston.

PNP Transistor. A semiconductor device composed of an N-type material sandwiched between P-type material in which the majority carriers are holes; useful where a transistor is needed to activate when conventional current is withdrawn from the base junction.

Porous Sintered Metal. A finely powdered metal compressed and brought to a near melt point (sintered), which assures retention of shape and has sufficient porosity to act as an air filter or air bleed.

Preferred Wall. Wall of attachment designed to encourage attachment in preference to any other wall.

Premature Detonation. A type of malfunctioning in which a munition functions before the arming delay has been completed.

Printed Circuit. The interconnecting pattern for an electronic circuit formed by using photographic processes and etching to leave fine copper lines on a fiber, epoxy, or glass insulating base.

Propellant Increment. Discrete units of propellant to be added or subtracted in the field to attain a desired range.

Proportional Fluid Amplifier. A part of a flueric timing system that serves as a timing oscillator.

Pseudofluids. Mediums that are not true fluids but behave similarly to fluids under motion. Tiny glass beads or greases and pastes behave as fluids in metering through an orifice and thus provide a time base.

P-Type or P-Channel Metal Oxide Semiconductor (MOS). A MOS transistor whose source and drain are P-type diffusions and an N-substrate; applying a voltage between gate and source produces a conducting channel of P-material between source and drain.

Pyro Time Fuze. A fuze using burning pyrotechnic for the timing function.

Q

Quartz Crystal. A small piece of quartz that is cut to physical dimensions to cause it to vibrate at a characteristic frequency when supplied with energy.

Quartz Crystal Oscillator. A stable oscillator that uses a quartz crystal to produce the resonant frequency. *See also* Quartz Crystal.

Quasicustom Integrated Circuit (IC). A partially customized IC.

R

Rain Sensitivity. Susceptibility of a nose fuze to initiate on raindrops during munition flight.

Ram Air. Airflow over or through a munition caused by the motion of the munition through the air; sometimes useful in operating a safety release mechanism.

Ram Air Environment. The dynamic air pressure developed on the nose of a munition as it travels through the air.

Ramming. Seating of a projectile in the gun breech as in loading a gun.

Random Access Memory (RAM). A memory system in which any memory location can be directly accessed as easily as any other and the data arrive at the output in approximately the same time.

Reaction Front. The zone between chemical reaction and the undisturbed explosive column.

Reaction Plunger. A spring-powered plunger, cocked and unlocked at impact and held in the nonfiring position by drag until target drag drops below a critical level such as when entering a void behind the target where the plunger moves rearward to fire the fuze.

Read-Only Memory (ROM). A memory device programmed at the factory and whose contents thereafter cannot be altered; therefore, no writing onto the chip is possible, only reading.

Relaxation Oscillator. Any oscillator whose fundamental frequency is determined by the time of charging or discharging of a capacitor or inductor through a resistor to produce waveforms that may be rectangular or sawtooth.

Ripple Filter. A low-pass filter designed to reduce the ripple current while freely passing the direct current from a rectifier or generator.

Rocket Case. That portion of a rocket containing the propellant.

Rocket Warhead. That portion of a rocket containing high-explosive filler and fuze.

Rolamite. A nearly frictionless elementary mechanism consisting of two or more rollers inserted in the loops of a flexible band, with the band acting to turn the rollers whose movement can be directed to perform various functions.

RS Flip-Flop. A binary logic element that has a bistable output state controlled by a SET (S) or a RESET (R) input. A high SET makes that output (Q) high, and a high RESET makes the output low.

Runaway Escapement. Mechanical device with a cyclic regulator that does not execute simple harmonic motion and varies in timing as a function of the applied torque. It is usually used to prevent the completion of arming until a safe separation distance has been attained.

Runaway System Clock. A system clock that is running at an undesirably fast frequency.

Rundown. Exercising of a clockwork to ascertain its ability to run.

Run-in. Closing phase of a guided missile on a target; terminal part of the flight path.

S

Sabot. Lightweight carrier in which a subcaliber projectile is centered to permit firing the projectile in the larger caliber weapon.

Safe Separation. Distance from the launcher at which the hazards to the launcher and its crew associated with functioning of the munition are acceptable.

Safety and Arming Device. A mechanism that provides safety and arming of a fuze at the desired time or distance for each event.

Safety Bypass. An undesirable pathway that circumvents the safety system of a fuze.

Safety Wire. Usually a shipping wire securing one or more of the fuze safeties in the unarmed position; generally removed prior to launch of the munition or after the munition (mine) has been installed in place.

Sand Test. A test for detonator output in which the amount of sand crushed is measured.

Saponification. Converting into soap; hydrolyzing a fat with an alkali to form a soap and glycerol.

Schmitt Trigger. A solid-state element that produces an output when the input exceeds a specified turn-on level and whose output continues until the input falls below a specified turnoff level.

Scroll. A spiral rotating track used in a mechanical time fuze to govern a timing lever.

Selected Arming Environments. Those environments that have been selected to cause arming of a fuze to the exclusion of all other environments.

Self-Destruct. Means whereby a munition destroys itself if no target is encountered within a predetermined range or time.

Self-Forging Fragment Lens. A property of the Misznay-Schardin effect in which a shallow-dished metal plate is projected at high velocities towards a target and a penetrating fragment is formed from the plate.

Sensitivity Plot. A curve delineating the threshold at which the zigzag device begins to operate and carry through to completion.

Sensor Interrogation. An electronic means of ascertaining the correct or incorrect status of the fuze circuitry at various times.

Sequential Leaf Mechanism. A plurality of hinged and interlocking leaves that move in sequence under acceleration.

Setback. Acceleration during launch, which causes components in fuzes to move rearward.

Setback Force. The rearward force of inertia, which is created by a forward acceleration of a projectile or missile during its launching phase; used to promote events that participate in the arming and eventual functioning of the fuze.

Setback Weight. A movable weight, usually spring biased, which in responding to the munition-launching acceleration powers a delay clockwork escapement and/or performs an unlocking function of the fuze out-of-line feature.

Shaped Charge. Explosive charge with a shaped cavity (usually conical) lined with sheet metal for directing explosive force in a preferred direction.

Shaped-Charge Warhead. A warhead designed for directionality in the release of energy, i.e., a focusing explosive output.

Shift Register. A memory in which data are entered at one end and must be shifted stage-by-stage through the entire memory before becoming available again.

Short Motor Burn. An abnormal burn of a rocket motor causing the round to drop short of the target.

Shutter. A barrier in an explosive train used to stop a detonating wave. An interrupter that opens or closes as a shutter. It is often used to obtain fuze safety.

Silicon-Controlled Rectifier (SCR). A semiconductor device in which current through a third element, called the gate, controls turn on, and the anode-to-cathode voltage controls turnoff.

Silicone Grease. A silicon-base grease having a flatter viscosity curve over temperature ranges than other greases.

Single In-Line Package (SIP). The standard packaging arrangement for integrated circuits that has all pins in line along the bottom edge of a thin, vertical, rectangular, plastic or ceramic package.

Single-Pole, Single-Throw (SPST). A switch or relay that can connect a single terminal to another terminal.

Sintered Metal. A coherent mass of metal formed by heating without melting.

Smart Weapon. Munition containing guidance capability.

Software. Collectively, any of the wide variety of applications programs, languages, operating systems, or utilities used in a computer.

Solar Cell. A photosensitive semiconductor cell used to produce a voltage directly from light.

Solid State. Descriptive term for a device, circuit, or system whose operation is dependent upon any combination of optical, electrical, or magnetic phenomena within a solid.

Spark Gap. Arc across terminals to ignite priming mix.

Spike Nose. A spike located on the forward end of a munition that is used to determine the optimum munition-target location for maximum damage effect; usually used with shaped charges.

Spin Axis. The axis about which the munition is made to spin for stabilization.

Spin Decay. Decrease in spin rate of a projectile from air drag; sometimes useful in operating a self-destruct mechanism.

Spin-Stabilized Projectile. Projectile stabilized during flight by being caused to rotate about its longitudinal axis. This is in contrast to a fin-stabilized projectile.

Spin Switch. Switch used in fuzes for spin munitions; opens or closes in response to the rise or decay of centrifugal force.

Spotting Charge. Pyrotechnic charge installed in a munition in lieu of an HE filler to indicate the detonation point.

Stab Firing Pin. A pointed pin used to stab initiate a stab primer in contrast to a rounded point percussion pin.

Staging. The disengaging and discarding of a burned out rocket unit.

Standard Cell. A cell that serves as a standard of electromotive force.

Standardized Tests. Tests contained in military or DOD standards. The standards contain information for selecting and performing the tests and assessing the results that can be applied to specific projects.

Standoff. As pertains to a shaped charge, the distance between the charge and the target at the time of initiation, which is required to effect penetration.

Static RAM. A random access memory in which data are stored in a conventional bistable flip-flop and need not be refreshed.

Stationary Ammunition. Ammunition that is not projected toward the target but remains in place and awaits the approach of the target.

Status Switch. Monitoring switch that detects the arming status of a safety and arming device.

Steel Block Dent Tests. This test consists of firing a detonator in direct end-on contact with a steel block. Depth of dent is a measure of output.

STINGER Fuze. A nose impact fuze used in a shoulder-launched guided missile against low-flying aircraft.

Stoichiometric Delay. Delay mix of definite proportions to insure theoretically complete combustion without the formation of gases and pressures.

Submunitions. Small, grenade-size munitions carried in and expelled from a projectile or canister.

Substrate. The supporting material upon or with which an integrated circuit is fabricated or to which an integrated circuit is attached.

Surface Mount Technology. The process of mounting components so that the entire body of the components projects in front of the mounting surface.

Synchronous Clear. A clear signal that is sent with the same period and phase as another reference signal.

Systems Acquisitions Process. A Department of Defense process for the orderly conduct of development projects. This process features distinct phases with defined objectives. Projects advance through the process with demonstrated performance.

T

Tailoring. The process of choosing or altering test procedures to simulate or exaggerate the effects of forcing functions to which an item will be subjected during its life.

Tantalum Capacitor. An electrolytic capacitor in which the anode is some form of tantalum. Examples include solid tantalum, tantalum foil electrolytic, and tantalum slug wet electrolytic capacitors.

Target Signature. Emanations from the target by infrared emissions, reflection of a laser beam, electronic emissions, or magnetic signature.

Tetryl. A lead and booster explosive no longer used because of toxicity problems during manufacture.

Thermal Battery. A solid electrolyte battery energized by melting the electrolyte by pyrotechnic means.

Thermal Switch. A switch that is activated by the application of heat.

Thermoplastic Resins. Resins that soften and melt when heated and harden when cooled; this heating and cooling sequence can be repeated indefinitely.

Thermosetting Resins. Resins that contain catalysts or curing agents. Heating initiates irreversible chemical reactions, which convert these resins to a permanently hardened or cured state.

Threshold Speed. Airspeed above which it is desired that a fuze be responsive to arming.

Through-Bulkhead Initiation. Transfer of a detonating wave from one side of a metal bulkhead to the other leaving the bulkhead intact.

Tilt Rod. A rod used in a mine fuze to initiate or trigger the mine when the rod is tilted relative to the mine.

Time Gated. A system that only permits certain arming or firing events to occur within a specific time bracket.

T-Lug. A "T"-shaped, die-cast lug used to retain one end of a hand grenade safety lever.

Transceiver. (data transmission). The combination of radio receiver and transmitting equipment in a common housing, usually for portable or mobile use, that employs common circuit components for both transmitting and receiving.

Transistor Transistor Logic (TTL). The generic name for several bipolar families that have evolved over the past 20 yr, such as Schottky (STTL) and low-power Schottky (LSTTL).

Trip Wire. Wire or cord extended from a mine or booby trap to trigger the munition when pulled or severed.

Truth Table. A table that describes a logic function by listing all possible combinations of input values and indicating the true output values for each combination.

Twin-t Oscillator. Oscillator that uses the principle of double integration to produce a constant oscillating signal at a frequency determined by the circuit constants and as a result of positive or regenerative feedback.

Type Classification. Formal process of approving the fuze design as acceptable for its mission and ready for introduction into the inventory.

U

Umbilical Retraction. Disengagement of an electrical or mechanical lead to a fuze where this action performs part of the fuze function.

V

Varicomp. A method for determining detonation transfer probabilities by using explosives of graded sensitivity.

Vernier. Scale used to indicate parts of divisions for fine adjustments of time and range.

Void Sensing. The ability of a munition to sense cessation of target drag when it has just passed through the target.

Volatile. May be used to describe a device that loses its stored data when the applied power is removed.

W

Wahl Factor. Compensation for the torsional stress concentration at the inner diameter of a helical coil spring.

Warren Loop. Part of an oscillator system for fluids.

Wickenburg Gear Tooth. A design allowing greater radial tolerances because of larger root depth.

Z

Zero g. A condition in which, during some parts of a trajectory, the force on internal parts counteracts the force of gravity.

Zigzag. A safing mechanism that discriminates between handling accelerations and launch accelerations of munitions. It consists of a spring-biased weight keyed by a pin to translate and oscillate simultaneously with reversal cycles.

Zigzag Pin. Locking pin or detent that is spring biased and releases under acceleration in a combination action of stop-start reversible rotation and linear displacement.

Zone Firing Weapons. Usually artillery rounds with adjustable propelling charges to match specific ranges or zones.

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SUBJECT TERM (KEY WORD) LISTING

Artillery
Batteries
Belleville spring
Bomb
Booster
Centrifugal force
Delay
Detonator
Electronic time
Firing pin
Fluidics
Grenade
Guided missile
Impact
Mechanical time
Mine
Mortar
Point detonating
Proximity
Rocket
Safety and arming device
Safety and arming mechanism
Setback force
Superquick
Tank main armament

Custodian:
Army—AR

Review activity:
Army—HD

Preparing activity:
Army—AR

(Project 13GP-A023)

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