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MILITARY STANDARDIZATION HANDBOOK

INSPECTION EQUIPMENT DESIGN

FSC 5220

AGO 10117A

DEPARTMENT OF DEFENSE
WASHINGTON, D.C.

MIL-HDBK-204
Inspection Equipment Design

1. This standardization handbook was developed by the Department of Defense in accordance with established procedure.

2. This publication was approved on 16 August 1962 for printing and inclusion in the military standardization handbook series.

3. This document provides information and guidance to personnel concerned with the design of inspection equipment. The handbook is not intended to be referenced in purchase specifications except for informational purposes, nor shall it supersede any specification requirements.

4. Every effort has been made to reflect the latest information on inspection equipment design. It is the intent to review this handbook periodically to insure its completeness and currency. Users of this document are encouraged to report any errors and any recommendations for changes or inclusions to Headquarters, DSA, Standardization Division, Washington 25, D.C.

FOREWORD

1. This handbook is intended as a guide in standardizing and systematizing the design of inspection equipment used by or for the Department of Defense.

2. The information contained in this handbook is a correlation of standard definitions, terminology, tables, illustrations, and design data necessary for the preparation of inspection equipment drawings and Inspection Equipment Lists.

3. The handbook is to be used by all who are engaged in the design of inspection equipment by or for the Department of Defense.

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CHAPTER 1. GENERAL PRACTICES FOR INSPECTION EQUIPMENT DRAWINGS

1.1 INTRODUCTION. This chapter establishes the basic terminology pertinent to the intent of this handbook and outlines all the general procedures applicable to inspection equipment with the exception of those involving actual design criteria. It presents the general approach to the Inspection Equipment Lists, the methods of preparing drawings for inspection equipment and the approach to the analysis made prior to actual design.

1.2 TERMINOLOGY. These paragraphs endeavor to provide a common language for those persons engaged in the design of acceptance inspection equipment. For convenience, the terminology has been grouped into three primary sections: General Terminology, Dimensional Terminology and Gage Terminology. Terminology peculiar to screw threads may be found in H28, Screw Thread Standards for Federal Services.

1.2.1 *GENERAL TERMINOLOGY.* These terms are those which apply to no special category but are in common usage in relation to inspection equipment design.

1.2.1.1 *Piece.* A piece is that portion of a part or assembly that is not capable of further subdivision for manufacturing purposes.

1.2.1.2 *Part.* A part is the finished piece or assembled piece which is assigned a number and is the smallest replacement unit in the design of an end item (bracket, resistor, toggle switch).

1.2.1.3 *Component.* A component is a group of connected assemblies and parts which is capable of operation independently but may be externally controlled or derive its power from another source (computer, transmission, electrical generator).

1.2.1.4 *End Item.* A combination of components, assemblies, and parts which is ready for its intended use.

1.2.1.5 *Product.* Product is the general term for that which is manufactured or produced in any fashion.

1.2.1.6 *Inspection Equipment.* Any equipment utilized for examination of a product in order to determine its conformance to drawings or specifications.

1.2.1.5 *Gage.* The term "gage", as used in this handbook, shall refer to those devices or mechanisms designed specifically for the acceptance or rejection of parts and assemblies so far as dimensional features are concerned. The term "gage" is not intended to cover test equipment (see below) or measuring equipment.

1.2.1.6 *Test Equipment.* Any device, mechanism, or instrument designed or required specifically for the purpose of appraisal or calibration of the functions, electrical aspects, or other phenomena exhibited by the parts or assemblies to be tested.

1.2.1.9 *Measuring Equipment.* Measuring equipment is defined as those devices which individually, collectively, or in conjunction with related items provide for a range of dimensional measurements.

1.2.2 *DIMENSIONAL TERMINOLOGY.* The terms listed in this section are those which are most frequently encountered in the process of dimensioning and tolerancing both products and acceptance inspection equipment. The subject is further defined in Mil-Std-8, Dimensioning and Tolerancing.

1.2.2.1 *Standard Size.* Standard size is one of a series of recognized or accepted sizes.

1.2.2.2 *Nominal Size.* The nominal size is the designation which is used for the purpose of general classification.

1.2.2.3 *Control Size.* A control size is one which is established to assist in fabrication of the part and is not gaged in acceptance inspection.

1.2.2.4 *Design Size.* The design size of a dimension is the size in relation to which the limits of tolerance for that dimension are assigned, (usually based on computations or empirical data).

1.2.2.5 *Basic Size.* The basic size of a dimension is the theoretical size from which limits of size for that dimension are derived by the application of the allowance and tolerance.

1.2.2.6 *Allowance.* An allowance is an intentional difference in correlated dimensions or mating parts. It is minimum clearance (positive allowance) or maximum interference (negative allowance) between such parts.

1.2.2.7 *Tolerance.* The tolerance on a dimension is the total permissible variation from that dimension.

1.2.2.7.1 *Unilateral Tolerances.* Unilateral tolerances are those which are applied to the basic or design size in one direction only.

1.2.2.7.2 *Bilateral Tolerances.* Bilateral tolerances are those which are applied to the basic or design size in both directions. The basic or design size may or may not be the mean size since the plus and minus tolerances do not have to be equal.

1.2.2.7.3 *Gage Tolerances.* Gage tolerances are applied to the gaging dimensions of gages in order to limit variations in size during their manufacture. The direction of the gage tolerance shall always be within the product limits.

1.2.2.8 *Clearance.* A clearance is the actual measured difference between mating parts.

1.2.2.9 *Limits.* Limits are the maximum and minimum sizes permissible for a specific dimension.

1.2.2.10 *Fit.* The fit between two mating parts is the relationship existing between them with respect to the amount of clearance or interference which is present when they are assembled.

1.2.3 *GAGE TERMINOLOGY.* The following terms are the most commonly encountered with reference to gages alone. Additional definitions appear in Commercial Standard CS8, Gage Blanks.

1.2.3.1 *Government Final Inspection Gages.* Government Final Inspection Gages are those used by or for the Department of Defense in the acceptance inspection of the finished product. These gages must insure that the product has been manufactured within the limits specified on its drawing or that the product is functionally acceptable.

1.2.3.2 *Manufacturing Gages.* Manufacturing gages are those used by the contractor in production and are also known as process or work gages.

1.2.3.3 *Gaging Aids.* Gaging aids are designed for items which are not produced in large quantities. These aids are used in conjunction with measuring equipment, i.e., surface plates, test indicators, precision measuring blocks, and require a much higher degree of skill in their use than gages.

1.2.3.4 *Gage Base.* A gage base is that portion of the gage to which gaging members and mechanisms are attached for complete assembly.

1.2.3.5 *Gage Blank.* A gage blank is the standardized form of the gage prior to heat treatment and finishing. The term usually applies to the gage blanks shown in Commercial Standard CS8.

1.2.3.6 *Gage Frame.* A gage frame is the body portion of the gage (usually portable) as distinct from the gaging pins, gaging buttons, anvils and adjusting or locking mechanism.

1.2.3.7 *Gage Handle.* The gage handle is that portion of a gage which is employed as supporting means for the gaging member or members.

1.2.3.8 *Gage Member.* The gaging member is that integral unit of a gage which is accurately finished to size and is employed for size control of the work.

1.2.3.9 *American Gage Design Standard (AGD).* The caption American Gage Design Standard has been adopted to designate gages made to the design specifications promulgated by the American Gage Design Committee, as contained in Commercial Standard CS8.

1.2.3.10 *Adjustable Gage.* An adjustable gage is one which can be adjusted to any limiting dimension within a given size range and locked in position.

1.2.3.11 *Fixed Gage.* A fixed gage is one which is finished to an exact size and cannot be adjusted in any manner. It may be single or multiple piece construction.

1.2.3.12 *Limit Gages.* Limit gages represent the limiting sizes within which the work will be acceptable.

1.2.3.12.1 *Go Gage.* A Go gage represents maximum material conditions of the mating parts. Go gages control minimum clearance between mating parts.

1.2.3.12.2 *Not Go Gage.* A Not Go gage represents minimum material conditions of the mating parts. Not Go gages control maximum clearance between mating parts.

1.2.3.12.3 *Maximum Gage.* A Max gage represents a maximum component limit such as depth, length or diameter, etc.

1.2.3.12.4 *Minimum Gage.* A Min gage represents a minimum component limit such as depth, length or diameter, etc.

1.2.3.13 *Functional Gage.* A functional gage is one which is designed to sizes implied by the function of the mating parts rather than to the actual sizes specified on the mating part drawings.

1.2.3.14 *Master.* A master is a device made to the highest degree of accuracy attainable and used mainly for reference or calibrating purposes.

1.2.3.14.1 *Master Gage.* A master gage is made to one of the specified (max or min) product limits within a high degree of accuracy as related to the product tolerance. A master gage is used as a referee gage to accept or reject products which have previously been gaged and found to be borderline cases.

1.2.3.14.2 *Master Check Gage.* A master check gage simulates the product dimensions that are to be gaged. The check gage is made accurately to within approximately 5% of the part tolerance and usually is made to either the max or min conditions. Master check gages are for setting, acceptance or surveillance.

1.2.3.15 *Wear Limit Gage.* A gage for determining when a limit gage or functional gage has worn to the maximum size permitted.

1.3 QUALITY ASSURANCE PROVISIONS. Section 4 of the procurement document (Federal Spec., Military Spec., or Purchase Description) for an item is entitled, (Quality Assurance Provisions" It contains complete and detailed information concerning the inspection requirements, classification, frequency of sampling, examinations, and the recommended method of inspection or applicable test method necessary to determine conformance of the item to specified requirements for acceptability. In order to facilitate a complete inspection and to support the inspection requirements, a certain amount of inspection equipment is needed. This equipment may be:

(a) A standard or commercially available item.
(b) Designed specifically for the characteristic or feature to be inspected.
(c) Selected from existing Government stocks.

Whatever the case, the equipment must be supported by related documentation in order to achieve the proper coordination between the item specification and the inspection equipment. It is recognized that each activity, due to differences in their needs and methods of operation, may have different approaches in effecting this coordination. The following section presents the general approach to this problem by one service and as such is presented only as an example. The practices for preparation of drawings as governed by MIL-D-70327, Drawings, Engineering and Associated Lists, are now standardized, thus Section 1.5, Inspection Equipment Drawings, is applicable to all services.

1.4 INSPECTION EQUIPMENT LISTS. The inspection equipment lists represent a complete organized record of all the prescribed inspection equipment required to support the quality assurance provisions for a specific item including all major and minor subassemblies. The lists also provide the proper coordination between the item or part to be inspected, the inspection equipment and the item specification.

1.4.1 *COMPOSITION OF THE LISTS.* Depending on the complexity of the end item, the structure of the lists could consist of the type of forms shown below:

(a) Principal Index of Inspection Equipment Lists
(b) Index of Inspection Equipment Lists.
(c) List of Inspection Equipment
(d) List of Inspection Equipment Numbers

1.4.2 *PREPARATION OF THE LISTS.* The IEL forms illustrated are 8½ x 11 and are designed to be prepared on electric typewriters employing 10 horizontal characters per inch and 6 vertical characters per inch. Examples of the various lists appear in figures 1 through 6. A general description of each list is provided below.

1.4.3 *PRINCIPAL INDEX OF INSPECTION EQUIPMENT LISTS.* This list lists all major assemblies, sub-assemblies, or installations which are required for a complete end item when this end item is a combination of other end items, or is of a very complex nature with a large number of sub-assemblies or installations. For each assembly, sub-assembly, or installation listed, the Index to Inspection Equipment Lists number is shown together with the activity responsible for that particular Index.

1.4.3.1 *Responsibility.* The principal index is prepared at the discretion of the activity responsible for the complete end item.

1.4.3.2 *Numbering.* The principal index carries the same seven digit part number as the assembly drawing of the complete end item. See figure 1.

1.4.4 *INDEX TO INSPECTION EQUIPMENT LISTS.* This list is a record of all the sub-assemblies and individual parts of an average end item or of an assembly, sub-assembly, or installation which is a part of an end item of such complexity that it requires a principal index. This list indicates by an appropriate symbol in the column preceding each part number whether or not the part requires inspection equipment. See figure 2.

1.4.4.1 *"L" Defined.* When the Letter "L" appears in the column preceding the part number, it signifies that there is a List of Inspection Equipment for that part or sub-assembly in the complete set of Lists and therefore inspection equipment is required for that part.

1.4.4.2 *"NL" Defined.* When the letters "NL" appear in the column preceding the part number, it signifies that no inspection equipment is required for that part and consequently no List of Inspection Equipment for this part will appear in the complete set of Lists.

IEL 9873241

REV LETTERS	ASSEMBLY, SUB ASSEMBLY OR INSTALLATION PART NUMBER	PART NAME	"INDEX OF EQUIPMENT LISTS" NUMBER	RESPONSIBLE ACTIVITY
	F 7046650	MOUNT ASSEMBLY, MACHINE GUN	7075025	
	F 8385013	INSTALLATION, CONTROLS, BRAKES & DRIVERS SEAT	8385013	
	F9873217	INSTALLATION, SUSPENSION	9873217	
	D8385030	INSTALLATION, FUEL LINES	NO LIST	
	F8397133	HULL ASSEMBLY, COMPLETE	8397133	
		FIRE CONTROL		
	F 7281904	AIMING CIRCLE M1	6112054	
	F 7261981	PERISCOPE M13	7299520	
	D 7812141	WRIST WATCH	NO LIST	
		WEAPONS		
	K 7558641	105MM HOWITZER	7239886	
	K 7569221	57MM RIFLE	7242311	

REV SYM	REVISION DATE	REV SYM	REVISION DATE	REV SYM	REVISION DATE
ORIG					

PRINCIPAL INDEX OF INSPECTION EQUIPMENT LISTS FOR: VEHICLE, TRACKED, AMPHIBIOUS M101

PREPARED | REVIEWED

SUBMITTED

APPROVED BY ORDER OF THE

IEL K 9873241 SHEET 1 OF 1

FIGURE 1. *Principal index of inspection equipment.*

IEL 9873217

REVISION LETTER	L-LIST NL-NO LIST	PART NUMBER	PART NAME	REVISION LETTER	L-LIST NL-NO LIST	PART NUMBER	PART NAME
	NL	F9873217	ASSEMBLED SUSPENSION				
	NL	F9873218	LIST OF SPARES				
	L	C9873219	STOP ASSEMBLY, SUSPENSION ARM				
	NL	B9873220	BRACKET ASSEMBLY				
	NL	B9873221	SHAFT				
	L	D9873222	SHAFT ASSEMBLY				
	L	C9873223	HUB ASSEMBLY, REAR WHEEL				
	NL	A9873224	SPACER				
	NL	F9873225	TRACK ASSY, LEFT (SEE INDEX IEL 9873225)				
	L	D9873226	STAND ASSEMBLY PINTLE				
	L	D9873227	STAND, PINTLE				
	NL	F9873228	TRACK ASSY, RIGHT (SEE INDEX IEL 9873228)				
	L	D9873229	STUD, WHEEL HUB				

REV SYM	REVISION DATE	REV SYM	REVISION DATE	REV SYM	REVISION DATE
ORIG					

INDEX OF INSPECTION EQUIPMENT LISTS FOR:
INSTALLATION, SUSPENSION
NEXT ASSEMBLY K9873241

PREPARED	REVIEWED	FRANKFORD ARSENAL
SUBMITTED		
APPROVED BY ORDER OF THE		IEL F 9873217 SHEET 1 OF 1

FIGURE 2. *Index of inspection equipment.*

IEL 9873222

REV LTR	NUMBER	CHARACTERISTIC	EQUIPMENT	DRAWING SIZE	NUMBER	DWG REV	CODE
		.5000-20UNF-2B					
		PD GO	PLUG, THREAD	-	5220-751-4033		
		PD NOT GO	PLUG, THREAD				
		750-16UNF-2A					
		PD GO	RING, THD	-	5220-751-4840		
			PLUG, THD SET	-	5220-751-4841		
		PD NOT GO	RING, THD	-	5220-751-5690		
			PLUG, THD SET	-	5220-751-5691		
		MAJOR DIA	SNAP, ADJ .7500/.7391 (4)	-	5220-747-9466		
		CONC DIA WITH THD & ADJACENT FACE	INDICATOR	D	7297530	A	
		DIA GO .68	PLUG, PLAIN CYL (.0057)	-	7430210		
		DIA NOT GO .6857	PLUG,PLAIN CYL,SPL	A	7558670		
		DEPTH OF DISC, MIN	LENGTH	A	7278830	A	
		PFL ANGLE (76°)	INDICATOR W/CHK	D	7297429	B	
		WIDTH SEAT	INDICATOR	D	7297524	A	
			SET. CHECK	B	7297525	A	

IEL 9873217 SUSPENSION ASSEMBLY

DAPD #2146 DTD
SQAP 9873222 DTD

THIS LIST APPLIES TO:

AND IS COORDINATED WITH:

REV SYM	REVISION DATE LIST	REVISION DATE PART	REV SYM	REVISION DATE LIST	REVISION DATE PART
ORIG					

LIST OF INSPECTION EQUIPMENT FOR:
SHAFT ASSEMBLY

PREPARED | REVIEWED

SUBMITTED

APPROVED BY ORDER OF THE

IEL D 9873222 SHEET 1 OF 1

FIGURE 3. *List of inspection equipment.*

1.4.4.2.1 *Excessive "NL" 's.* Whenever the proportion of "NL" 's to "L" 's on a particular list would become excessive (over 50%) of the total parts, the parts need not be listed. A qualifying note must be placed on the first sheet of the list as follows: "Parts Listed on XXXXXXX Which Do Not Appear On This List Do Not Require Inspection Equipment". The number of the product drawing that lists the drawing numbers of all the parts of the end item may be used.

1.4.4.3 *Numbering.* The Index to Inspection Equipment Lists generally carries the part number of the assembly, sub-assembly, or installation drawing for the item for which it is being prepared. (A number from a special series for indexes within a particular service may be used if it is desired).

1.4.4.4 *Auxiliary Uses.* An index may also be prepared to record spare parts, parts common, and parts peculiar from similar major items which themselves are no longer on active status, but for which there are continuing spare part or replacement requirements.

1.4.5 *LIST OF INSPECTION EQUIPMENT* This list records all the inspection equipment required to inspect an individual part. The characteristic to be inspected, the type of equipment for the inspection and its stock number, are the basic information furnished by this list. Additional information may be added in accordance with the needs of the individual service. See figure 3.

1.4.5.1 *Numbering.* Each sheet is numbered by inserting the number of the applicable part in the space provided after the standard IEL notation. The letter size of the part drawing is placed in the small block between "IEL" and the part number. In those cases where a letter or letters are used in conjunction with numbers to identify a part, the letter(s) will become part of the IEL number (IEL ALX1532, IEL FC2395, IEL SKFSA2217).

1.4.5.2 *Assembly and Sub-Assembly Lists.* All inspection equipment used in the acceptance of a completed assembly or sub-assembly shall appear on the List of Inspection Equipment for that assembly or subassembly whether the features inspected appear on the assembly drawing or on its detail drawings. Notes cross-referencing the list for the assembly drawing shall appear on the lists of the details in place of the features that are gaged at assembly. If there are no features inspected at the detail stage, a dummy list carrying only the cross-reference to the assembly drawing lists shall be prepared. The revision area of this list should be maintained current with the detail drawing in order to direct attention to the location of inspection equipment that may require revision.

1.4.5.3 *Multiple Application.* When an IEL package is to be prepared for an item which has common parts with existing items, it is probable that a substantial portion of the Lists of Inspection Equipment has already been prepared. Parts peculiar to new items will require their own new Inspection Equipment Lists.

1.4.6 *LIST OF INSPECTION EQUIPMENT NUMBERS.* This form provides an alpha-numerical listing of all the inspection equipment stock numbers pertaining to each item for which an Index to Inspection Equipment Lists was prepared. Two separate types of Lists of Inspection Equipment Numbers are provided, a Basic List and a Cross-Reference List.

1.4.6.1 *The Basic List.* The Baisc List lists all the numbers alpha-numerically, segregating the Mil–Std numbers from the drawing numbers. The drawing numbers are grouped under each drawing size "A", "B", etc. The Basic List is shown in figure 4.

1.4.6.2 *The Cross-Reference List.* For those applications requiring additional information on the list, the Cross-Reference List is provided. It still provides for segregation of Standard and Special inspection equipment but it also lists for each stock number the various Lists of Inspection Equipment upon which it appears. Further, a column is provided for other desired uses such as indicating method of supply, availability or similar information. See figures 5 and 6.

1.4.7 *REVISION OF INSPECTION EQUIPMENT LISTS.* All of the lists except the List of Inspection Equipment are revised generally in accordance with standard drawing practices.

1.4.7.1 *Revision for Lists of Inspection Equipment.* The revision system for Lists of Inspection Equipment is based on the following:

(a) Whenever the part drawing is revised dimensionally regardless of whether the applicable equipment is affected, the latest part revision date shall be added to the List of Inspection Equipment.

(b) The addition of a part revision date or number indicates a revision to the List of Inspection Equipment and, accordingly, a revision date shall be entered.

REV LTR | IEL 9873217

A COMPLETE SET OF DRAWINGS SHALL INCLUDE ALL DRAWINGS LISTED BELOW PLUS A "LIST OF INSPECTION EQUIPMENT" FOR EACH NUMBER LABELED "L" ON INDEX

A	C		MIL-STD 114
7297423	7297580		5220-751-4033
7564215	7959920		MIL STD 115
8657371	7959922		5220-751-4247
7558670	7959925		MIL-STD 116
7278830	7959918		5220-751-4840
			5220-751-4841
			MIL STD 117
			5220-471-5690
			5220-751-5691
			MIL STD 118
B	D		5220-747-9390
7307621	7298200 (3)		5220-747-9466
7307622 (2)	8658203		MIL STD 110
8657375	7297530		5220-743-0210
7297525	7297429		
	7297524		
	F		INDEX TO LISTS IEL 9873217
	8658202		LIST OF NOS. IEL 9873217

REV SYM	REVISION DATE	REV SYM	REVISION DATE	REV SYM	REVISION DATE
ORIG					

LIST OF INSPECTION EQUIPMENT NUMBERS FOR:

INSTALLATION, SUSPENSION

PREPARED | REVIEWED

SUBMITTED

APPROVED BY ORDER OF THE

IEL | F | 9873217 | SHEET 1 OF 1

FIGURE 4. *List of inspection equipment numbers (basic list).*

IEL 9873217

THIS LIST CONCERNS ■ SPECIAL INSPECTION EQUIPMENT ☐ STANDARD INSPECTION EQUIPMENT
A COMPLETE SET OF DRAWINGS SHALL INCLUDE ALL DRAWINGS LISTED BELOW PLUS A "LIST OF INSPECTION EQUIPMENT" FOR EACH NUMBER LABELED "L" ON INDEX IEL

REV LETTERS	EQUIPMENT STOCK NO.		PARTS APPLICABLE	NO REQD		REV LETTERS	EQUIPMENT STOCK NO.	PARTS APPLICABLE	NO REQD
	A								
	A7297423	A	9873219	1					
	A7564215	B	9873223	1					
	A8657371	A	9873223 9873226	1					
	B								
	B7307621	A	9873227	1					
	B7307622	A	9873226	1					
	B7567375	A	9873229	1					
	C								
	C7297580	D	9873226	1					
	C7959920	A	9873222 9873223	1 1	Ø				
	C7959922	A	9873222	2					
	C7959925	C	9873222	1	Ø				
	C7959918	A	9873222	1					
	D								
	D7298200	A	9873226	1			INDEX TO LISTS IEL 9873217		
	D8658203	B	9873223	1					
	F								
	F8658202	B	9873222	1			LIST OF NUMBERS IEL 9873217		

Ø WHEN ORDERING SPECIFY SIZE

REV SYM	REVISION DATE	REV SYM	REVISION DATE	REV SYM	REVISION DATE
ORIG					

LIST OF INSPECTION EQUIPMENT NUMBERS FOR:
INSTALLATION, SUSPENSION

PREPARED | REVIEWED
SUBMITTED
APPROVED BY ORDER OF THE

IEL F 9873217 SHEET 1 OF 2

FIGURE 5. *Cross reference list (special inspection equipment).*

IEL 9873217

THIS LIST CONCERNS ☐ SPECIAL INSPECTION EQUIPMENT ■ STANDARD INSPECTION EQUIPMENT
A COMPLETE SET OF DRAWINGS SHALL INCLUDE ALL DRAWINGS LISTED BELOW PLUS A "LIST OF INSPECTION EQUIPMENT" FOR EACH NUMBER LABELED "L" ON INDEX IEL

REV LETTERS	EQUIPMENT STOCK NO.	PARTS APPLICABLE	NO REQD		REV LETTERS	EQUIPMENT STOCK NO.	PARTS APPLICABLE	NO REQD	
	MIL-STD 114								
	5220-751-4033	9873222							
	MIL-STD 115								
	5220-751-4247	9873222							
	MIL-STD 116								
	5220-751-4840	9873222							
	5220-751-4841	9873222							
	MIL-STD 117								
	5220-751-5690	9873222							
	5220-751-5691	9873222							
	MIL-STD 118								
	5220-747-9390	9873222							
	5220-747-9466	9873222							
		9873226	(2)						
	ORD STD 7949800								
	5210-790-0234	9873226							
		9873229	(3)						

REV SYM	REVISION DATE	REV SYM	REVISION DATE	REV SYM	REVISION DATE
ORIG	11/17/58				

LIST OF INSPECTION EQUIPMENT NUMBERS FOR:

INSTALLATION, SUSPENSION

PREPARED | REVIEWED

SUBMITTED

APPROVED BY ORDER OF THE

IEL F 9873217 SHEET 2 OF 2

FIGURE 6. *Cross reference list (standard inspection equipment).*

This system represents the minimum procedures for maintaining Lists of Inspection Equipment current. However, it is not intended to prohibit the responsible installation from revising the List of Inspection Equipment for all part changes (material and other specification changes as well as dimensional revisions) if desired. It is mandatory, for successful operation, which once established, the system used must be maintained consistent without change within the given installation.

1.5 INSPECTION EQUIPMENT DRAWINGS. Inspection Equipment Drawings are prepared in accordance with MIL-D-70327 Engineering Drawings and Lists and its complement of the first 31 Mil-Stds. This handbook restates the basic procedures set forth in MIL-D-70327 with additional detail concerning their application.

1.5.1 *TYPES OF INSPECTION EQUIPMENT DRAWINGS.* Inspection equipment drawings may be either of two general types, detailed drawings or specification type drawings.

1.5.1.1 *Detailed Drawings.* Detailed drawings are those drawings which completely depict all the information necessary in the fabrication of an item of inspection equipment.

1.5.1.2 *Specification type drawings.* When it is desired to procure a device purely on the merits of its performance or upon the manufacturer's specifications, an envelope drawing is prepared. It depicts the device in outline or pictorial form only and specifies the required performance or characteristics. The manufacturer's name or model number shall not be used; only industry standardized model numbers. When it is necessary to specify the manufacturer's name and model number, a qualifying note may be applied or a specification control drawing may be used. (See Mil-Std-7 and figure 7.)

1.5.2 *PREPARATION OF INSPECTION EQUIPMENT DRAWINGS.* Inspection equipment drawings may be prepared as Mono-Detail drawings, as Detail Assembly drawings or as a combination of the two.

1.5.2.1 *Mono-Detail Drawings.* Mono-Detail drawings are those drawings which depict only one detail or part per drawing. See figure 8.

1.5.2.2 *Detail Assembly Drawings.* Detail assembly drawings are those assembly drawings which have some or all of the dimensions placed on the assembly views in order to eliminate or reduce the number of separate detail drawings as in Figures 9 and 10.

1.5.2.3 *Selection of Type of Drawing.* The choice of drawing type is determined by several factors. The number of interchangeable parts, the necessity for field maintenance and repair, the quantity to be procured, and the method of manufacture, all play a part in the decision as to whether mono-detail or detail assembly drawings shall be used.

1.5.2.3.1 If the equipment is complex and can be broken down into a large number of individual parts, some of which are standardized or interchangeable, and if it is utilized in field service operations or is to be procured in large quantities, the mono-detail system is preferred. Most test equipment and automatic gaging equipment falls in this category.

1.5.2.3.2 If the equipment is not overly complex, contains relatively few standard or interchangeable parts, is procured in small quantities, and is stocked and issued as an entity, then the detail assembly approach or a variant is preferable. Most gages fall in this category.

1.5.3 *CLASSIFICATION OF DRAWINGS.* For purposes of standardization, stock control and identification, inspection equipment and inspection equipment drawings are divided into two general categories, Standards and Specials.

1.5.3.1 *Standards.* Standard inspection equipment is equipment that has a universal application for a specific function and whose physical characteristics have been standardized at the Department of Defense level. Equipment standardized and utilized throughout the Department of Defense is referred to as Military Standard equipment.

1.5.3.1.1 *Cataloging.* Catalogs have been prepared for the various types of Military Standard gages. The gages are listed in order of ascending size and are numbered in sequence.

1.5.3.1.2 *Standard Drawings.* Drawings are prepared by the individual services for prototypes of Military Standard equipment or equipment that is similar in design to Military Standard equipment but is not included in the dimensional scope of the Mil-Std catalogs. This equipment is referred to for convenience as Standard equipment. Drawings are prepared for this equipment with the aim of ultimate inclusion in the Mil-Std catalogs.

1.5.3.2 *Special drawings.* Special inspection equipment drawings are those which are primarily applicable to one particular type of part and are subject to individual design peculiarities. This does not preclude the possibility of special equipment having multiple application, because the identical

NOTES

1. REQUIREMENTS:
   - A. THE COMPLETE REQUIREMENTS FOR PROCUREMENT OF GAGE DESCRIBED SHALL CONSIST OF ALL REQUIREMENTS SPECIFIED HEREON.
   - B. DIAL : 0-20-0, WITH REVOLUTION COUNTER AND TOLERANCE HANDS.
   - C. GRADUATIONS : .0005
   - D. CAPACITY : .670 - .770
   - E. GAGING LENGTH : 6.0
   - F. RANGE OF SENSITIVE CONTACT : .100
2. MARKING:
   - A. THE FOLLOWING MARKING TO BE ENGRAVED ON BRASS PLATE AND FASTENED TO GAGE HANDLE BY SELF-TAPPING MACHINE SCREW.

      8645156
      DIA GAGING RANGE
      MIN .67 MAX .77
      US GOVT INSP
3. ITEM DESCRIPTION (FOR ENGINEERING REFERENCE ONLY):
   - A. ITEM : INDICATOR GAGE (HOLE)
   - B. TYPE : RETRACTING CONTACTS
4. THIS ITEM MAY BE PROCURED FROM THE FOLLOWING SOURCE:
   FEDERAL PRODUCTS CORPORATION
   PROVIDENCE, R. I.
   MODEL 1243P-1 :
5. REFERENCE PART:
   - A. FOR SETTING RING SEE IEL

SPECIFICATION CONTROL DRAWING

FIGURE 7. *Specification control drawing.*

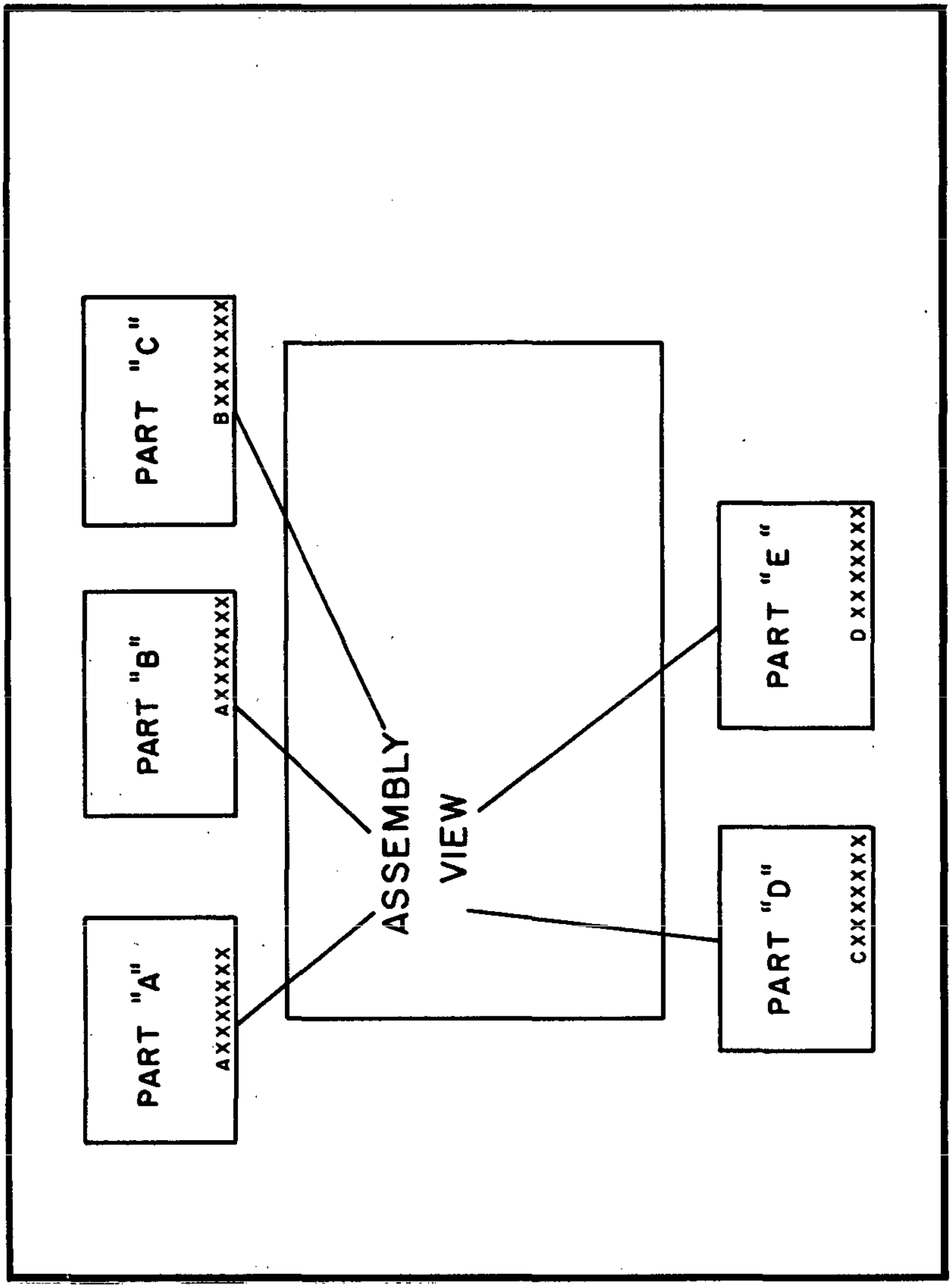


FIGURE 8. *Mono-detail drawing.*

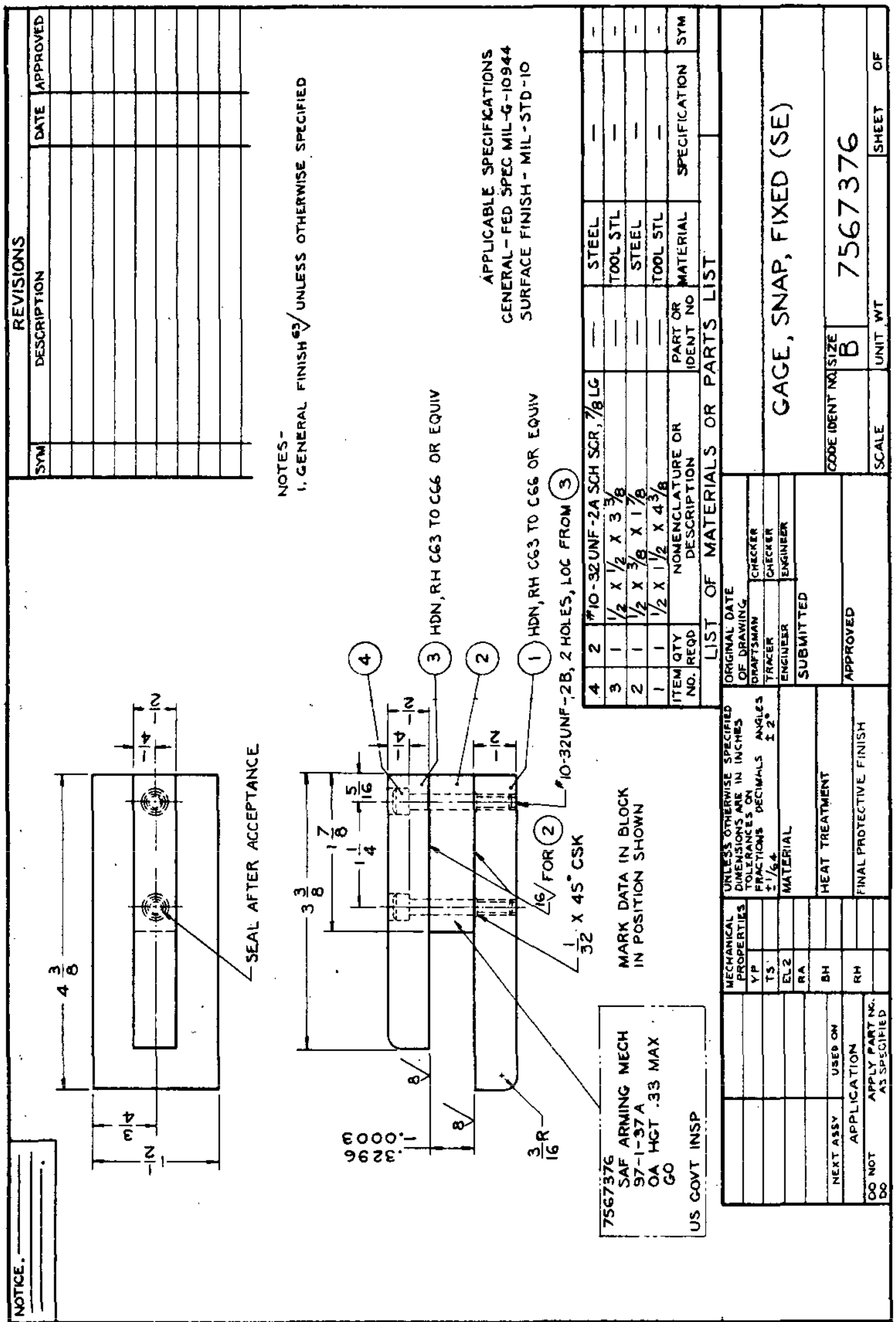


FIGURE 9. Detail assembly drawing.

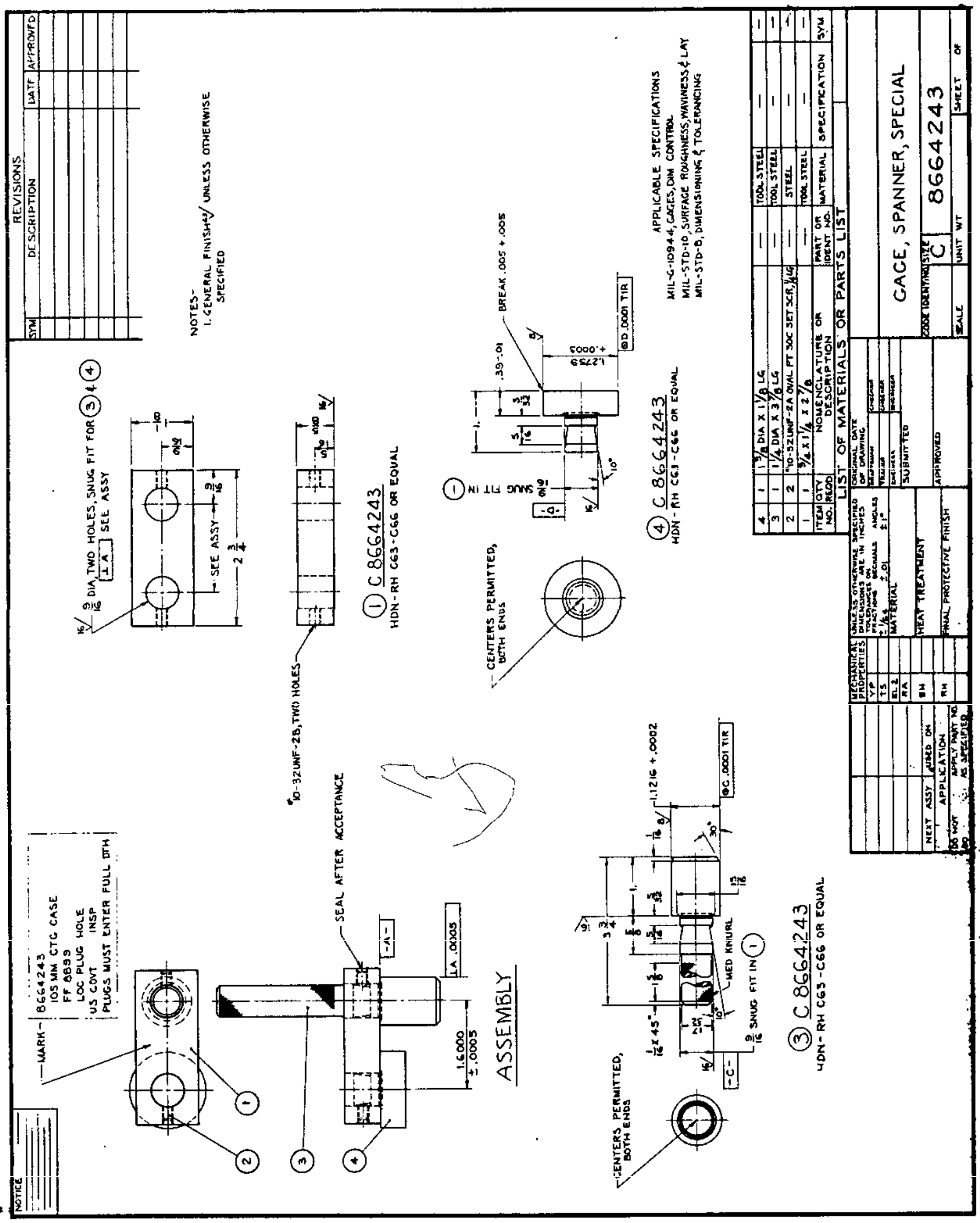


FIGURE 10. *Detail assembly drawing with breakouts.*

part features may re-appear on several similar items; e.g., diameter bourrelet for 105mm shells, multiple lead threads, diameter of retaining ring grooves, etc. Special drawings shall require referencing of the applicable parts.

1.5.4 *INSPECTION EQUIPMENT DRAWING PRACTICES.* The methods of presentation, terminology, dimensioning and tolerancing, shall be in accordance with MIL-D-70327 Engineering Drawings and Associated Lists, the latest applicable Military Standards numbered 1 through 31, and as prescribed in this handbook.

1.5.4.1 *Clarity.* An inspection equipment drawing is, in effect, a legal document. Therefore, the basic for rejections shall be so indicated on the drawing as to fully protect the Government from accepting inferior workmanship, especially in the event of controversies which could result from misinterpretation of the drawing. Therefore, it is of the utmost importance that all drawings be clear in every respect and free from ambiguity at any point. To assure that the designer's intent is clearly described, the following should be noted.

1.5.4.1.1 *Enlarged Sections.* An enlarged section of the equipment shall be shown where the complexity of the particular detail makes such enlargement essential.

1.5.4.1.2 *Minor Clearances.* Both important and minor angles, radii and chamfers must be toleranced to prevent the manufacturer from taking excessive latitude on these features, thus causing the equipment to function improperly.

1.5.4.2 *Dimensioning and Tolerancing.* The dimensioning and tolerancing of inspection equipment drawings shall conform to the practices set forth in MIL-STD-8, Dimensioning and Tolerancing.

1.5.4.2.1 *Gaging Dimensions.* Gaging dimensions are those which control the location and accuracy of precision gaging surfaces and, therefore, are of the utmost importance. Therefore, it is imperative that these dimensions be carefully applied and accurately checked.

1.5.4.2.2 *Detail Dimensions.* The detailed parts or pieces of inspection equipment shall be dimensioned in a manner which will insure correct assembly and economical manufacture. Accordingly, the following precautions should be taken.

1.5.4.2.2.1 *Positional Tolerances.* The allowable eccentricity, misalignment and similar features between various pieces or parts of equipment shall be specified, especially when the requirements are of a higher degree of accuracy than that specified in MIL-G/10944. If a dimension which is vitally concerned with the function of the equipment is covered within the limits of accuracy of MIL-G-10944, it is recommended that a symbol and cross-reference to a note referencing MIL-G/10944 be applied.

1.5.4.2.2.2 *Dimensioning System.* It has been the practice to specify in decimal form those dimensions which are critical to the proper functioning or operation of the equipment or which must be rigidly checked in the acceptance inspection of the equipment, while those dimensions which are non-critical are specified in fractional form. Although this system may be continued for convenience, it is no longer mandatory and conversion to the complete decimal system of dimensioning is recommended.

1.5.4.2.2.3 *Application of Dimensions and Tolerances.* Detail assembly dimensions should always be carefully cross-checked to eliminate any possible conflict. The tolerances should be carefully applied on piece or detailed dimensions to assure that an accumulation of them will not cause interference when assembling the part with its mate or mates. Further, dimensions shall never be duplicated on separate views or enlarged sections. (If it is absolutely necessary to refer to a dimension in two or more places on a drawing or set of drawings, that dimension shall be identified by a symbol which shall be used as a substitute for the actual dimensions in all places where it must be repeated.)

1.5.4.2.3 *Reference Dimensions.* Reference dimensions are applied to drawings as an aid in manufacture and acceptance inspection. Reference dimensions shall be computed with an accuracy which is in keeping with the degree of accuracy required for the final product. For rigidly controled parts, the rounding of numbers should not be accomplished until the final result has been computed. Measurements over rolls and wires, for example, are sometimes given as reference figures. (MIL-STD/120 outlines various means for precision measurements over rolls or wires and gives related formulae for calculations.) All reference dimensions are based on maximum material conditions unless otherwise labeled; for instance, a dimension based on mean metal condition should be labeled, "REF MEAN". Reference dimensions also should be used on detailed pieces to indicate critical requirements which must be controlled at assembly.

1.5.4.3 *Delineation of Commercial Items.* Drawings for commercial gages, equipment and related items such as bases, frames, clamps, etc., need only show the necessary object line at assembly. Dimensions are not required unless the commercial gage or item requires modification or the designer believes some difficulty may arise in procurement.

1.5.4.4 *Scale.* Designs should be drawn to full size whenever practical. Small type gages, for example may be drawn several times size to achieve the necessary clarity. The scale to which the majority of views and sections are drawn shall be entered in the prepared space as provided on the drawing format, in fractional form such as 1/1, 1/4, or 2/1. The scale of each view or section drawn to other than the predominating scale shall be entered directly below the view or section as "SCALE 2/1". In the event that an item is drawn several times the size, an outline of the assembly, drawn to actual scale, should be provided somewhere near the oversize assembly.

1.5.4.5 *Abbreviations.* MIL-STD/12 should be used as a standard for all abbreviations. In general, drawing notes and specifications describing fits, alignment and assembly requirements should not include abbreviations unless the meaning is unquestionably clear. On the other hand, the identification data shall contain the maximum number of abbreviations that may be used without sacrificing clarity.

1.5.4.6 *Identification Data.* The identification data to be applied to the equipment shall be as concise as possible and consistent with the proper procedures as applied to the various categories of equipment. Abbreviations shall be used as noted above. Identification data shall never be applied on any precision surface.

1.5.4.7 *Cross-Reference.* All special inspection equipment drawings shall carry cross-reference to the applicable part drawing number in the Application column. Any other part drawings required to establish critical dimensions shall be listed as reference parts.

1.5.4.8 *Drawing Titles.* The title applied to the drawing of inspection equipment shall conform to any accepted nomenclature for that equipment and shall be phrased in the inverted form as outlined in MIL-STD-28. (See also paragraph 3.1.1).

1.5.4.9 *Drawing Symbols.* Drawing symbols are a considerable aid in keeping general notes to a minimum.

1.5.4.9.1 *Hardness Symbols.* A preferred series of hardness symbols is recommended so that each appearance of a particular symbol will consistently indicate the same hardness; e.g., an asterisk (*) will always mean Rockwell Hardness C63 to C66 or equivalent. Such a series is shown in Chapter 2.

1.5.4.9.2 Surface Finish Symbols. MIL-STD-10, Surface Roughness, Waviness and Lay, serves as a basis for specifying the required surface finish.

1.5.4.9.3 *Tolerancing with Symbols.* MIL-STD-8, Dimensioning and Tolerancing, shall be the standard for expressing tolerance symbolically.

1.5.4.9.4 *Welding Symbols.* MIL-STD/19, Welding Symbols shall be used on drawings to indicate the application of all welding processes.

1.5.5 *REFERENCING OF SPECIFICATIONS ON DRAWINGS.* Those specifications pertaining to inspection equipment that are necessary to insure an acceptable piece of equipment shall be referenced on the drawing of said equipment.

1.5.5.1 *Gage Specifications.* MIL-G/10944, Gages, Dimensional Control, covers the minimum essential requirements for all types of dimensional control gages. It also references all specifications applicable to gages and gage drawings, except the two noted below. Therefore, only MIL-G/10944 need be listed on the gage drawing unless extreme clarity is required. There are two other new specifications;

(a) MIL-G-45653, Gages, Cylindrical Plug and Ring, Plain
(b) MIL-G-45654, Gages, Plug and Ring, Thread

which are used in place of MIL-G/10944 on the drawings for those particular type of gages.

1.5.6 *RELATED PUBLICATIONS.* The listing below presents those publications and documents of major interest to the design of inspection equipment. It is essential that each inspection equipment design agency maintain these documents current to the latest available revision.

1.5.6.1 *Specifications.*

MIL-G-10944—Gages, Dimensional Control
MIL-I-18422—Dial Indicators
MIL-I-45607—Inspection Equipment, Supply and Maintenance
MIL-D-45608—Design and Drawings of Inspection Equipment
MIL-G-45653—Gages, Cylindrical Plug and Ring, Plain

MIL-G-45654—Gages, Plug and Ring, Thread
MIL-D-70327—Drawings, Engineering and Associated Lists

1.5.6.2 *Standards.*

MIL-STD-1	General Drawing Practices
MIL-STD/2	Drawing Sizes
MIL-STD-7	Types and Definitions of Engineering Drawings
MIL-STD-8	Dimensioning and Tolerancing
MIL-STD-9	Screw Thread Conventions and Methods of Specifying
MIL-STD-10	Surface Roughness, Waviness & Lay
MIL-STD-12	Abbreviations for use on Drawings
MIL-STD-19	Welding Symbols
MIL-STD-24	Revision of Drawings
MIL-STD-28	Drawing Titles, Approved Method for Assignment of
MIL-STD-29	Springs, Mechanical Drawing Requirements for
MIL-STD-30	Associated Lists (Data List, Index List and List of Material)
MIL-STD-110	Gages, Plug, Plain Cylindrical, Go
MIL-STD-111	Gages, Plug, Plain Cylindrical, Not Go
MIL-STD-112	Gages, Ring, Plain, Go
MIL-STD-113	Gages, Ring, Plain, Not Go
MIL-STD-114	Gages, Plug, Thread Go
MIL-STD-115	Gages, Plug, Thread, Not Go
MIL-STD-116	Gages, Ring Thread, Go
MIL-STD-117	Gages, Ring, Thread, Not Go
MIL-STD-118	Gages, Snap, Plain Adjustable
MIL-STD-120	Gage Inspection
MIL-STD-133	Thread Minor Diameter Go Plain Plugs
MIL-STD-134	Thread Minor Diameter Not Go Plain Plugs
MIL-STD-273	Gages, Plug, Thread Setting, Class W, for Go Gages
MIL-STD-274	Gages, Plug, Thread Setting, Class W, for Not Go Gages

1.5.6.3 *Other Publications.*

Commercial Standard CS8, Gage Blanks
Screw Thread Standards for Federal Services, H28

1.5.5 *APPROVAL OF INSPECTION EQUIPMENT DRAWINGS.* The approval of inspection equipment drawings shall rest with the responsible activity. The procedures for approval set forth by each activity shall guarantee compliance with this handbook and related service documents in all respects. In cases where design is accomplished by contract, an adequate design liaison and surveillance program is essential to educate the commercial facility as to correct procedures, design specifications, drafting practice, etc., in order to insure an acceptable product for the Government.

1.5.8 *DISTRIBUTION OF INSPECTION EQUIPMENT DRAWINGS.* The distribution of inspection equipment drawings shall be in accordance with the procedures established by each responsible activity.

1.5.9 *REVISION OF INSPECTION EQUIPMENT DRAWINGS.* Revision of inspection equipment drawings shall be accomplished in accordance with MIL-STD-24, Revision of Engineering Drawings.

1.5.10 *SECURITY CLASSIFICATION.* Normally, inspection equipment drawings will not carry a security classification. However, if an equipment drawing in any way reveals the nature of classified materiel, the drawing shall have the same security classification as the item to which it pertains.

1.6 ENGINEERING ORDERS. In accomplishing the distribution or revision of inspection equipment drawings, a formal document must be prepared to direct the attention of the contracting officer to the engineering action being taken. This document is referred to by various names but is most generally known as an Engineering Order. It is the document which acts as a basic transmittal and cover sheet to identify and summarize an engineering release or change action. The Engineering Order directs procurement and contracting actions into contracts for procurement and manufacture of Government materiel which is committed to production or is in the process of such commitment. See figure 11.

1.7 ANALYSIS OF INSPECTION REQUIREMENTS.

1.7.1 *OBJECT OF INSPECTION.* The object of inspection is to insure that the part being inspected conforms with all requirements specified either by the engineering drawing of the part or by related specifications.

1.5.2 *BASIC CATEGORIES OF INSPECTION.* There are three general categories of inspection requirements: dimensional, performance, and material.

ORDNANCE CORPS
ENGINEERING ORDER

FOR REGULATION PERTAINING TO THE USE OF THIS FORM SEE ORDM-4-4 MANUAL

ENGR ORDER NO. FOM 65511
SHEET 1 OF 3 SHEETS

TO: Ordnance Division, Army Inspection of Ordnance
Ordnance Agencies Concerned

DATE: 1-27-60

FROM: Engineering Division, Sub-Office, OTAC
Food Machinery & Chemical Corp., 1105 Coleman St., San Jose

COMMAND SYMBOL OTAC

YOU ARE HEREBY NOTIFIED OF THE FOLLOWING ENGINEERING ACTION, TO BE APPLIED TO PROCUREMENT OR PRODUCTION ONLY UNDER INSTRUCTIONS ISSUED BY THE CONTRACTING AGENCY.

DESCRIPTIVE DATA

MATERIAL (ORD ITEM)
Carrier, Personnel, Full Tracked, Armored, M113

AUTHORITY
ECR FOM 65511
AOS Identification
OMS Code
4020 24 2201 11

REASON FOR ENGINEERING ACTION: To overcome an impracticable production condition by eliminating cold shuts and shearing of material of Arm in Area of small radii during forging operation and thus provide for a more sound forging.

ENGINEERING ACTION:

Minor

This Engineering Order is issued to revise Suspension Support Arm 10875006 and 10875007 by increasing the radius of fillets from 7/32 to 1/2 at intersection of Arm with Trunnion and Wheel Hub Bosses.

YES	NO		YES	NO	
	X	MODIFICATION TO PRIOR PRODUCTION FEASIBLE		X	DAMWO RECOMMENDED
	X	MODIFICATION RECOMMENDED/REQUIRED		X	Repair Parts
			X		Inspection Equipment

APPLICATION

☒ EXISTING CONTRACTS/ORDERS NOW IN PRODUCTION ☐ FUTURE CONTRACTS/ORDERS NOT YET IN EXISTENCE
☐ EXISTING CONTRACTS/ORDERS NOT YET IN PRODUCTION

CLASSIFICATION

URGENCY OF CHANGE
MANDATORY, CLASS IV (CLASS I & II AFFECTS IMWO)
☐ OPTIONAL CLASS V ☐ INFORMATIONAL CLASS VI
APPLICATION

END ITEM REF.

☐ INITIAL RELEASE

DISTRICT ACKNOWLEDGMENT

AUTHORIZATION SECURED
INDICATE: ☐ OCO ☒ COMMAND

RECEIPT ACKNOWLEDGED BY:

DATE SIG: CONTRACTING OFFICER OR AUTH. REP. ORD DIST.

APPROVED BY: 1-29-60
For: Chief
Engineering Division, OTAC

CLASS I - PRIOR ITEM IS UNSUITABLE FOR ISSUE
CLASS II - PRIOR ITEM IS UNSUITABLE FOR COMBAT USE
CLASS III - NON INCORPORATION MAY CREATE DIFFICULTY
CLASS IV - INCORPORATION PROVIDES IMPROVEMENT
CLASS V - INCAPABLE OF AFFECTING PART

FIGURE 11. *Engineering order.*

1.7.2.1 Dimensional inspection requirements relate to conditions of size, form, position, or assembly.

1.7.2.2 Performance inspection requirements relate to the functioning of the end item or any of its sub-assemblies.

1.7.2.3 Material inspection requirements relate to the physical properties of the item such as weight, hardness, strength, etc.

1.5.3 *RESPONSIBILITIES OF INSPECTION EQUIPMENT ENGINEER.* It is the responsibility of the inspection equipment design engineer to thoroughly analyze all pertinent product requirements, prescribe the equipment deemed necessary to effect a creditable inspection and design the equipment as required.

1.7.3.1 The inspection equipment design engineer shall prescribe the necessary inspection equipment to inspect all defects excepting purely observational defects. Defects requiring comparison standards such as surface finish blocks, scratch and dig standards, etc., are not to be regarded as observational defects.

1.7.3.2 The equipment design engineer shall conduct a thorough analysis of all aspects of the inspection situation in order to provide the inspection equipment most consistent with the overall requirements. This analysis is discussed in the following paragraphs.

1.7.4 *ANALYSIS OF PRODUCT DRAWINGS.* As a prelude to the preparation of the inspection equipment lists and drawings, the inspection equipment design engineer shall conduct a thorough analysis of each part and its position and function at assmebly to assure that:

(a) The available part print is to the latest revision.

(b) The dimensions as applied will insure an acceptable product and necessary interchangeability, and are in accordance with MIL–STD–8.

(c) The tolerances as applied are to the maximum practical value which will not impair the functioning of the product.

(d) The dimensions and tolerances as applied will not create interference at maximum material conditions (except where desired), and are consistent with identical features on similar items which have different model numbers.

(e) The dimensions conform to recognized standard preferred sizes for threads, drilled holes, splines, ball bearing housings, bushings, etc.

(f) New drawings are not identical to drawings for established spare parts or other standards.

1.7.4.1 Recommended changes based on this analysis should be submitted to the responsible product design activity.

1.7.5 *ANALYSIS OF QUALITY ASSURANCE PROVISIONS.* When quality assurance provisions are included in the specifications for the item, the inspection equipment design engineer shall check to insure that:

(a) The Inspection Requirements are consistent in all respects with those previously issued for an identical or similar item.

(b) Inspection equipment has not been specified for dimensions on the part drawings which do not appear in the Inspection Requirements.

1.7.5.1 In the event that clarification or revision of the applicable quality assurance provisions is believed essential, recommendations should be submitted to the activity responsible for these specifications.

1.7.6 *DETERMINATION OF INSPECTION EQUIPMENT REQUIREMENTS.* In the preparation of the equipment lists, the analysis of specifications and product drawings is of considerable value since this analysis will convey to the inspection equipment design engineer the critical nature of certain dimensions and functions which should be inspected to insure interchangeability and proper functioning of the item. Since the great variety of inspection situations makes it virtually impossible to establish rigorous rules for governing these requirements, paragraphs 1.7.6.1 and 1.7.6.2 are offered for general guidance.

1.7.6.1 Inspection Equipment is Required:

(a) When specified in the Inspection Requirements issued by a material branch of the particular department.

(b) For parts and sub-assemblies which are supplied as spares and which must be interchangeable.

(c) For parts and sub-assemblies which are not supplied as spares but which mate with spares.

(d) Where the dimension is critical with regard to the proper functioning of the item.

(e) For special requirements as specified in the overall item specifications.

1.7.6.2 Inspection Equipment is Generally Not Required:

(a) For non-critical sizes having large tolerances or which are manufactured by methods which consistently reproduce the required size such as die-casting or stamping.

(b) For dimensions controlling the fit of one piece with another which are permanently attached (as by staking, soldering or welding) prior to acceptance inspection.

(c) For most "atmospheric fits" where variation in size or contour will not cause interference or disturb the functional characteristics of the item.

(d) For dimensions not specifically defined on the part drawing. (Example: Hole shown on a centerline but having no dimension or tolerance for its exact location and where the location will affect neither interchangeability nor the functioning of the item.)

(e) For dimensions specified without tolerance or limits and possessing no functional value. This includes "reference," "advisory," "construction," and "control" dimensions.

1.7.6.3 *Justification of Extent of Inspection Equipment Design.* In planning for the design of a complete set of equipment, the total cost of design and supply must be considered relative to the overall cost of manufacture for the complete item of materiel. As a general rule, the cost should not exceed 5% to 8% of the total monetary allotment of the contract.

1.7.6.3.1 *Design of Inspection Equipment for Experimental Items.* In designing for experimental items, improvised methods of inspection should be employed wherever feasible. Existing stock gages should be salvaged wherever practical to achieve economical gaging and maximum coverage. This will effect the greatest saving to the Government, since only a small percentage of experimental items are standardized for high production.

1.7.6.3.2 *Design of Inspection Equipment for Standardized Items.* When design is initiated for standardized items which will be produced in large quantities, design units can effect the greatest saving by providing gages and equipment having automatic or manual quick-operating features. The high initial cost of the equipment will be amortized by the subsequent saving in inspection time.

1.8 SELECTION OF INSPECTION EQUIPMENT. The type of inspection equipment to be employed in the inspection of a specific feature is established when the equipment list is initially prepared. However, in the actual design of the equipment, it may differ from the one first planned. In selecting the type of equipment, it is economically advisable to employ standard equipment if possible. When this is not practical, the design of special equipment is necessary. The design of expensive special equipment should be limited to standardized major items where high rate of production will amortize the extra cost.

1.8.1 *REQUIRED ATTRIBUTES OF INSPECTION EQUIPMENT.* Inspection equipment should possess certain fundamental qualities, namely: accuracy, practicality, and economy.

1.8.1.1 *Accuracy.* The name, "Inspection Equipment" applies to tools of specific types, but the name in itself does not necessarily imply a high degree of accuracy. The equipment should be designed to do its particular job, and the degree of accuracy should be commensurate with the accuracy required by the component.

1.8.1.2 *Practicality.* A design must be practical from a standpoint of both operation and manufacture. A good design should provide ease of application with a minimum loss of time and motion to the operator. Further, design considerations should minimize excessive or intricate machining and fabrication problems. Finally, thought should be given to the acceptance inspection of the equipment and, accordingly, to fully protect the Government, the drawing and applicable specification shall provide the equipment acceptance inspection facility with definite grounds for acceptance or rejection.

1.8.1.3 *Economy.* As a piece of inspection equipment is only one of the many tools required to produce the complete item of materiel, care must be taken to insure that it is economically satisfactory from an equipment manufacturing and component inspection viewpoint. However, precision and durability shall not be sacrificed to economy.

CHAPTER 2. ELEMENTS OF INSPECTION EQUIPMENT DESIGN

2.1 INTRODUCTION. This section defines basic inspection equipment design practices pertaining to construction and fabrication, tolerances, material and general specifications.

2.2 TOLERANCES AND ALLOWANCES

2.2.1 GENERAL. It is not the purpose of this manual to deal with all tolerances. Only general construction tolerances and tolerances to be applied to gaging dimensions will be discussed in detail.

2.2.2 *TOLERANCES FOR GENERAL CONSTRUCTION DIMENSIONS.* The determination of a suitable tolerance is governed primarily by the functional requirement of the dimension and secondarily by the economy of manufacture of the part. Where standard fits are involved, such as with screw threads and anti-friction bearing mountings, the tolerances have been standardized and reference tables are available. In other cases, the determination of tolerances depends upon experience in the type of manufacture involved.

2.2.3 *GAGE TOLERANCING POLICY.* Gage tolerances and allowances shall always be applied within the product limits, i.e., the extreme limits of the gage must in all cases fall within the acceptable product limits. The unilateral system shall be used in applying tolerances to gaging dimensions which control the extreme product limits. The bilateral system is preferred in applying tolerances to gaging dimensions which are based on mean or intermediate product dimensions, such as for location of holes.

2.2.4 *TOLERANCES FOR GAGING DIMENSIONS.* The tolerances applied to the functioning dimensions of gage designs shall be in accordance with tables I, II, and III, unless the tolerance specified imposes an impossible machining problem. In the case of large or complex gaging dimensions where the tolerance specified in the tables or computed on the basis of ten percent of the product tolerance results in impractical tolerances, the product designer may allow additional tolerance or a larger percentage of the product tolerance will have to be consumed. To be practical, the gage tolerance should not be less than fifteen millionths of an inch per inch. On extremely large gaging dimensions, this figure will accumulate rapidly and consume the greater portion of the product tolerance. Care must be taken to avoid tolerances that cause confusion between the product and gage due to excessive encroachment upon part tolerances.

2.2.4.1 *Tolerances for Maximum or Minimum Limit Gages.* Where product dimensions are prescribed as maximum or minimum values without a given tolerance, the gage tolerance shall be based on an assumed product tolerance of .01 or the sum of the tolerances on the dimensions making up the overall dimension to be gaged, whichever is the lesser value.

2.2.4.2 *Tolerances Applicable to "After Painting" Gages.* For those specific gages used to measure maximum dimensions after painting, apply a gage tolerance based on 10% of thickness of paint or the tolerance specified in the tables for a component tolerance of .002 whichever is the larger.

2.2.5 *WEAR ALLOWANCE.* Wear allowance shall be applied on all fixed gage contact surfaces to provide a small amount of extra metal which lengthens the useful life of the gage. Excepted from this rule are all Not Go gages, adjustable snap or length gages which may be reset, flush pin gages, height or depth gages on which wear occurs on both surfaces in the same direction, certain classes of thread gages, taper gages with greater than 15° included angle, After Painting gages, and gages designed to reduce gage encroachment upon product tolerance through the use of wear-resistant materials such as tungsten carbide, etc.

2.2.6 *SPECIFIC GEOMETRIC REQUIREMENTS.* The tolerances directly specified on gage drawings for requirements such as concentricity, parallelism, perpendicularity, centrality, flatness, etc. shall be to the maximum that will still insure an accurate gage, but in general shall not exceed 10% of the part tolerance on that requirement. The method of specifying tolerance shall be in accordance with MIL-STD-8.

2.2.7 *IMPLIED GEOMETRIC REQUIREMENTS.* The general nature of gages requires that concentricity, parallelism, perpendicularity, centrality and flatness and other requirements be maintained within general close limits. A section covering this is included in MIL-G-10944 for the express purpose of controlling implied geometric requirements.

2.2.6 *SURFACE FINISH.* The graphic surface finish symbol as outlined in Figure 12, shall be used to designate the quality of surface desired. For application of this symbol see tables IV and V.

2.3 GENERAL CONSTRUCTION PRACTICES.

THIS TABLE SHALL APPLY TO :

1. TAPER PLUG AND RING GAGES (INCLUDED ANGLE UP TO AND INCLUDING 15°0'), FIXED SNAP GAGES, FLAT PLUG GAGES (EXCLUDING FLAT CYLINDRICAL TYPE). WEAR ALLOWANCE REQUIRED. COLUMNS 1, 2, AND 3 ARE APPLICABLE.
2. TAPER PLUG AND RING GAGES (INCLUDED ANGLE GREATER THAN 15°0'). WEAR ALLOWANCE NOT REQUIRED. COLUMNS 2 AND 3 ARE APPLICABLE.
3. MAX AND MIN GAGES, E. G., DEPTH, LENGTH, AND FLUSH PIN TYPES. WEAR ALLOWANCE NOT REQUIRED. COLUMN 2 APPLICABLE FOR BOTH MAX AND MIN TOLERANCES

SIZE RANGE		COMPONENT TOLERANCE	COL 1	COL 2	COL 3
ABOVE	TO & INCLUD'G		WEAR ALLOWANCE	TOLERANCE GO	TOLERANCE NOT-GO
.0	.825	.0005		.00004	.00004
.825	1.510			.00006	NO "NOT GO" GAGE USED
1.510	2.510			.00008	
2.510	4.510			.00010	
4.510	6.510			.00013	
6.510	8.510			.00015	
8.510	10 510			.00017	
10.510	UP			.00020	
.0	.825	.001	.00010	.00005	.00005
.825	1.510		.00010	.00006	.00006
1.510	2.510			.00008	.00008
2.510	4.510			.00010	.00010
4.510	6.510			.00013	NO "NOT GO" GAGE USED
6.510	8.510			.00015	
8.510	10.510			.00017	
10.510	UP			.00020	
.0	4.510	.002	.00010	.00010	.00010
4.510	6.510			.00020	.00013
6.510	8.510			.00020	.00016
8.510	UP			.00020	.00020
.0	.825	.003	.00010	.00010	.00010
.825	4.510		.00010	.00020	.00010
4.510	8.510		.00010	.00020	.00020
8.510	10.510			.00030	.00020
10.510	UP			.00030	.00030
.0	2.510	.004	.00020	.00020	.00010
2.510	4.510		.00020	.00020	.00020
4.510	8.510		.00020	.00030	.00020
8.510	12.510		.00010	.00040	.00020
12.510	UP		.00010	.00050	.00020
.0	2.510	.005	.00030	.00020	.00010
2.510	4.510		.00020	.00020	.00020
4.510	8.510		.00020	.00030	.00020
8.510	10.510		.00020	.00040	.00020
10.510	UP		.00010	.00050	.00030
.0	2.510	.006	.00030	.00020	.00010
2.510	4.510		.00030	.00020	.00020
4.510	6.510		.00020	.00030	.00020
6.510	8.510		.00020	.00030	.00030
8.510	10.510		.00020	.00040	.00030
10.510	12.510		.00020	.00050	.00040
12.510	UP		.00010	.00060	.00040
.0	1.510	.007	.00040	.00020	.00010
1.510	2.510		.00030	.00020	.00020
2.510	4.510		.00030	.00030	.00020
4.510	6.510		.00030	.00030	.00030
6.510	8.510		.00030	.00040	.00030
8.510	10.510		.00020	.00050	.00030
10.510	12.510		.00020	.00060	.00040
12.510	14.510		.00020	.00070	.00040
14.510	UP		.00010	.00080	.00050

SIZE RANGE		COMPONENT TOLERANCE	COL 1	COL 2	COL 3
ABOVE	TO & INCLUD'G		WEAR ALLOWANCE	TOLERANCE GO	TOLERANCE NOT-GO
.0	1.510	.008	.00040	.00020	.00010
1.510	2.510		.00040	.00020	.00020
2.510	4.510		.00030	.00030	.00030
4.510	6.510		.00030	.00040	.00030
6.510	8.510		.00030	.00040	.00040
8.510	10.510		.00030	.00050	.00040
10.510	12.510		.00020	.00060	.00050
12.510	14.510		.00020	.00070	.00050
14.510	UP		.00020	.00080	.00060
.0	.825	.009	.00040	.00020	.00010
.825	1.510		.00040	.00030	.00010
1.510	2.510		.00040	.00030	.00020
2.510	6.510		.00040	.00040	.00030
6.510	8.510		.00040	.00050	.00040
8.510	10.510		.00030	.00060	.00040
10.510	12.510		.00030	.00070	.00050
12.510	14.510		.00030	.00080	.00050
14.510	UP		.00030	.00090	.00060
.0	.825	.010	.00040	.00030	.00010
.825	1.510		.00040	.00030	.00020
1.510	4.510		.00040	.00040	.00030
4.510	6.510		.00040	.00050	.00040
6.510	8.510		.00040	.00060	.00040
8.510	10.510		.00040	.00070	.00050
10.510	12.510		.00040	.00080	.00050
12.510	14.510		.00030	.00090	.00060
14.510	UP		.00030	.00100	.00060
.0	1.510	.012	.00040	.00060	.00020
1.510	4.510		.00040	.00070	.00030
4.510	8.510		.00040	.00080	.00040
8.510	12.510		.00040	.00090	.00050
12.510	UP		.00030	.00100	.00060
.0	1.510	.014	.00040	.00060	.00020
1.510	4.510		.00040	.00080	.00030
4.510	8.510		.00040	.00100	.00040
8.510	12.510		.00040	.00120	.00050
12.510	UP		.00040	.00140	.00060
.0	2.510	.016	.00040	.00080	.00020
2.510	6.510		.00040	.00100	.00040
6.510	12.510		.00040	.00120	.00060
12.510	UP		.00040	.00140	.00080
.0	4.510	.020	.00040	.00100	.00040
4.510	6.510		.00040	.00100	.00060
6.510	12.510		.00040	.00150	.00080
12.510	UP		.00040	.00200	.00100
.0	4.510	.025 UP	.00040	.00100	.00080
4.510	6.510		.00040	.00100	.00100
6.510	12.510		.00040	.00150	.00150
12.510	UP		.00040	.00200	.00200

FOR COMPONENT TOLERANCE AND/OR SIZE RANGE NOT SHOWN, USE NEXT SMALLER COMPONENT TOL

TABLE I. *Gage tolerances (general).*

THIS TABLE SHALL BE USED FOR ALL CYLINDRICAL PLUG AND RING GAGES

SIZE RANGE ABOVE	SIZE RANGE TO & INCL	COMPONENT TOLERANCE	COL 1 WEAR ALLOWANCE	COL 2 TOLERANCE
GO GAGES				
.031	.825	MASTER		.00002
.825	1.510			.00003
1.510	2.510			.00004
2.510	4.510			.00005
4.510	6.510			.00006
6.510	9.010			.00008
9.010	12.010			.00010
.031	.825*	.0005		.00004
.825	1.510*			.00006
1.510	2.510*			.00008
2.510	12.010		USE APPROVED COML MEASURING DEVICE	
2.510	4.510*	.001		.00010
4.510	12.010		USE APPROVED COML MEASURING DEVICE	
.031	.825	.002	.00010	.00007
.825	1.510		.00010	.00009
1.510	2.510		.00008	.00012
2.510	4.510		.00006	.00015
4.510	6.510		.00005	.00019
6.510	12.010		USE APPROVED COML MEASURING DEVICE	
.031	.825	.004	.00020	.00010
.825	1.510		.00020	.00012
1.510	2.510		.00020	.00016
2.510	4.510		.00020	.00020
4.510	6.510		.00020	.00025
6.510	9.010		.00010	.00032
9.010	12.010		.00010	.00040
.125	1.510	.008 & UP	.00040	.00030
1.510	2.510		.00040	.00040
2.510	6.510		.00030	.00050
6.510	12.010		.00020	.00060

SIZE RANGE ABOVE	SIZE RANGE TO & INCL	COMPONENT TOLERANCE	WEAR ALLOWANCE	COL 3 TOLERANCE
NOT GO GAGES				
.031	.825	.0005		.00004
.825	2.510		SNUG FIT ON GO	
2.510	12.010		USE COML MEAS DEVICE	
.825	1.510	.001		.00006
1.510	2.510			.00008
2.510	4.510			.00010
4.510	12.010		USE COML MEAS DEVICE	
4.510	6.510	.002		.00013
6.510	12.010		USE COML MEAS DEVICE	
6.510	9.010	.004		.00016
9.010	12.010			.00020
.125	.825	.006 & UP		.00010
.825	1.510			.00012
1.510	2.510			.00016
2.510	4.510			.00020
4.510	6.510			.00025
6.510	9.010			.00032
9.010	12.010			.00040

*USE FOR ALL GAGES REQUIRING AIR GROOVES

THIS TABLE SHALL BE USED FOR ALL ADJUSTABLE SNAP AND LENGTH GAGES (TOLERANCES ARE IN TEN-THOUSANDTHS OF AN INCH)

COMPONENT TOLERANCE	SIZE RANGE: ABOVE 0. TO & INCL 2.500	ABOVE 2.500 TO & INCL 5.687	ABOVE 5.687 TO & INCL 12.000	ABOVE 12.000 TO & INCL 18.750	ABOVE 18.750 TO & INCL 25.500	ABOVE 25.500 TO & INCL 30.125
.020 UP	4	5	6	7	8	8
.015	4	5	6	7	7	7
.012	4	5	6	6	6	6
.010	4	5	6	6	6	6
.009	3	4	5	5	5	5
.008	3	4	5	5	5	
.007	3	4	5	5	5	
.006	3	4	5	5		
.005	3	4	5	5		
.003	2	2	3			
.001	1					

FOR COMPONENT TOLERANCE AND/OR SIZE RANGE NOT SHOWN, USE NEXT SMALLER COMPONENT TOL

APPROVED 3-1-56 REVISED

TABLE II. *Plug and ring gage tolerances.*

TABLE III. *Adjustable snap and length gage tolerances.*

2.3.1 *FABRICATION*

2.3.1.1 *Fabrication by Screws.* This is the most common method of fabrication. The length of engagement should range from 1 to 1½ times the diameter of the screw. Smaller gages such as built-up snap types and precision locating elements of fixture gages usually employ a fine pitch screw while a coarse pitch screw is considered adequate for securing large fixture gage elements where precision location is not of vital importance. Unified screw threads shall be specified. Where angularity, alignment or other types of precision location must be maintained within .005 or less, precision dowel pins or keyways should be used in conjunction with the screws. For general practices, see figure 13.

2.3.1.2 *Fabrication by Welding.* Welding is frequently used in the fabrication of larger equipment. It is a rapid, permanent, and economical means of fabricating. For method of specifying welding by symbols, see MIL-STD-19. The main disadvantage with welded constructions is the possibility of dimensional change due to the gradual release of internal stresses set up during the welding process. A stress relieving or artificial seasoning treatment of the welded assembly should always be specified to minimize this effect. Gaging dimensions of a high accuracy should never depend on welded assemblies.

2.3.1.3 *Fabrication by Brazing, Soldering, etc.* Brazing and soldering are used mainly for applying carbide inserts, balls, and other wear resistant anvils or locating surfaces to the equipment.

2.3.1.4 *Integral Part vs. Fabricated Type.* Manufacturing economy and ease of salvage are prime considerations in determining whether a part should be made in one piece or fabriacted from several pieces. Parts should be fabricated, if complex machining and grinding operations can be eliminated, even though several additional simple operations are required.

RECOMMENDED MICRO-INCH VALUES ACCORDING TO SIZE AND TOLERANCES			
SIZE RANGE		APPLY 4√ TO ALL GAGING TOLERANCES LYING BETWEEN THESE VALUES	
ABOVE	TO & INCL		
.029	.825	.00003	.00009
.825	1.510	.00004	.00011
1.510	2.510	.00006	.00014
2.510	4.510	.00007	.00017
4.510	6.510	.00009	.00022
6.510	9.010	.00012	.00028
9.010	12.010	.00015	.00035

APPLY 2√ TO GAGING TOLERANCES BELOW THESE VALUES

APPLY 8√ TO GAGING TOLERANCES ABOVE THESE VALUES

TABLE IV. *Surface finish applications.*

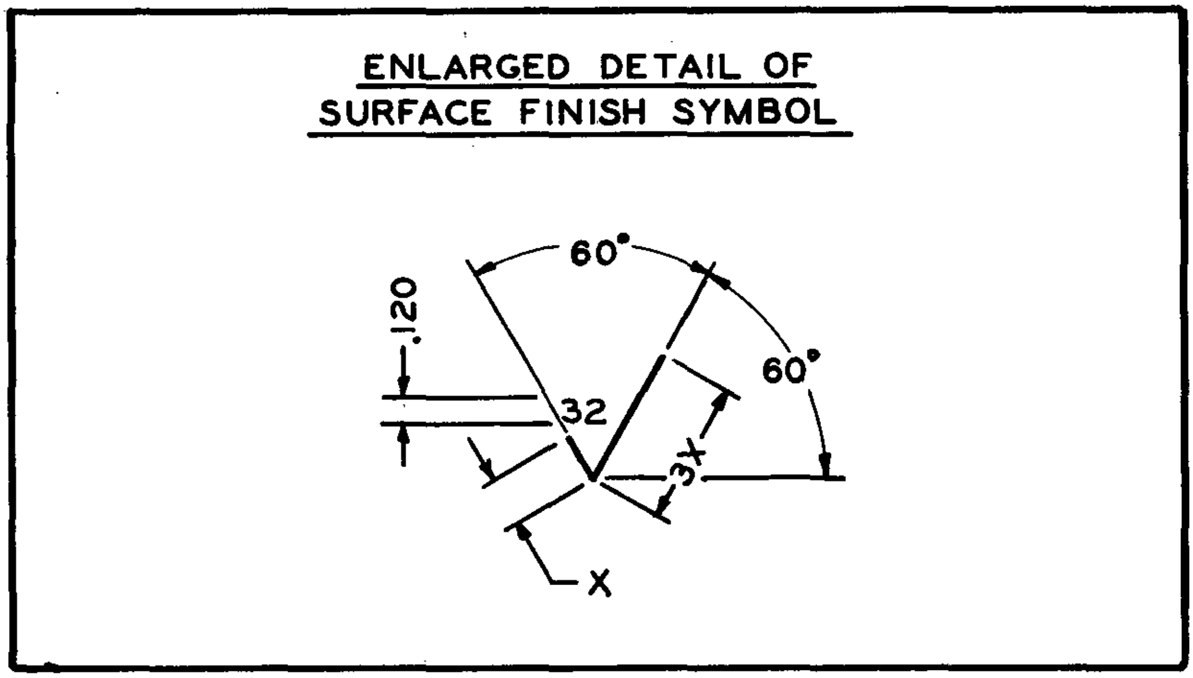


FIGURE 12. *Surface finish symbol.*

2.3.2 *LOCATION*

2.3.2.1 *Locating by Dowels.* See figure 14. To prevent relative movement between precisely located parts, hardened and ground steel dowel pins are used. They are often referred to as precision dowel pins. However, in using dowels, workmanship plays an important part in the final accuracy since a good fit is imperative. It is advisable to use a dowel pin of 3/16 diameter or larger to insure the likelihood of a precision fit unless space will not permit. Wherever possible, the length of engagement in each piece should be 1½ to 2 times the diameter of the dowel. Where repeated disassembly and assembly is required, the backing up method is preferred over dowel pins.

2.3.2.2 *Soft Plugs.* Where two hardened pieces must be located with respect to each other, or a pin must be located through a soft piece into a hard piece, soft steel plugs driven into the hardened pieces are recommended to facilitate machining at assembly

2.3.2.3 *Locating by Taper Pins.* Taper pins are used for the same general purpose as straight dowel pins. However, they are less susceptible to faulty workmanship. Taper pins are preferred because of their positive locational repeatability and their relative ease of removal.

2.3.2.4 *Locating by Keyways.* Locating by keyways is a suitable method of maintaining locational accuracy in one direction. However, the main disadvantage to this method as compared to dowels or taper pins is the higher cost entailed in the machining process. This may be reduced on smaller pieces by using the entire cross-section as a key.

A keyway will prevent shift in only one direction and, therefore, dowels are usually employed to overcome shift in the other direction. Keyways are used where locational accuracy must be maintained on several interchangeable elements which are common to one particular piece of equipment. The use of keyways is highly satisfactory where the factor of strength must be considered in maintaining locational accuracy. See figure 15.

2.3.2.5 *Locating by Backing Up Method.* By using a finished surface to back up a gaging element, locational accuracy can be maintained. Two finished surfaces in planes 90° apart will provide locational stability in two directions. This particular method of locating provides for repeated dis-

GENERAL:

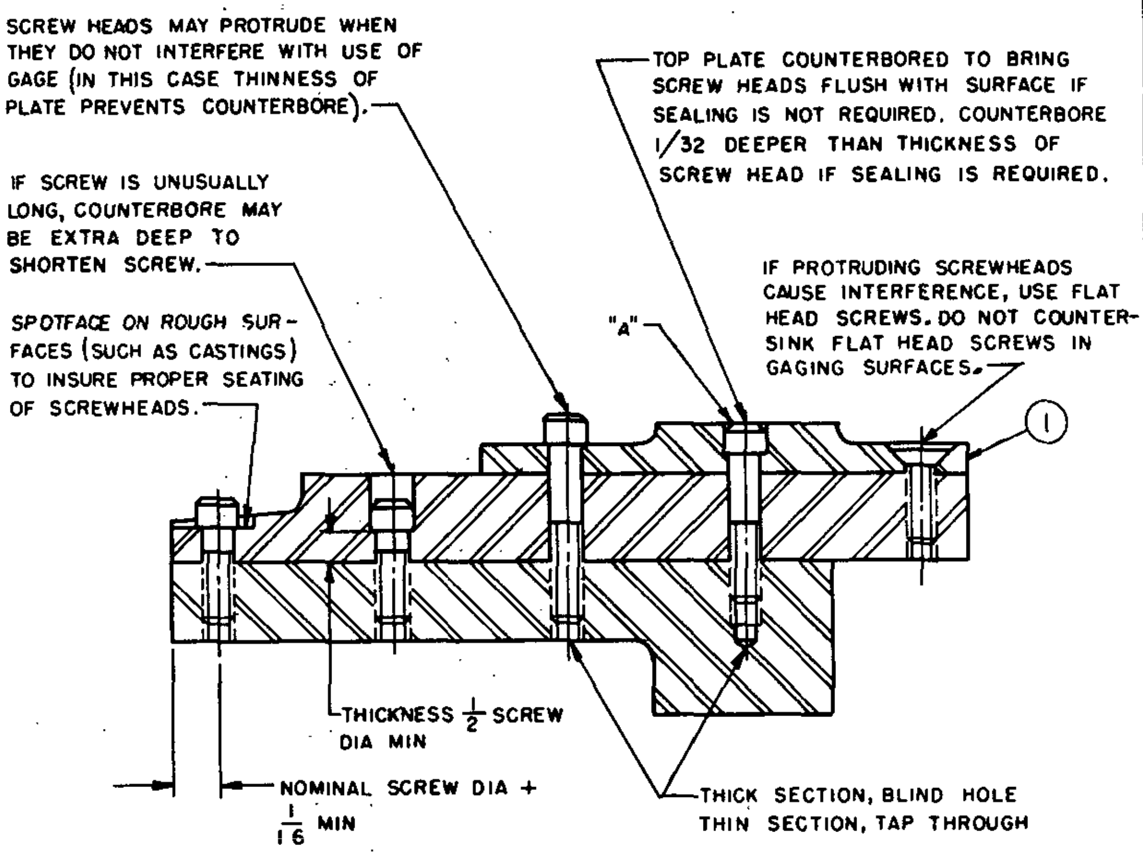
1. THE NUMERICAL VALUES SPECIFIED IN THESE TABLES REPRESENT THE MAXIMUM ALLOWABLE ROUGHNESS ON THE DESIGNATED SURFACE.
2. REQUIREMENTS FOR NATURAL FINISHES (CASTINGS, FORGINGS, ETC) SHALL NOT BE SPECIFIED ON DRAWINGS.

RECOMMENDED VALUES

TYPES OF FITS SURFACES, ETC.	MICRO-INCH VALUES						
	4√	8√	16√	32√	63√	125√	250√
EQUIVALENT FINISH DESIGNATION	PRECISION GROUND & LAPPED	GROUND & POLISHED	fg ff	f	f	cf	cf
COMPONENT CONTACTING SURFACES PRESENTING LINE OR POINT CONTACT	■						
CRITICAL SLIDE & BEARING FITS	■						
LESS CRITICAL SLIDE FITS (FLUSH PINS) *		■					
FEELER OR SIGHTING SURFACES			■				
PRECISION LOCATED SNUG, PUSH, DRIVE OR PRESS FITS *			■				
REFERENCE SURFACES FOR MEASURING PURPOSES			■				
FREE OR RUNNING FITS				■			
NON PRECISION LOCATED SNUG, PUSH, DRIVE OR PRESS FITS *				■	■		
OVERALL CLEANUP FINISHES (HAND GAGES)					■		
OVERALL CLEANUP FINISHES (BASES OR OTHER UNIMPORTANT MACHINED SURFACES)						■	■

* THE CLASS FIT SHALL BE CONSIDERED WHEN SPECIFYING THE REQUIRED FINISH. DEVIATIONS FROM THE RECOMMENDED VALUES ARE PERMITTED IF JUSTIFIED.

TABLE V. *Surface finish applications.*



METHOD OF DETAILING (EXAMPLE—SCREW "A")

1. LOCATION DIMENSIONS FOR COUNTERBORE SHALL BE SHOWN ON DETAIL OF PART SCREW ENTERS FIRST OR (1). A NOTE SHALL BE SHOWN "FOR $\frac{X}{X}$ SCH SCR, X HOLES".
2. THE PART THAT IS TAPPED TO RECEIVE THE SCREW SHALL HAVE A NOTE "$\frac{X}{X}$—X XNF—XB, X HOLES, LOCATE FROM (1)".
3. ANY INTERMEDIATE PARTS SHALL HAVE A NOTE "FOR $\frac{X}{X}$ SCR, X HOLES, LOCATE FROM (1)" (PART ENTERED FIRST).

FIGURE 13. *Fabrication by screws (general practices).*

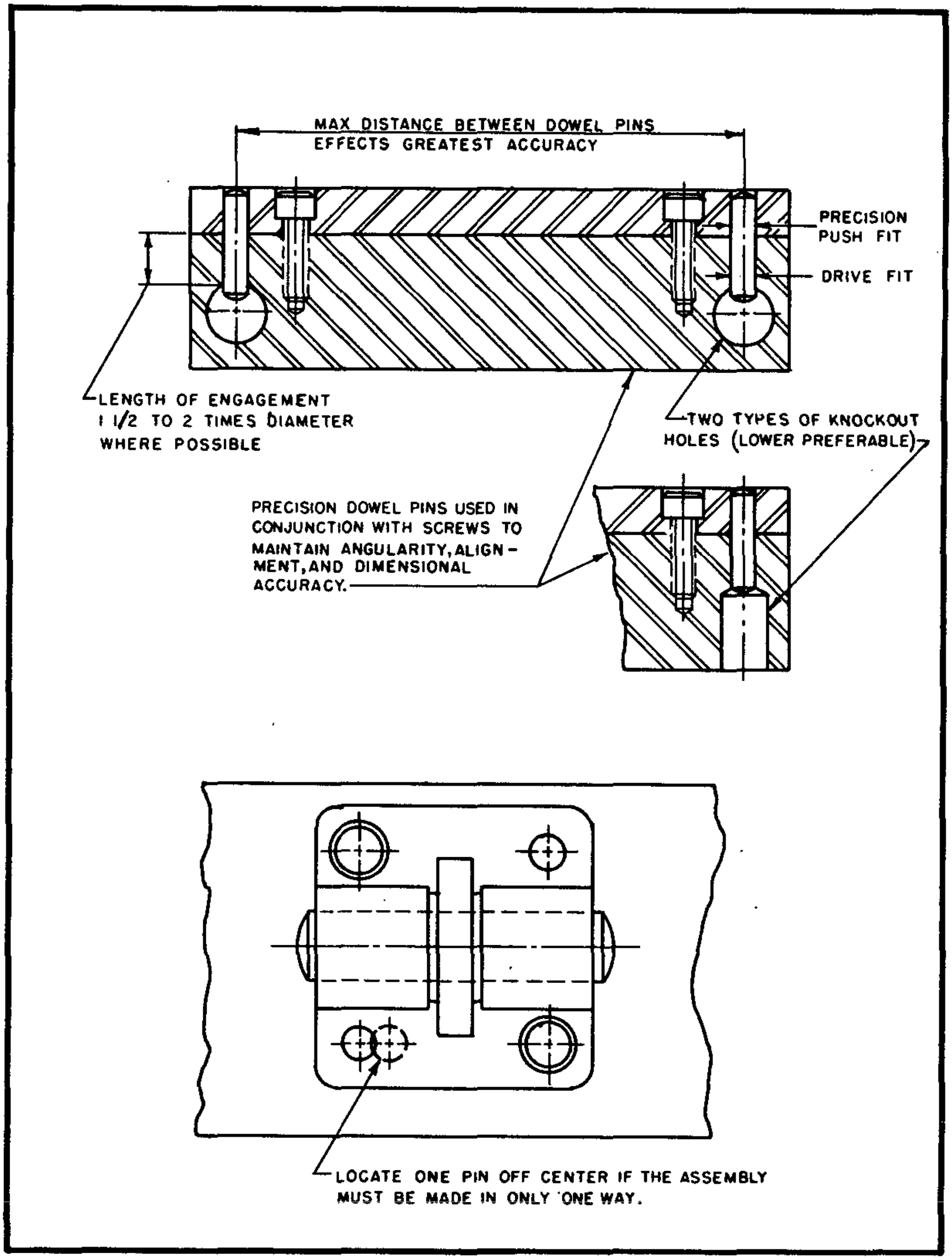


FIGURE 14. *Locating by dowels.*

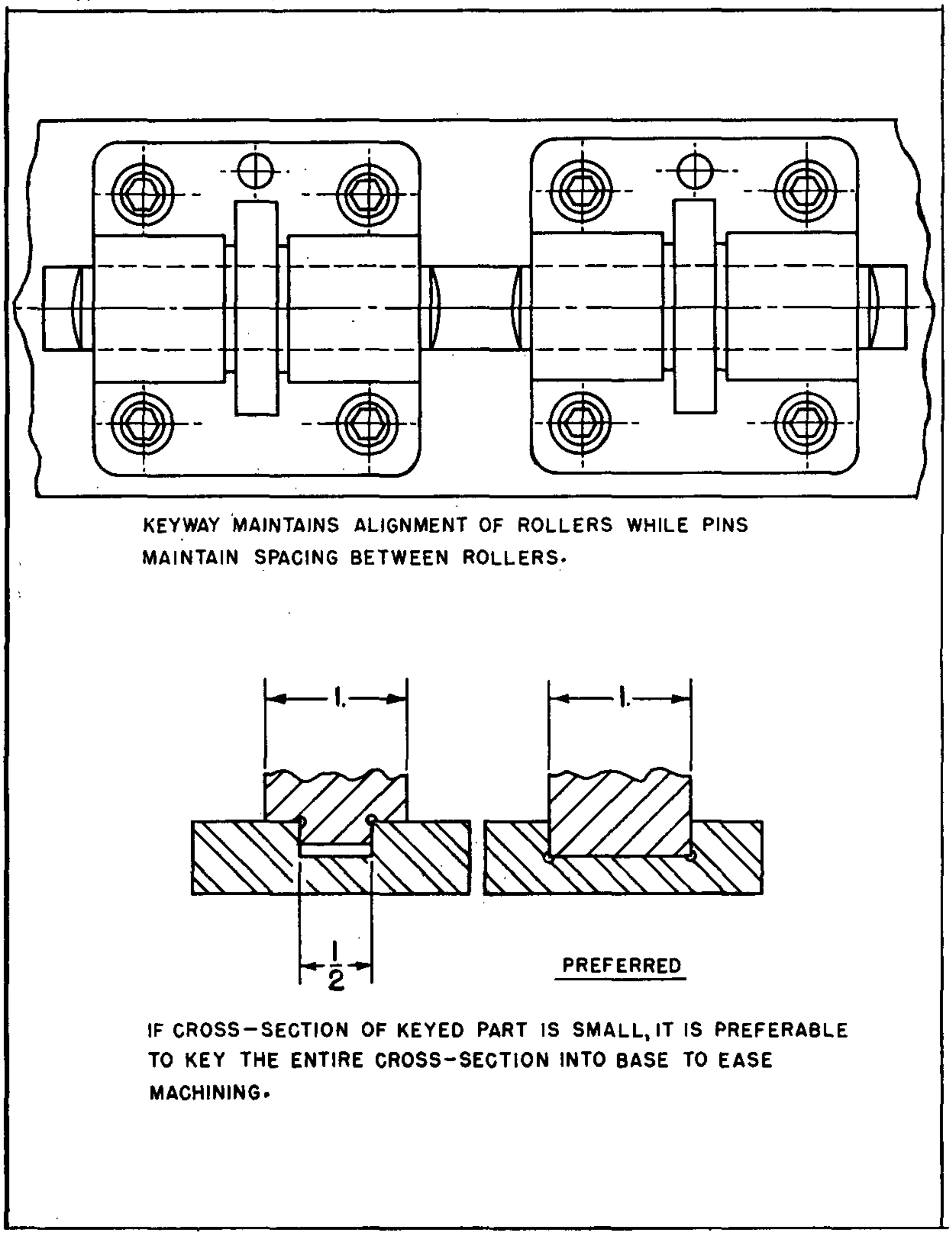


FIGURE 15. *Locating by keyway.*

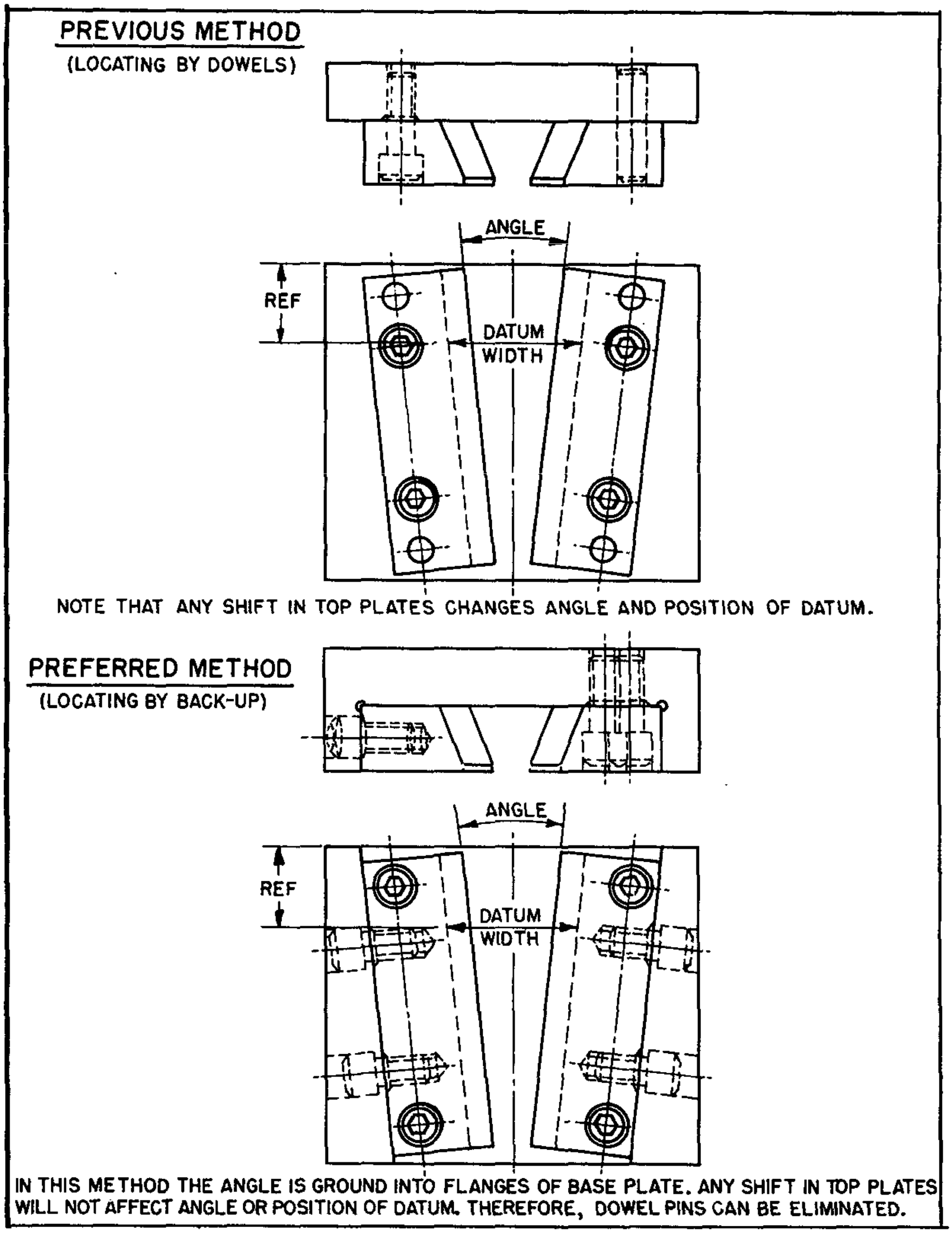


FIGURE 16. *Locating by back-up method.*

assembly and assembly without loss of dimensional accuracy. See figure 16.

2.3.3 *ADJUSTING DEVICES*

2.3.3.1 *Screws.* The use of screws is a very common method for providing adjustments. A fine pitch screw together with a locking nut will usually suffice for most purposes. Various type special screws are also used for locating and anti-backlash devices.

2.3.3.2 *Locators and Special Mechanism.* Where speed is essential in operation, quick acting adjusting devices should be designed using locating buttons and spring loaded elements to reduce unit inspection time.

2.3.4 *INTERCHANGEABLE AND REPLACEABLE ELEMENTS.*

2.3.4.1 An interchangeable element is one of a related series which makes a piece of equipment applicable to several related items.

2.3.4.2 A replaceable element is one that is subject to extreme wear or impact and may require frequent renewal. These type elements should be designed on an interchangeable basis.

2.3.4.3 Both replaceable and interchangeable elements shall be prepared on separate drawings and assigned a stock number. On equipment drawings utilizing these replaceable or interchangeable elements, they will be shown on the assembly view, be given a part number and proper reference made in the standard parts block to their assigned stock numbers.

2.3.5 *STANDARD PARTS OR MECHANISMS.* A standard part or mechanism is one that is applicable to several similar type pieces of equipment; for example, the bearing supports for shell concentricity gages. The development and application of standard parts is to be encouraged.

2.3.5.1 When a part or mechanism is designed that can be widely adapted for use on other pieces of equipment, a separate drawing should be prepared. The parts should be cataloged or indexed to provide an easy reference for the designer. The use of standard parts will generally reduce costs and delivery time.

2.3.6 *COMMERCIAL PARTS.* The use of commercial parts is preferred wherever their application is practical. In general, procurement time and costs are less as compared to specially designed parts.

2.3.7 *UNIVERSAL TYPE EQUIPMENT.* Universal type equipment is one which gages a particular function on various sizes of one type of material. The equipment in itself is designed on an adjustable basis to include the necessary size range. However, care should be exercised to insure that the expense entailed to include a wide size variation will be amortized in application. It is often better to provide a series of two, three, or four universal types to cover a certain size range than to design an extremely expensive and cumbersome unit to cover the entire size range. The development of universal type equipment is to be encouraged, particularly where it can be applied to a series of experimental items which do not warrant individual equipment. The designer should employ as many standard parts, interchangeable elements and commercial parts as possible in designing this type equipment.

2.3.8 *CASTING vs. MACHINED PARTS.* Generally, it is advisable to cast most bases and frames for large pieces of equipment. Elements which are difficult to machine or fabricate should be cast. It is usually a definite economic saving to supplant complex machined parts and large cumbersome pieces with castings when designing standard parts or equipment for standardized items.

2.3.9 *QUICK OPERATING DEVICES.* Complicated fixture gages usually are slow in operation and, therefore, the use of various quick operating devices is recommended to reduce the product inspection time.

2.3.10 *HELICAL COMPRESSION AND EXTENSION SPRINGS.* In inspection equipment, helical springs are used extensively on fixture type gages. They perform many functions such as: (a) returning moving parts to their original position, (b) in conjunction with arms or pressure pads to hold a component in a predetermined position while being gaged, (c) to retract gaging elements while component is being positioned, (d) to automatically seat multiple flush pin type elements where it is impractical for operator to seat each element individually.

2.3.10.1 Such springs, while important to the function of the gage, generally do not require a high order of accuracy in design or manufacture and it has been determined there is a need for a simplified method of calculation for springs of this nature. Such a method is presented here. For complete spring design data, consult Mil-Std-29, Springs, Mechanical Drawing Requirements For.

2.3.10.2 The data in this section, with its accompanying load-deflection tables, is sufficient for general design purposes and is not intended for use on unusual designs for highly accurate springs. All tabular values are slide rule calculations and are, in general, rounded off but are sufficiently accurate for common use.

2.3.10.3 Three (3) basic factors are generally known at the start of any spring design problem. They are Load, Deflection, and Space and are predetermined by the type of action and method of load application. These basic factors are then used to determine the secondary design factors: Wire diameter, Free length, Solid length, and Number of active coils.

2.3.10.4 Load (P) is the force built up by compressing or extending the spring to counteract an applied load in a mechanism, a known factor of weight in pounds. Loads should be specified at some definite compressed or extended length, not at some deflected distance from the free length, as the free length should be a reference dimension. Tolerances should preferably be applied to the loads.

2.3.10.5 Deflection (F) is the movement of a spring from its free or unloaded length to a prescribed operating position, which is established by the mechanism for which the spring has been designed. Deflection per coil is the total deflection of a spring under a given load, divided by the number of active coils.

2.3.10.6 Space is determined by the movement and dimensions of the associated parts, the spring being designed to conform to space limitations.

2.3.10.7 The type of ends should be specified on the drawing. When an extension spring is required, the ends shall be depicted and dimensioned.

2.3.10.8 Active coils (n) are those coils which permit deflection under applied loads. All coils are active in extension springs.

2.3.10.9 Wire diameter (d) is dependent upon load, deflection and working space, and should be specified in decimals to eliminate any confusion resulting from the various wire gauge sizes.

2.3.10.10 Free length is the overall length of spring in a free or unloaded position. For compression springs, assume a free length 1¼ to 2 times the working length. For unusual working length to spring diameter ratios, this figure may require adjustment.

2.3.10.11 Spring index is the ratio of the mean spring diameter to the wire diameter. The best proportioned springs, from the standpoint of manufacture and design, have a spring index of between 7 and 10, although indexes from 6 to 14 are frequently used.

2.3.10.12 Solid length is the length of a compression spring when it has been fully compressed and the coils are touching. It equals the diameter of the wire times the total number of coils.

2.3.10.13 Pitch is the spacing or dimension between the individual active coils of a spring.

2.3.10.14 Initial tension is the load in pounds which opposes the opening of the coils of an extension spring by an external force. It is wound into the spring during the coiling operation. The spring will have a uniform rate after the applied load overcomes the load due to initial tension.

Use of the Load-Deflection Tables

The values in the Load-Deflection tables represent the deflection per coil (f) of a spring under a load (P). The values may be increased or decreased in direct proportion to any desired change in load (P). See Table VI.

Example #1. Design a compression spring to work in a ⅜″ bore and exert a force of 6 lbs. at a working length of ⅝″.

Known:	O.D. of spring	23/64 (.359)
	Load (P)	6 lbs.
	Working Length	⅝
	Free Length	1. (assumed)
Required:	Wire diameter (d)	
	Solid length	
	Number of active coils	

In the 23/64 O.D. row of the Load-Deflection tables, the nearest figure for load (P) to the stipulated load of 6 lbs. is found to be the number 5.69 lbs. with a corresponding deflection per coil (f) of .064. Directly above these figures, at the top of the column, find the wire diameter which is .038. To find the deflection per coil (f_2) for 6 lbs., divide the value of (f), .064, by the value for (P), 5.69, and multiply by the required load (P) of 6 lbs.

$$f_2 = \frac{.064}{5.69} \times 6 = .0675$$

The number of active coils (n) is determined by dividing the total deflection of the spring (1 − ⅝ = ⅜) by the new deflection per coil (f_2).

$$\frac{.375}{.0675} = 5\tfrac{1}{2} \text{ active coils}$$

Total number of coils equals 5½ active coils plus 2 coils for squaring ends or 7½ coils.

The solid length equals the wire diameter (d) multiplied by the total number of coils.

$$.038 \times 7\tfrac{1}{2} = .285$$

Final design values—

Data—.038 wire diameter
$\frac{23}{64}$–$\frac{1}{64}$ O.D. of coil
6 lb. ± .6 lb load at
$\frac{5}{8}''$ compressed length
.285 solid length (given *as a max figure if space* is limited)
Ends squared

Reference Data—1. Free length
$7\frac{1}{2}$ total coils,
$5\frac{1}{2}$ active

Example #2. Design an extension spring $\frac{7}{16}$ outside diameter, full loop ends, in line, to exert a force of 8 lbs. at a 2. extended length inside loops.

Known: O.D. of spring $\frac{7}{16}$ (.437)
Load (P) 8 lbs.
Working Length 2. inside loops

Required: Wire diameter (d)
Free length, inside loops
Number of coils

In the $\frac{7}{16}$ row of the Load-Deflection tables, the nearest figure for load (P) to the stipulated load of 8 lbs. is found to be the number 9.14 lbs. with a corresponding deflection per coil (f) of .076. Directly above these figures, at the top of the column, find the wire diameter, which is .047. To find the deflection per coil (f_2) for 8 lbs., divide the value of (f) .076, by the value for (P), 9.14, and multiply by the required load (P) of 8 lbs.

$$f_2 = \frac{.076}{9.14} \times 8 = .066$$

Pitch equals the deflection per coil (f_2) plus the wire diameter.

$$P = .066 + .047 = .113$$

Length of loop = Inside diameter of coil (assumed) = .437 − (2 × .047) = .343.

Length over extended coils = 2. − (2 × .343) = 1.314

Number of coils equals the length over the extended coils divided by the pitch.

$$\frac{1.314}{.113} = 11.6 \text{ coils}$$

Free length = 11.6 × .047 = .545

Free length inside loops = .545 + (2 × .343) = 1.23

Final design values—

Data—.047 wire diameter
$\frac{7}{16}$ O.D. of coil
8 lb ± .8 lb load at 2. extended length, inside loops
Full loop ends, in line

Reference data—
1.23 Free length, inside loops
11.6 Total coils
Specify initial tension if required

2.4 MATERIALS: SELECTION, HEAT TREATMENT AND APPLICATION.

2.4.1 *GENERAL.* The selection of a proper steel in the construction of a gage is one of the most critical decisions a designer has to make. In an effort to remove some of the mystery surrounding steel selection, chemical analysis, tempering, etc., it is the aim of this section to give the designer a brief insight into the causes and effects of heat treatment of steel and the role it plays in the field of dimensional control. A gage drawing, however, accurately drawn and perfect in detail, remains inadequate so long as the physical materials from which it is to be fabricated are not judiciously chosen with respect to the tasks the gage must accomplish. A gage designer must further be guided in his selection of material by the degree of production expected, not only of the part to be inspected, but also of the gage. In other words, a gage for a high production part may dictate the use of cemented carbide gaging surfaces instead of tool steel and a particular *gage* that is expected to be made in large numbers (or become a basic or standard gage) may necessitate the use of a casting for a large part of the gage rather than machining the various parts from steel, which is costly and time-consuming. The designer must also take into consideration the shape or general configuration of the part when selecting steel. Parts of uniform or nearly uniform section can stand a more severe heat treatment than parts that have irregular form or have narrow protrusions. From the foregoing, which are just a few of the things a designer must consider when selecting steels, it can be seen that material selection is of the utmost importance to the designer.

2.4.1.1 *Heat Treatment* (defined). It is often erroneously assumed that heat treatment of steel applies only to the hardening and tempering of steel. According to the definition accepted by the American Society of Metals and the Society of Automotive Engineers, heat treatment is "an operation or combi-

O.D. OF SPRING		WIRE DIAMETER																		
		.010	.012	.014	.016	.018	.020	.022	.024	.026	.028	.030	.032	.034	.036	.038	.041	.047	.054	.062
7/64 (.109)	f	.026	.019	.015	.013	.011	.009	.008	.007	.006	.006	.005								
	P	.334	.590	.958	1.46	2.12	2.98	4.06	5.38	7.00	8.96	11.3								
1/8 (.125)	f	.031	.025	.021	.018	.015	.013	.011	.010	.009	.009	.007	.006	.006						
	P	.290	.507	.823	1.25	1.82	2.54	3.44	4.55	5.9	7.8	9.45	11.1	14.3						
9/64 (.140)	f	.041	.033	.027	.023	.020	.017	.015	.014	.012	.011	.010	.009	.008	.007	Tables are based on 75% of Max Allow. Stress and are corrected for curvature stress				
	P	.254	.448	.721	1.10	1.58	2.20	2.99	3.94	5.10	6.49	8.13	10.0	12.3	14.8					
5/32 (.156)	f	.051	.041	.035	.029	.025	.022	.019	.017	.015	.014	.013	.011	.010	.010					
	P	.227	.398	.642	.97	1.4	1.95	2.63	3.47	4.48	5.69	7.1	8.76	10.07	12.9					
11/64 (.172)	f	.062	.051	.042	.036	.031	.027	.024	.022	.020	.018	.016	.015	.013	.012					
	P	.206	.359	.578	.875	1.26	1.75	2.36	3.1	4.0	5.06	6.31	7.8	9.49	13.6					
3/16 (.187)	f	.075	.061	.051	.044	.038	.033	.030	.027	.024	.022	.020	.018	.016	.015	.014				
	P	.187	.328	.525	.796	1.14	1.59	2.14	2.81	3.62	4.58	5.7	7.0	8.52	10.2	12.2				
13/64 (.203)	f		.072	.061	.052	.045	.040	.035	.032	.029	.026	.024	.022	.020	.018	.017	.015			
	P		.301	.482	.728	1.05	1.45	1.96	2.56	3.3	4.16	5.18	6.36	7.73	9.27	11.0	14.1			
7/32 (.219)	f		.085	.071	.061	.053	.047	.042	.038	.034	.031	.028	.026	.024	.022	.020	.018			
	P		.278	.445	.671	.965	1.34	1.80	2.36	3.03	3.83	4.75	5.82	7.06	8.5	10.0	12.3			
15/64 (.234)	f		.098	.083	.071	.062	.055	.049	.044	.040	.036	.033	.030	.028	.026	.024	.022			
	P		.258	.414	.623	.895	1.24	1.67	2.18	2.80	3.54	4.39	5.37	6.52	7.81	9.28	11.8			
1/4 (.250)	f			.095	.081	.071	.063	.056	.051	.046	.042	.038	.035	.033	.030	.028	.025			
	P			.386	.581	.837	1.16	1.55	2.03	2.61	3.29	4.08	4.99	6.04	7.23	8.62	11.0			
17/64 (.265)	f			.108	.093	.081	.072	.064	.058	.053	.048	.044	.041	.037	.035	.032	.029	.024		
	P			.362	.545	.784	1.08	1.45	1.90	2.44	3.07	3.81	4.66	5.64	6.75	8.03	10.2	16.3		
9/32 (.281)	f			.121	.105	.092	.081	.073	.065	.059	.054	.050	.046	.043	.040	.037	.033	.027		
	P			.342	.512	.736	1.02	1.37	1.77	2.28	2.88	3.56	4.37	5.26	6.32	7.50	8.65	15.2		
19/64 (.297)	f				.117	.102	.091	.082	.074	.067	.061	.056	.052	.048	.045	.042	.038	.031		
	P				.484	.695	.962	1.29	1.69	2.16	2.71	3.36	4.12	4.97	5.95	7.04	8.96	11.3		
5/16 (.312)	f				.130	.114	.102	.091	.083	.075	.069	.063	.058	.054	.050	.047	.043	.035	.029	
	P				.458	.657	.910	1.22	1.60	2.04	2.56	3.17	3.87	4.68	5.61	6.63	8.45	13.5	20.0	
21/64 (.328)	f				.145	.127	.113	.101	.092	.083	.077	.070	.065	.060	.056	.053	.046	.039	.033	
	P				.436	.625	.866	1.16	1.51	1.94	2.42	3.1	3.7	4.45	5.31	6.29	8.0	12.7	19.1	
11/32 (.344)	f					.139	.124	.112	.101	.092	.085	.078	.072	.067	.062	.058	.053	.044	.037	
	P					.595	.822	1.10	1.44	1.83	2.31	2.86	3.48	4.21	5.04	5.96	8.17	12.0	18.0	
23/64 (.359)	f					.154	.137	.123	.111	.102	.093	.086	.079	.074	.069	.064	.059	.049	.041	
	P					.569	.783	1.05	1.37	1.75	2.20	2.73	3.32	4.01	4.80	5.69	7.20	11.4	17.2	
3/8 (.375)	f						.150	.135	.122	.111	.102	.094	.087	.081	.076	.071	.065	.054	.045	.037
	P						.750	1.00	1.31	1.67	2.10	2.60	3.17	3.82	4.56	5.42	6.85	10.9	16.3	26.0
25/64 (.390)	f							.147	.133	.121	.112	.103	.096	.089	.083	.078	.071	.059	.050	.041
	P							.962	1.25	1.60	2.02	2.49	3.04	3.66	4.38	5.18	6.55	10.4	15.5	24.8
13/32 (.406)	f							.160	.145	.132	.121	.112	.104	.097	.090	.085	.077	.064	.055	.045
	P							.920	1.20	1.54	1.93	2.38	2.91	3.51	4.18	4.95	6.28	9.95	14.9	23.6
27/64 (.422)	f							.173	.157	.143	.132	.121	.113	.105	.098	.092	.084	.070	.059	.049
	P							.887	1.15	1.46	1.85	2.29	2.80	3.36	4.02	4.75	6.02	9.52	14.2	22.6

TABLE VI. *Load deflections for helical springs.*

O.D. OF SPRING		WIRE DIAMETER																		
		.022	.024	.026	.028	.030	.032	.034	.036	.038	.041	.047	.054	.062	.072	.080	.091	.094	.105	.120
7/16 (.438)	f	.186	.169	.155	.142	.131	.122	.114	.106	.100	.091	.076	.065	.053	.044					
	P	.352	1.11	1.42	1.79	2.20	2.68	3.24	3.86	4.56	5.78	9.14	13.6	22.4	34.0					
29/64 (.453)	f	.201	.182	.166	.153	.142	.131	.123	.115	.108	.098	.082	.070	.058	.048					
	P	.821	1.07	1.36	1.72	2.12	2.58	3.11	3.72	4.40	5.56	8.80	13.1	20.8	32.6					
15/32 (.468)	f		.195	.179	.165	.152	.142	.132	.123	.116	.106	.089	.075	.063	.052					
	P		1.03	1.32	1.65	2.04	2.49	3.01	3.59	4.24	5.36	8.48	12.6	19.9	31.4					
31/64 (.484)	f		.210	.192	.177	.163	.151	.142	.133	.124	.114	.095	.082	.068	.056					
	P		1.00	1.27	1.60	1.97	2.40	2.90	3.46	4.08	5.16	8.17	12.2	19.2	30.1					
1/2 (.500)	f			.206	.189	.175	.163	.152	.142	.133	.122	.102	.088	.073	.060	.052				
	P			1.23	1.55	1.91	2.32	2.80	3.34	3.95	5.00	7.88	11.7	18.5	29.0	40.5				
17/32 (.531)	f			.234	.215	.199	.185	.173	.162	.152	.139	.117	.100	.084	.070	.060				
	P			1.16	1.45	1.79	2.18	2.62	3.14	3.70	4.66	7.36	11.0	17.3	27.0	37.6				
9/16 (.562)	f				.242	.224	.209	.195	.183	.172	.158	.133	.113	.095	.079	.069				
	P				1.37	1.68	2.05	2.48	2.94	3.48	4.39	6.93	10.3	16.2	25.3	35.3				
19/32 (.594)	f					.251	.234	.219	.204	.193	.177	.149	.128	.107	.090	.078	.065			
	P					1.59	1.94	2.34	2.78	3.28	4.15	6.53	9.71	15.2	23.8	33.0	50.1			
5/8 (.625)	f					.280	.261	.243	.229	.215	.197	.166	.143	.120	.101	.088	.074			
	P					1.51	1.84	2.21	2.63	3.11	3.93	6.16	9.19	14.4	22.4	31.2	47.6			
21/32 (.656)	f						.290	.270	.254	.238	.219	.185	.160	.134	.113	.099	.083			
	P						1.75	2.10	2.50	2.96	3.73	5.85	8.70	13.6	21.2	29.6	45.0			
11/16 (.688)	f							.298	.280	.264	.242	.205	.176	.149	.125	.110	.092	.089		
	P							1.99	2.38	2.81	3.55	5.58	8.25	13.0	20.2	28.1	42.7	46.2		
23/32 (.719)	f								.308	.290	.268	.225	.195	.164	.138	.121	.102	.099		
	P								2.28	2.68	3.38	5.31	7.88	12.4	19.4	26.8	40.0	44.0		
3/4 (.750)	f									.317	.291	.246	.214	.179	.152	.133	.112	.109	.093	
	P									2.56	3.23	5.06	7.50	11.8	18.3	25.4	38.7	41.9	60.5	
25/32 (.781)	f										.318	.270	.233	.196	.166	.145	.124	.120	.103	
	P										3.10	4.86	7.20	11.3	17.5	24.3	36.9	39.9	57.5	
13/16 (.812)	f										.345	.293	.253	.214	.181	.160	.135	.131	.112	
	P										2.97	4.66	6.90	10.8	16.8	23.2	35.4	38.2	55.3	
27/32 (.844)	f											.316	.274	.232	.196	.173	.147	.143	.123	
	P											4.48	6.61	10.4	16.1	22.2	33.9	36.6	52.7	
7/8 (.875)	f												.296	.250	.212	.189	.159	.155	.133	
	P												6.38	10.0	15.5	21.4	33.4	35.1	50.6	
29/32 (.906)	f												.320	.271	.239	.202	.172	.167	.140	
	P												6.15	9.62	14.9	20.6	31.4	33.7	49.8	
15/16 (.937)	f												.343	.291	.248	.218	.185	.180	.156	.132
	P												5.94	9.28	14.4	19.8	30.0	32.6	46.8	71.2
31/32 (.969)	f												.369	.305	.265	.234	.200	.194	.168	.142
	P												5.73	8.95	13.9	19.1	29.0	31.1	45.3	68.5
1.00	f												.395	.334	.284	.251	.214	.209	.160	.153
	P												5.53	8.65	13.4	18.5	28.0	30.3	43.6	66.0

TABLE VI. *Load deflections for helical springs*—Continued.

nation of operations, involving the heating and cooling of a metal or alloy in the solid state for the purpose of obtaining desirable conditions or properties." Heat treatment therefore includes hardening, tempering, annealing, or any other process which employs the use of heat to impart special properties to a metal. Heating and cooling for the sole purpose of mechanical working is excluded from the meaning of this definition.

2.4.1.2 *Theory of Heat Treatment.* Carbon is the chief hardening element of steel. In a fully annealed steel, carbon is in a certain form called pearlite and if the steel is heated uniformly above a certain temperature (called the critical or upper transformation point) a change in the structure occurs and the pearlite becomes austenite. (It is interesting to note that the steel becomes non-magnetic at this point and is one way of determining the correct hardening temperature.) If the steel is allowed to cool slowly, the austenite changes back into pearlite at the lower transformation point which is anywhere from 85° to 215°F. below the upper transformation point. These critical points have a direct relation to the hardening of steel. Unless a temperature sufficient to reach the upper transformation point is obtained, so that the pearlite may be changed into austenite, no hardening action can take place and unless the steel is cooled suddenly before it reaches the lower transformation point, thus preventing the austenite from changing back into pearlite, no hardening can take place. When steel is cooled suddenly from the upper transformation point to above 400°F. or to room temperature the austenite is transformed into a hard needle-like structure called martensite. It is this structure (which takes the place of the pearlite) that determines the hardness of a steel of stated carbon content. The lowest rate of cooling which results in the transformation of austenite into martensite without production of any pearlite is called the critical cooling rate; it is largely dependent upon the carbon content of the steel, being greater for low-carbon steels than for high-carbon steels.

2.4.1.3 *Hardenability.* The information in 2.4.1.2 is based on the assumption that the piece of steel subjected to treatment is of such small size that the change of temperature throughout its mass occurs at a constant rate. In actual practice, however, in a piece of steel of practical size, the outside surface cools more rapidly because it is in direct contact with the quenching medium while the center cools more slowly, with corresponding differences in the formation of the various microstructures. However rapid the cooling, therefore, martensite is formed only as an outside layer, while the structure of the interior may grade to coarse pearlite at the center. The depth of the case of martensite depends to a considerable extent upon the size of the austenite grains at the start of cooling; the coarser the initial grain structure, the deeper is the hardening for any stated rate of cooling. Constitution of the steel is the other important factor in depth of hardening; the action of alloying metals has the effect of permitting transformation of the austenite to martensite to a greater depth than is possible with plain carbon steel. Although alloying metals have a notable effect upon the hardenability of steel, they have little effect upon its maximum hardness, which for any stated heat treatment is determined chiefly by the carbon content.

2.4.1.4 *Annealing and Stress Relieving.* Annealing may be performed by one of several methods, depending on the results desired. The purposes of annealing may be: (1) to soften steel for greater ease in machining, (2) to relieve stresses and hardness resulting from cold working, (3) to refine the grain and reduce brittleness.

(a) *Full annealing*—The steel is usually placed in tightly closed boxes, heated to a temperature about 100°F. above the critical range, and held at that temperature for a period of at least one hour for each inch of maximum section. After the heating period, the steel is ordinarily allowed to cool very slowly in the furnace. Cooling may also be accomplished by placing it in some insulating material to prolong the time of cooling as compared to unrestricted cooling in air. Fully annealed steel is soft and ductile and free of internal stress.

(b) *Sub-critical annealing*—If a large amount of metal is removed by machining, considerable internal stresses can be set up in the steel. These stresses are likely to cause distortion in hardening, even though oil-hardening, non-deforming tool steel is used. It is therefore desirable to remove these stresses before the tool is hardened. Sub-critical annealing or stress relieving is accomplished by placing the steel in containers packed with protective material and heating to just below the critical range (about 1050°F. to 1200°F.). The rate of cooling depends on the carbon content, the rate decreasing with increasing carbon. It is somewhat more rapid than the rate used for a full anneal. The resulting product is less soft than fully annealed steel, but is practically free of stresses.

(c) *Normalizing*—Normalizing is a special case of annealing and is intended to put the steel in a uniform, unstressed condition of proper grain size and refinement so that it will properly respond to further heat treatments. Normalizing may or may not (depending on composition) leave steel in a sufficiently soft state for machining. The steel is heated to about 100° above the critical range and held there just long enough for complete transformation to austenite. It is then removed from heat and allowed to cool in still air at room temperature.

(d) *Spheroidizing*—To soften high carbon steel sufficiently for machining, it is spheroidized. Steel is heated for extended periods just above the critical range, then the temperature is allowed to fall to just below the critical range and maintained for an extended period. Slow cooling is the final step.

2.4.1.5 *Hardening and Quenches.* Steel is hardened primarily to increase its wear resistance. This is accomplished by heating in a furnace to a predetermined temperature and quenching in the proper medium. The purpose of quenching steel is to fix in it some of the structural changes or modifications which have been caused by heating the steel above the critical range. The more rapidly the steel is cooled from the hardening temperature, the more changes will be retained in the steel and the harder it will be. In view of this, it might be assumed that the more rapid the quenching the better the results. This, however, is not always true, because too rapid quenching sometimes causes internal stresses which may be harmful. It is therefore advisable to use the mildest quenching which will cool the steel with sufficient rapidity to develop the required hardness and penetration. The rate of cooling, which determines hardness for any stated composition of steel, is adjusted by choice of quenching method. In order to obtain the maximum hardness of any steel, it must be cooled from the hardening temperature at a certain minimum cooling rate. This rate is called the critical cooling rate and will vary for different types and analyses of steel. In the case of straight carbon steels, the rate is very high and as a result, carbon steels are shallow hardening because the heat cannot be removed fast enough to secure hardness except in an area relatively close to the surface. The addition of alloying elements to steel reduces the critical cooling rate more or less in proportion to the amount and kind of elements used. Steels containing a relatively large amount of alloying elements can be hardened very deeply because they will harden even at a comparatively slow cooling rate. The most common quenches are water, brine, oil, and air.

(a) *Water*—Quenching in water at temperatures below 100°F. provides rapid cooling and is used frequently for carbon steels of a wide range of carbon content and for medium carbon low-alloy steels. For carbon steels, only water quenching is sufficiently rapid to give full hardness. For maximum effect the water may be agitated violently or applied as a spray.

(b) *Brine*—When a piece of hot steel is plunged into water, bubbles of steam form around it, momentarily insulating the hot steel from the action of the cooling water. This may result in soft spots on the finished article. Quenching in a brine consisting of 10% rock salt dissolved in water, prevents this action. The salt crystals that crystallize near the surface of the steel, as water is vaporized, explode as they come into contact with the hot steel and agitate the solution sufficiently to break down the bubbles of steam.

(c) *Oil*—Oil is a slower and much milder quench than water. Because cooling in oil is less rapid than in water, oil quenching produces less rapid change of volume and consequently much less distortion than does water quenching. The oil is generally a mineral oil of sufficiently low viscosity to permit free circulation around the piece being quenched. The quenching property of oil is increased materially by vigorous agitation.

(d) *Air*—If the degree of hardening obtainable by quenching in air is adequate for the purpose for which the steel is required, that process has the advantage of giving a product with the absolute minimum of internal stress and distortion, because the transformation takes place relatively uniformly throughout the mass of steel. With some steels of high alloy content, the transformation process is so slow that cooling in still air produces sufficient hardness to make the steel suitable even for cutting tools.

2.4.1.6 *Case Hardening.* In order to harden low carbon (.10% to .25% approx.) steel it is necessary to increase the carbon content so that it may respond to proper heat treatment. This involves two operations. The first is the carburizing operation which consists of soaking the piece in a carbon-rich medium for a specified length of time, depending on the extent of carburization desired. The carbon will then be absorbed by any surface that is exposed to this medium, producing a thin, high-carbon case ranging from .8% to 1.2% carbon. The second operation is that of heat treating the carburized parts so as to obtain a hard outer case and at the same time give the low-carbon core the required physical properties. Generally, the piece may be heated and quenched in much the same way as a high-carbon steel or it may be quenched directly from the carburizing temperature. The various methods for carburizing the low-carbon medium alloy steels are outlined below:

(a) *Pack Carburizing*—The articles to be carburized are cleaned and packed loosely in a metal box with carbonaceous material or commercial carburizing compounds. Carbonaceous materials include coal, charcoal, charred bones, bone meal, and hide scraps. Barium, ammonium compounds, soda ash, and various salts act as energizers in hastening the reaction. The box is then sealed and placed in a carburizing oven at a temperature of about 1700°F. for the desired length of time.

(b) *Gas Carburizing*—A process in which the carburizing is carried out in an atmosphere of carburizing gases such as carbon monoxide, or hydrocarbons such as butane, ethane, methane, or propane. The process is flexible and more accurately controllable than pack carburizing; it can be used to produce almost any desired hardness, depth, or carbon content of the case. Portions of the work which do not require hardening may be protected by a layer of copper plating.

(c) *Nitriding*—Nitriding is a process by which extremely high surface hardness combined with exceptionally high wear resistance can be obtained on steel. Nitrided steel is resistant to corrosion and fatigue. Parts may be machine finished before nitriding, because practically no distortion occurs during the process and no further heat treatment is required. Large sections of work can be hardened successfully by nitriding. The process consists of heating the steel in an atmosphere of nitrogen (ammonia gas) at a temperature of approximately 950°F. for the desired length of time, then cooling slowly. Carbon steel, when nitrided, is too brittle; therefore, special nitriding steels have been developed. The principal nitride forming-alloying elements are Aluminum, Chromium, and Molybdenum.

(d) *Cyaniding*—Cyaniding is, in effect, a combination of carburizing and nitriding. In this process a thin case between .001 and .015 inch in thickness is produced by immersing steel in a molten salt bath containing a cyanide, usually sodium cyanide. This process is followed by quenching.

2.4.1.7 *Tempering.* When a piece of steel has been hardened fully, it is hard, brittle and internally stressed to such an extent that it may fail in service. It is necessary, therefore, to apply to a piece of hardened steel some sort of after treatment to make it less brittle (and therefore tougher) or to relieve internal stresses. This is accomplished by reheating a piece of hardened steel to a relatively low temperature as compared to the hardening heat and leaving it soak for a specified time, then quenching in the proper medium. This process generally causes the piece to lose some of its hardness. It is this final hardness that is specified on the print. It will be sufficient for this section to merely outline the different methods of tempering.

(a) *Color Method*—This method takes advantage of the fact that as the temperature of steel increases, it goes through various color stages varying from light straw (380°F. approx) through dark blue (560° approx). A trained observer can estimate the temperature of a piece of steel in this way to within about 20° of its true temperature before quenching.

(b) *Austempering*—An interrupted quench process which consists of quenching the steel in a bath of molten salt at a temperature between 450°F. and 900°F., depending upon microstructure desired, and maintaining that temperature until transformation of austenite into bainite (an intermediate structure between martensite and pearlite) is complete. The result is a steel of great toughness and ductility.

(c) *Martempering*—An interrupted quench which consists of quenching the steel in a bath of molten salt at a temperature just above the martensitic formation point and held there long enough for temperature equalization throughout the work, then removed and cooled slowly in air. The result is a fully martensitic structure which has high hardness and low distortion.

2.4.2 *EFFECTS OF ALLOYING ELEMENTS.* An alloy steel is one to which has been added one or more elements in addition to the carbon and the small amounts of sulphur, phosphorous, silicon and manganese that are present in all plain carbon steels. The effect of these elements is to impart to steel certain properties that plain carbon steels do not possess such as: increased hardenability (carbon steels harden through only in thin sections), less danger of cracks and distortion in quenching, greater toughness and ductility, and increased wear resistance.

(a) *Carbon* (*C*)—Carbon increases the steel's capacity to harden till about .90% carbon is reached when the steel will become file hard upon quenching. Adding more carbon than this does not increase the measurable hardness, but it imparts greater wear resistance. A good average carbon content seems to be around 1.05% This makes a very hard steel with high wear resistance, yet is not fussy or sensitive to heat treatment.

(b) *Manganese M*(*n*)—Manganese imparts a certain amount of strength, toughness, and elasticity. It is present in all steels to about .20% and can be present to about .50% before being regarded as a special alloy addition. Adding more manganese increases the hardness penetration. In fact, so powerful is its effect that the addition of about 1.60% manganese to a .90% carbon steel would cause a 2″ cube to harden clear through to the center, whereas without the extra manganese, the depth of hardness would only be about 3/32″. Furthermore, it causes steel to harden so rapidly and deeply that it is no longer safe to quench in water but must be quenched in oil; the steel now becomes an oil-hardening, nondeforming tool steel. Manganese also has a favorable effect on stability.

(c) *Silicon* (*Si*)—Silicon, like manganese, is present in practically all tool steels in percentages of .10% to .30%. As an alloy, silicon is almost never used alone, or simply with carbon. It is generally used in conjunction with some deep hardening element like manganese or chromium to impart strength and toughness and help to increase the hardness penetration. As an alloy it may be found in amounts of .50% to 2.0%. When silicon is present in considerable amounts, it has a tendency to decarburize the steel in hardening.

(d) *Phosphorous* (*P*) *and Sulphur* (*S*)—Generally regarded as harmful impurities. Present in all steels, phosphorous is thought to have the good effect, however, in increasing the steel's machinability and resistance to atmospheric corrosion. Sulphur also helps a steel's machinability. Sulphur and Phosphorous are usually kept below a maximum of .03%. In good quality tool steels, it is not uncommon to find them below .015%.

(e) *Chromium* (*Cr*)—The prime benefits of chromium are to increase the hardness penetration and to impart great wear resisting qualities. The increased wear resistance is not necessarily accompanied by greater hardness. In sufficient quantities it confers oil hardening qualities to steel, though not as effectively as manganese. The low and medium chromium steels do not hold size as accurately as manganese steels, those that are water hardening changing size even more than plain carbon steels. A steel containing 5.0% chromium together with 1.0% molybdenum is very deep hardening and suitable for air quenching. Steels of 11% to 14% chromium and 1.5% to 2.2% carbon, commonly called "high carbon, high-chromium steels" have relatively high wear resistance, and may be either oil or air hardened, and their stability or size holding property is high.

(f) *Nickel* (*Ni*)—The use of nickel in tool steels adds toughness and greater tensile strength but has little effect on hardenability. Its primary effect is to impart toughness and wear resistance when used in conjunction with some hardening alloy such as chromium. Nickel tends to make the steel oil-hardening rather than water-hardening.

(g) *Tungsten* (*W*)—In amounts up to 1.5% tungsten gives high carbon steel increased wear resistance. In greater amounts, together with high percentages of carbon, the steel will acquire such wear resistance as to be difficult to grind. When united with carbon, tungsten forms tungsten-carbide. The carbide is brittle and must be bonded together with a tough metal like cobalt, and sintered (powdered) to form an insert usually brazed to an alloy steel.

(h) *Vanadium* (*V*)—Elasticity is the special quality imparted by vanadium. Sometimes added in small quantities (about .15%) to plain carbon steel, it does not affect hardness or hardness penetration, but toughens it by keeping its grain size small.

(i) *Molybdenum* (*Mo*)—Molybdenum is more effective than any other common alloying element in imparting oil-hardening and air-hardening properties to steel. It has the greatest hardening effect of any element except carbon, but at the same time minimizes enlargement of the grain, with the result that toughness is retained. Like tungsten, it increases red-hardness and wear resistance. Molybdenum, however, encourages decarburization in heat treatment.

2.4.3 *STABILIZATION AFTER HARDENING.* When a piece of steel is heated above the critical point as in hardening, the carbon and any alloying elements dissolve into a dense, tough structure called austenite. On quenching, austenite transforms only partially into martensite, a harder, stronger, and larger crystalling structure. This change to martensite is characterized by an increase in volume of the steel, creating internal stresses. To relieve these stresses and to transform more austenite into martensite, tempering is required. Tempering has the effect of decomposing some of the retained austenite. One hundred percent martensite is the ideal aimed at in tempering but is rarely realized. The remaining austenite is one of the chief causes of dimensional instability since at normal temperatures the retained austerite decomposes into martensite causing small but measurable dimensional changes in a plus direction because its product is larger in structure. High precision gages need a stabilization treatment if they are to maintain their accuracy over a period of time, otherwise the expansion due to decmoposition of retained austenite will eventually change dimensions outside of the permissible tolerance. These dimensional changes are on the average (depending on analysis and heat treatment of the steel) of about .0001 to .0002 inch per inch or smaller. Insignificant or ordinary tooling, they are important on precision gages. The object of the stabilization treatment is to transfrom the retained austenite so that none remains which could transform later on. Sub-zero or cold treatments transform the retained austenite almost completely and renders the gage dimensionally stable. Gages also derive other benefits from cold treatments, Rockwell "C" hardness is increased two or three points, wear life in increased and the probability of grinding cracks is reduced. Generally the cold treatment process consists of heating the steel to tempering temperature and then cooling back to room temperature. This is followed by sub-zero chilling to about −120°F. in a refrigerator or dry ice for a similar amount of time and then allowing the steel to return to room temperature. It may be necessary to repeat this process three or four times to achieve the proper stability. The gage is then finish ground and lapped to size.

2.4.4 *MACHINE STEEL.* Machine steel is a trade name given to any of the hot or cold finished, low-carbon, free-machining steels. It is a relatively inexpensive, easily obtainable, versatile steel that finds many applications in the construction of inspection equipment. It machines easily, can be welded without the use of fluxes, and can be bent or formed to many shapes. It is exceptionally amenable to carburizing and attains a high degree of hardness when case-hardened. For large gaging surfaces that do not receive intensive wear and the gaging dimention is not of a high degree of accuracy, case-hardened, hot-finished machine steel is recommended. The hot finished type is the more stable of the two steels and should be used in preference to the cold finished type whenever machine steels are employed to make up or have a direct relation with any gaging dimension. A drawback of hot-rolled steel is that it has a heavy scale that must be removed by machining. Cold finished machine steel is probably more widely used because it has a clean, scale-free surface and is available in a multitude of reasonably accurate sizes and shapes. In fact, a large portion of the time, it may be used in the as-finished condition with a minimum of machining being required, other than sizing to length and tapping for screws. Both types of machine steel have a serious distortion factor, when being heat treated, due to the severe quench required. Therefore, caution should be exercised when designing case-hardened, machine-steel parts. Rapid changes of section and thin protrusions should be avoided. Generous radii and fillets should be provided to prevent cracking during the heat treat process. These limitations, however, should not cause the designer to shy away from the use of the machine steel; rather it is the mark of a good designer to minimize these drawbacks by taking them into account and designing around them. Case-hardened steels, in fact, do not enjoy the wide application they are capable of. With a little thought, the designer will find that the glass-hard fine finishes and tough core of case-hardened steels will supplant many of the expensive tool steels that are specified indiscriminately today. When a part is to be case-hardened, carbon steel (carburizing grade) should be specified in order to be sure of getting a steel with the most desirable and predictable properties.

2.4.5 *TOOL STEELS.* "Tool Steel" is a blanket term that is generally applied to medium or high carbon steels of special quality prepared by the electric furnance method, held to rigid physical and chemical standards, and processed with extreme care from ingot to finished product. The result is a steel that hardens more deeply, has more wear resistance, yet can be machined with relative ease. Practically all tool steels are of such a composition that they are capable of attaining a high degree of hardness when submitted to suitable heat treatment. Tool steels may be classified under two headings: Carbon tool steel and Alloy tool steel.

a. Carbon Tool Steel may be had in either water-hardening or oil-hardening grades. The grade desired should be specified on the drawing. The water-hardening grade may be specified for a large portion of the precision parts of inspection equipment that receive average wear, are of fairly uniform section and the desired properties are such that case-hardened steel will not suffice. Again the drawbacks of water-hardening steels are comparatively high distortion and danger of cracking during heat treating. Three of the main reasons for specifying the oil-hardened rather than the water-hardening grades are:

(1) to get more wear resistance
(2) To get a tougher steel
(3) To secure greater safety and hardening accuracy in heat treating

Tool steel should be viewed with care when selecting steel for large parts or parts that are to receive intensive wear. In the former case, carbon steel with the critical areas case-hardened is recommended while in the latter case, tungsten-carbide inserts or similar wear-resistant materials are preferred. For parts under the size of a 3/8" cube or larger than 1" in cross section and also parts of any size possessing abrupt changes of section or irregular sections, carbon tool steel (oil hardening) should be specified.

b. Alloy Tool Steel is a steel that has had various alloying elements, such as chromium, vanadium, tungsten, etc., added during the steel-making process. They are steels that possess wear-resistance equal to two or more times that of ordinary steel and are applicable to inspection equipment in the oil and air hardening grades. Oil-hardening, non-deforming tool steel comes under the classification of an alloy tool steel and should be specified for parts that are of such intricate form that a minimum of distortion, deep hardening and extra wear life is desirable. Graphitic tool steel has much the same properties

	USUAL WORKING HARDNESS	QUENCHING MEDIUM	DEPTH OF HARDNESS PENETRATION	DISTORTION WHEN HARDENING	WEAR RESISTANCE	MACHINABILITY (BEFORE HARDENING)	GRINDABILITY	DIMENSIONAL STABILITY	TOUGHNESS
CARBON STEEL (CASE HARDENED)	15N 90/92.5 (ROCK.60/66)	OIL OR WATER	VERY SHALLOW	HIGH	FAIR	FAIR	GOOD	FAIR	FAIR
CARBON TOOL STEEL	ROCK. C 60/67	WATER	SHALLOW	MEDIUM TO HIGH	GOOD	VERY GOOD	EXCELLENT	VERY GOOD	GOOD
CARBON TOOL STEEL	ROCK. C 60/66	OIL	MEDIUM	LOW TO MEDIUM	GOOD	VERY GOOD	EXCELLENT	GOOD	GOOD
TOOL STEEL (NON-DEFORMING)	ROCK. C 63/66	OIL OR AIR	DEEP	LOW	GOOD TO VERY GOOD	GOOD	GOOD	VERY GOOD[2]	VERY GOOD
GRAPHITIC TOOL STEEL	ROCK. C 63/66	OIL	DEEP	LOW	GOOD TO VERY GOOD	VERY GOOD TO EXCELLENT	EXCELLENT	VERY GOOD[2]	GOOD
HIGH SPEED STEEL	ROCK. C 63/66	AIR	VERY DEEP	VERY LOW	VERY GOOD	FAIR TO POOR	FAIR	VERY GOOD[2]	VERY GOOD
TUNGSTEN CARBIDE	-	-	-	-	EXCELLENT	-	FAIR TO POOR	EXCELLENT	FAIR[3]

1. DEPENDING ON UNIFORMITY & THICKNESS OF SECTION
2. COLD TREATMENT SHOULD BE SPECIFIED TO INSURE DIMENSIONAL STABILITY ON CLOSELY TOLERANCED GAGES
3. DEPENDING ON GRADE SELECTED

TABLE VII. *General properties of gage steels.*

but the wear resistance is extremely high. High speed steel is an air hardening steel and is generally used for parts that have carbide inserts brazed in place but the parts must retain its hardness. The decision to utilize one of these steels should take into consideration their lack of free machining properties and higher first cost, with the exception of graphitic tool steel which machines almost as easily as cast iron. Whenever it is desired to use one of these steels, the applicable federal specification shall be referenced in note form at the top of the drawing or below the steel selected.

c. *Drill Rod* is a high carbon steel which is obtainable in numerous fractional and decimal sizes with the outside diameter ground accurately to size. Gagemakers frequently substitute drill rod for tool steel when making cylindrical parts. Being finished on diameter, it is a very convenient material for pins, plugs, handles, buttons, small anvils or short flush pins. It is a little more difficult to machine than most tool steels, but it hardens easily. On the drawing, tool steel should be specified to elimate the possiblity of low carbon drill rod being used.

2.4.6 *CAST STEEL.* A good grade of cast steel with properties similar to that of tool steel is sometimes used on complex parts to economize on machining operations where the parts must later be hardened. Cast steel is stronger than cast iron and very tough, and for this reason should be used instead of cast iron on test equipment and any other equipment that may be subject to considerable shock or impact.

2.4.7 *CAST IRON.* Most large fixture equipment bases are made from fine grain, gray cast iron. It is also used for odd shaped members which can be cast more conveniently than they can be machined from standard size stock, fine grained gray cast iron is suitable for most bases and small parts.

2.4.8 *SEMI-STEEL.* The chief application of semi-steel is a substitute for cast iron where the casting is very complex and added strength is needed. Various types of semi-steel offer wear resistant properties, resistance to grain growth and thus greater dimensional stability. Semi-steel can be welded and lends itself to heat treating.

2.4.9 *SINTERED CARBIDES.* The use of tungsten, tantalum or boron carbide is preferred on gaging surfaces which are subject to extreme wear and where hardened steel parts would require frequent replacement. The life of carbide surfaces far exceeds the life of hardened tool steel, so that wear allowance in most cases in unnecessary. Carbide blanks are a powdered metal product, and are produced to the desired form by pre-forming, sintering and shaving. Consequently, any further forming or resizing can only be accomplished by grinding. Therefore, the inserts used for gaging surfaces should conform to the general forms or shapes commercially produced. Where inserts are subject to impact or shock, the proper grade must be selected. Inserts should be supported or "backed-up" from as many directions as possible.

2.4.10 *SAPPHIRE.* Synthetic sapphire is next to boron carbide in hardness and wear resistance. Its use is usually limited to small rings and plugs. Its non-magnetic and non-sparking properties make it excellent for use in equipment for components containing explosives.

2.4.11 *MAGNESIUM AND ALUMINUM.* Magnesium alloy contains 85% magnesium, the remainder being aluminum, manganese and zinc. This chemical composition produces an alloy relatively strong and tough and at the same time very light in weight. These characteristics make magnesium alloy especially adaptable for frames and handles particularly on large pieces of equipment which must be carried to the job by the inspector. The same general characteristics contained in magnesium alloy are present in aluminum except to a lesser degree. In addition, this material is readily adapted to test equipment where resistance to corrosion must be maintained in tanks and other liquid reservoirs.

2.4.12 *BRASS, BRONZE AND COPPER.* These metals and their alloys are generally used only for accessories. Copper is especially adaptable for electrical contacts, etc., on electronic equipment. Brass can be used for name plates. Phosphor bronze is an excellent material for special springs. Bronze is frequently employed for bearings. Brass, bronze, beryllium copper and other similar nonferrous metals are used exclusively for ammunition inspection equipment when any amount of explosive powder is exposed because of their non-magnetic and non-sparking properties. Beryllium copper has a relatively high strength and hardness value for nonferrous material and therefore it is excellent for the body sections of non-sparking equipment.

2.4.13 *PLASTICS.* In times of emergency when materials such as steel, aluminum, brass, etc., are not available, this material is useful for handles, guides, name plates, and other accessories.

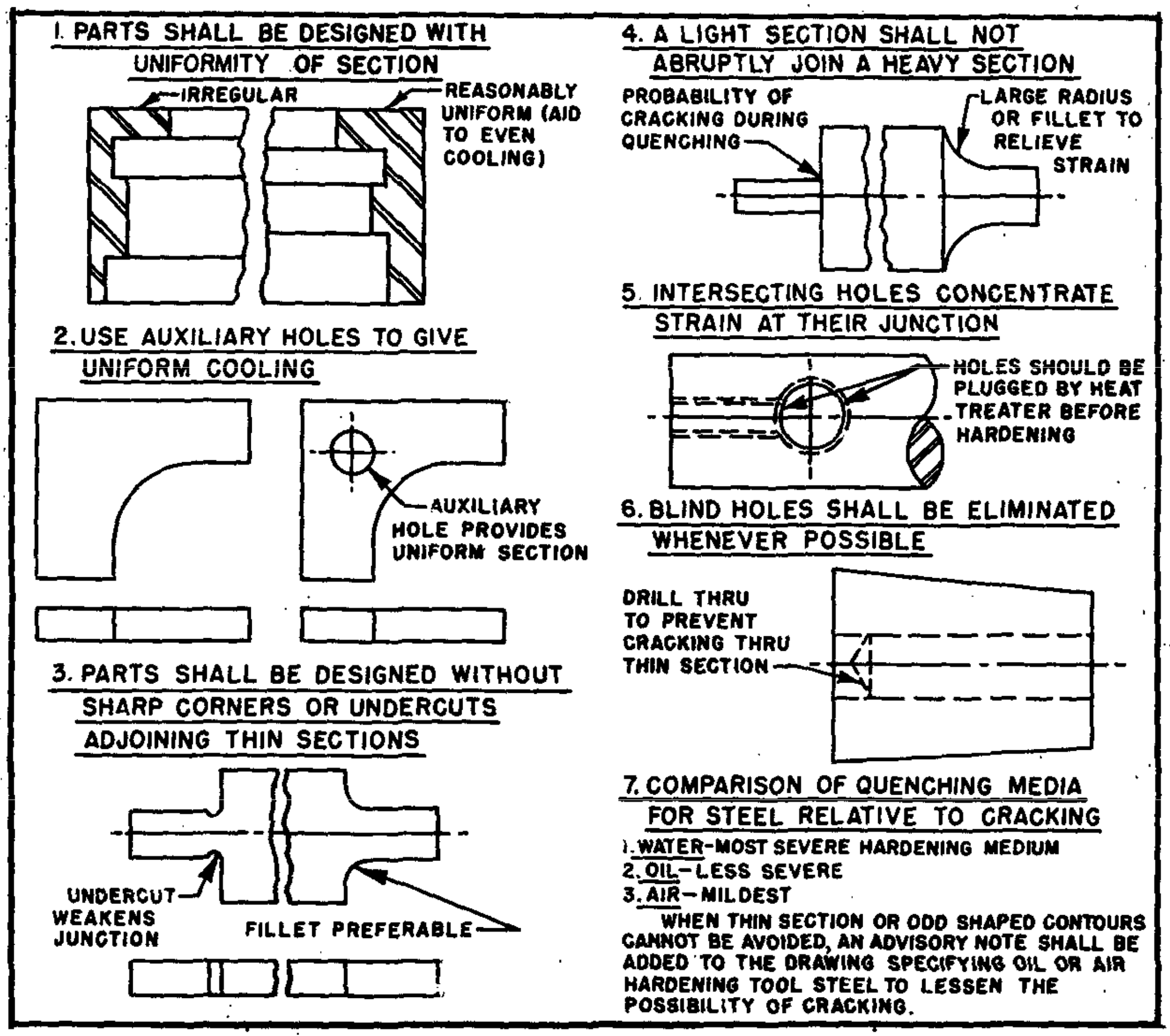


FIGURE 17. *Design precautions to aid heat treating.*

TYPE STEEL	THICKNESS	ROCKWELL HARDNESS OR EQUIVALENT	PREFERRED SYMBOLS	REMARKS
TOOL STEEL	UP TO .0625	C50 TO C55	⌖	THE HARDNESS SHALL BE BASED ON THE THINNEST SECTION OF THE GAGE
TOOL STEEL	.0625 TO & INCL .125	C55 TO C60	Φ	
TOOL STEEL	.125 TO & INCL .1875	C60 TO C63	⧖	
TOOL STEEL	ABOVE .1875	C63 TO C66	✳	
THDS & SERRATED GAGES (TOOL STL)	———	C60 MIN	✴	———
SPRING STEEL	———	C45 TO C55	§	INTERMEDIATE RANGE PERMISSIBLE WITHIN C45 TO C55
MACHINE STEEL	———	15N 90MIN	⊖	CASE OR PACK HARDEN .02 MIN DEPTH AFTER GRINDING
GRAPHITIC TOOL STEEL	———	C61 TO C64	△	———

TABLE VIII. *Recommended hardness values and symbols for steel.*

Method of Specifying Steel on Drawing

Steel (hot-finished)

For soft portions of inspection equipment that have a direct relation with a gaging dimension.

Steel (cold-finished)

For posts, indicator brackets, etc., soft parts that have no connection with a gaging surface.

Carbon steel (carburizing grade)—case harden

Large gaging surfaces that are not highly accurate, sliding members, pins, parts that do not receive intensive wear.

Carbon tool steel (water-hard)—harden

For precision parts of inspection equipment that are of fairly uniform section, that receive average wear and must be hardened.

Carbon tool steel (oil-hard)—harden

Small parts where there is a danger of cracking or distortion during hardening. Parts of irregular section that receive average wear and must be hardened.

Tool steel (non-deform., oil-hard)—harden

Parts of complex design where a minimum of distortion during hardening and where uniform properties and a little extra wear life is desired.

Graphic tool steel—harden

Generally on larger parts of inspection equipment where a long wear life is desired. Also recommended for thread plug and ring gages.

High speed steel—harden

Precision parts of inspection equipment where high wear resistance is desired or parts that must retain hardness after brazing carbide inserts.

2.5 PROTECTION OF MATERIALS.

2.5.1 *CHROMIUM PLATING.* This is a process whereby a thin layer of chromium is deposited on gages or parts of gages for the purpose of increasing wear life or the salvage or modification of gages. Tests reveal that chromium plated surfaces outwear the finest tool steels by from 2 to 19 times. When specifying chromium plating, the hardness of the base metal should be a minimum of Rockwell C60 to prevent chipping of the plate. The base metal may be a plain carbon steel to keep the cost low. A surface finish of 16 microinches or better should be specified on the base metal since chromium plate follows with high fidelity any surface irregularities produced by machining.

a. Dimensional Chromium Plating—Chromium may be deposited on a pre-sized gage to the thickness of the wear allowance, generally in amounts of from .00005 to .0002. A copper sulphate solution applied to the gage will indicate when the wear allowance has been expended. The remaining chromium can then be stripped and the gage replated. Dimensional chrome plating is generally limited to plain plug and ring gages.

b. Wear Surface Plating—This method is usually employed on precision parts of inspection equipment. A minimum thickness of chromium plate after grinding to size, is specified, usually, .0001 to .0005.

c. Salvage Plating—In salvage or modification work, thicknesses up to .02 may be used. Expensive inspection equipment may be saved by grinding worn areas and building up the surface again with chromium, then regrinding to size.

2.5.2 *PROTECTIVE FINISHES.* Bases, frames, handles, and other non-functioning parts of equipment should be protected by an enamel, a paint, or other similar commercial finish. Mil-G-10944 sets forth the minimum requirements for painting and other protective finishes applicable to gages. Black-oxide finish may be applied to all non-gaging surfaces. It has poor corrosion resistance alone; however, it will prevent finger marking. When given a light coat of oil, the corrosion resistance is greatly increased. It has the advantages of being inexpensive and results in a surface buildup on the order of .000025 inches. Black-oxide finish is a surface discoloration and shall be applied to all optical staging fixtures to prevent glare.

MATERIAL	BASES & FRAMES	POSTS, BLOCKS, ETC	MOVING PARTS	GAGING ANVILS & SURFACES	MISCELLANEOUS
TOOL STEEL (HARDENED)	FOR SMALL BASES WHICH HAVE A GAGING SURFACE	FOR SMALL & MEDIUM SIZE PARTS THAT REQUIRE HARDENING	FOR PRECISION PARTS SUBJECT TO WEAR	USED FOR MOST GAGING SURFACES REQUIRING NORMAL WEAR LIFE AND ON ALL STANDARD GAGES	HANDLES INTEGRAL WITH GAGING MEMBERS
HIGH SPEED STEEL (HARDENED)		WHERE CARBIDE IS INSERTED & BRAZED, & POST (BLOCK) MUST RETAIN HARDNESS		USED WITH CARBIDE INSERTS TO MAINTAIN REQUIRED HARDNESS AFTER BRAZING	
DRILL ROD		SUBSTITUTE FOR TOOL STEEL TO REDUCE MACHINING ON ROUND PARTS	SMALL PRECISION PARTS		
MACHINE STEEL	FOR MEDIUM SIZE FRAMES & BASES THAT REQUIRE HARDENING	FOR LARGE PARTS WHICH CAN BE LEFT SOFT		FOR LARGE GAGING SURFACES THAT DO NOT RECEIVE EXCESSIVE WEAR (HARDEN)	HANDLES, STOPS, ETC
COLD FINISHED STEEL					HANDLES, STOPS, ETC
CAST IRON	FOR MEDIUM & LARGE FRAMES OR BASES OF INTRICATE SHAPE		APPLICABLE FOR FREE MOVING PARTS		
CAST STEEL	FOR LARGE & INTRICATE SHAPES WHICH REQUIRE HARDENING	FOR INTRICATE PARTS THAT CAN REMAIN SOFT (CAST INTEGRAL WITH BASE OR FRAME)	FOR PARTS THAT ARE TOO INTRICATE TO MACHINE & A PRECISION HARDENED FIT IS REQUIRED		
SAPPHIRE					FOR SMALL PLUGS & RINGS, NON SPARKING USES
MAGNESIUM ALLOY	FOR LARGE FRAMES WHICH MUST BE PORTABLE TO AID INSPECTION				
ALUMINUM	FOR LARGE FRAMES WHICH MUST BE PORTABLE TO AID INSPECTION				HANDLES
PLASTICS & WOOD					HANDLES, BRACES & SUPPORTS
MUSIC WIRE					SPRINGS
GRAPHITIC STEEL			USED TO INCREASE WEAR RESISTANCE ON LARGE PARTS WHEN CARBIDE INSERTS ARE IMPRACTICAL		
CARBIDE			USED AS INSERTS ON PRECISION PARTS TO INCREASE WEAR LIFE	INSERTS FOR LARGE GAGING SURFACES RECEIVING EXCESSIVE WEAR	
BRASS BRONZE COPPER			BUSHINGS FOR ROTATING FITS		SPRINGS, IDENTIFICATION TAGS

TABLE IX. *Gage materials and applications.*

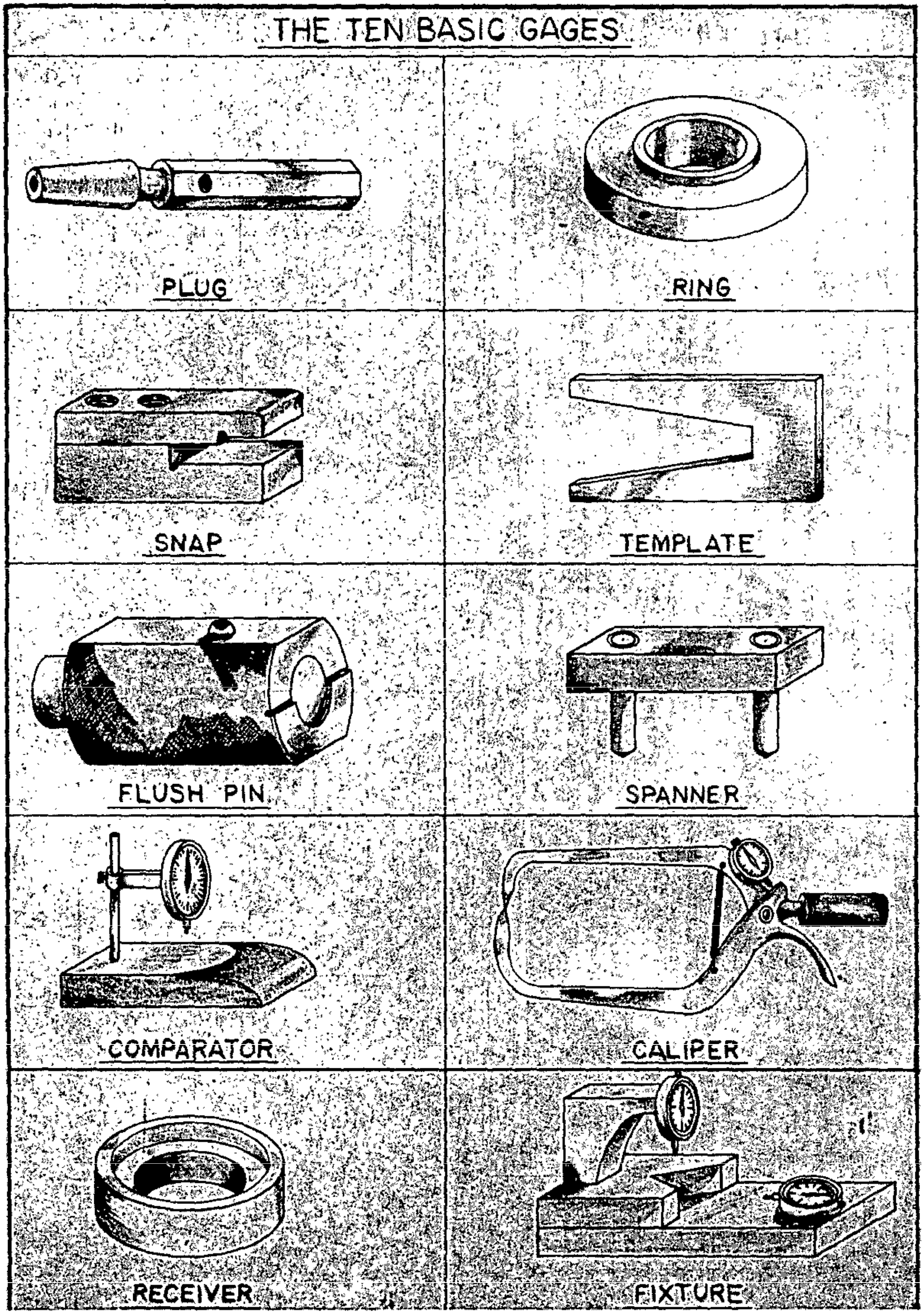


FIGURE 18. *Ten basic gages.*

CHAPTER 3. THE DESIGN OF THE BASIC GAGES

3.1 INTRODUCTION. This chapter presents the design information pertinent to the basic gages with the exception of thread, spline, and serration gages which are to be found in the next chapter.

3.1.1 *GAGE NOMENCLATURE.* Current gage nomenclature is a conglomeration of functions, appearances, and trade names. In an effort to bring some standardization to this nomenclature, ten basic gage types have been selected. They are named according to their physical appearance rather than the feature inspected or possible trade name. It is realized that there are always exceptions but with a little judicious use of the names provided it is felt that nearly all gages can be placed in one of the following groups:

1. Plug	6. Spanner
2. Ring	7. Comparator
3. Snap	8. Caliper
4. Template	9. Receiver
5. Flush Pin	10. Fixture

The definition of each type and some background discussion is provided in the following paragraphs.

3.1.2 *PLUG GAGE.* A plug gage is defined as any gage which simulates a male part or has an outside measuring surface that tests the size of a hole.

3.1.3 *RING GAGE.* A ring gage is defined as any gage of circular cross-section that verifies the size of a single cylindrical or tapered surface. This definition is somewhat restricted in comparison with the one for plug gages. This is done to provide a clear distinction between Ring and Receiver Gages.

3.1.4 *SNAP GAGE.* A snap gage is defined as any gage whose gaging surfaces are flat, parallel and opposing, separated by a frame or a spacer. Strictly speaking, (dictionary-wise) that which the industry refers to as a Snap gage is a Caliper gage. It was felt, however, that usage of the term Snap is so common that it was doubtful if Caliper could be successfully applied; so the term Snap was retained for rigid frame devices with fixed or adjustable jaws while Caliper was assigned to those gages with one or more movable arms that actuate an indicating device (see 3.1.8).

3.1.5 *TEMPLATE GAGE.* A template gage is defined as any gage which is merely a guide to the form of the work being executed, having either a profile, a sighting surface, a scribe line or similar comparison feature. It is proposed in this category to include all the former plate type, length, depth, width, and height gages that were made from a piece of 1/4 or 3/8 steel and presented steps, scribe lines or profile against which the part was compared. Plate-type shaps were relegated to the Gage, Snap, Fixed category.

3.1.6 *FLUSH PIN GAGE.* A flush pin gage is defined as one which utilizes a pin of known length moving in relation to a reference surface to indicate acceptability or unacceptability.

3.1.7 *SPANNER GAGE.* A gage consisting of a holder and precisely located pins or bushings which verify the relative position of features such as plain or threaded holes, bosses or slots.

3.1.8 *CALIPER GAGE.* A caliper gage is any gage with movable arms (or a combination of fixed and movable arms) that transfer a part feature inserted between or placed over them to an indicating mechanism.

3.1.9 *COMPARATOR GAGE.* Any gage which utilizes an indicating device to directly contact the work and indicate its departure from a preset size with a minimum of auxiliary devices. This category is the weakest of the group but was intended primarily to include those commercial or homegrown devices with an anvil, column, base and indicating device, either air, electric or mechanical. It is not intended to include optical projectors as optical comparators.

3.1.10 *RECEIVER GAGE.* Receiver gages are precisely what the name implies. They receive the part and verify its dimensions. The name shall be applied only to gages which consist predominantly of internal *surfaces* or portions of surfaces arranged to verify part dimensions. Gages consisting solely of external surfaces shall be classed as Gage, Plug, Multi-Element. See paragraph 3.2.6 for more discussion of this type gage.

3.1.11 *FIXTURE GAGES.* Any gage consisting predominantly of *devices* arranged to verify the features of a part shall be labeled a fixture gage. The distinction is rather clear, it is believed,—fixture gage consists predominantly of *devices*, a receiver gage of *surfaces*.

3.1.12 A list of sample gage titles follows. The underlined portions are for use where space considerations, on an IEL, for example, preclude use of the full title. Inverted nomenclature should be applied to both drawing and IEL equipment listings.

Plug gages

Gage, plug, adjustable
Gage, plug, air
Gage, plug, flat
Gage, plug, flat cylindrical
Gage, plug, multi-element cylindrical
Gage, plug, spline
Gage, plug, spline, taper tooth master
Gage, plug, surveillance check
Gage, plug, taper
Gage, plug, taper thread
Gage, plug, taper thread-setting
Gage, plug, thread
Gage, plug, thread-setting

Ring gages

Gage, ring, air
Gage, ring, plain
Gage, ring, spline
Gage, ring, taper
Gage, ring, taper thread
Gage, ring, thread

Snap gages

Gage, snap, plain adjustable
Gage, snap, plain adjustable (length)
Gage, snap, fixed (built-up)
Gage, snap, fixed (solid)
Gage, snap, indicating (mech)
Gage, snap, indicating (elec)
Gage, snap, indicating (air)
Gage, snap, spline
Gage, snap, spline-roll
Gage, snap, thread
Gage, snap, thread-roll

Template gages

Gage, Template, (profile)
Gage, Template (length)
Gage, Template (depth)
Gage, Template, (height)

Spanner gages

Gage, spanner
Gage, spanner, multi-pin
Gage, spanner, multi-hole
Gage, spanner, indicating

Flush pin gages

Gage, flush pin, external
Gage, flush pin, internal
Gage, flush pin, multiple

Receiver gages

Gage, receiver
Gage, receiver, profile
Gage, receiver, profile and alignment

Fixture gages

Gage, fixture
Gage, fixture, accessory
Gage, fixture, flush pin
Gage, fixture, indicating

3.2 PLUG GAGES. A plug gage has been defined as any gage which simulates a male part or has an outside measuring surface that tests the size of a hole.

3.2.1 *PLAIN CYLINDRICAL PLUG GAGES.* The most common form of the plug gage is the plain cylindrical plug. It consists of a single cylindrical diameter on a plug coupled with a suitable handle, the best examples of which are the standards set forth in Commercial Standard CS8, Gage Blanks.

3.2.1.1 *Military Standards for Plain Cylindrical Plug Gages.* There are four Mil-Std catalogs containing plain cylindrical plug gages, Mil-Stds 110 and 111 which are a general listing of available Go and Not Go plug gages and Mil-Stds 133 and 134 which are a listing of the Go and Not Go plug gages used in the acceptance of the minor diameter of internal threads. These gages bear no limiting identification data so may be used for any suitable plain plug application. Each catalog is discussed separately below.

3.2.1.1.1 *Mil-Std-110.* This catalog is the prime source of Mil-Std Go plug gages. It covers the range from 0.31 to 2.510 inches inclusive and is arranged in increments of .001 inches and .03125 inches.

3.2.1.1.2 *Mil-Std-111.* This catalog is the prime source of Mil-std Not Go plug gages. It covers the range from .031 inches to and including 2.510 inches in increments of .001 inches. It also includes gages in increments of .0005 inches for a part tolerance of .0005 across the range of .031 inches to and including .8255 inches.

3.2.1.1.3 *Mil-Std-133 and 134.* These catalogs are a listing of all the Go and Not Go plain cylindrical plug gages applicable to the inspection of the minor diameters of standard classes of internal threads. The gages are not marked with the particular thread designation but merely with the gage part number, function and size, i.e., 5220-7512800, Go .0465 so they may be universally applied to their particular hole size and tolerance combination. Many of the gages listed therein do not appear in Mil-Stds 110 and 111; therefore, these catalogs can be considered as a source of plain cylindrical plug gages.

3.2.1.2 *Special Cylindircal Plug Gages.* These gages are designed using the basic design data pertaining to standard and Mil-Std plug gages, but possessing a unique design feature such as a step or cutout. Special plug gages should be designed so that they may be modified from American Gage Design Standard Blanks whenever possible. The tolerances and wear allowances on gaging dimensions shall be in accordance with the applicable tables found in Chapter 2.

3.2.1.2.1 *Pilot Plug Gages.* This type of gage is used to gage holes where the combination of size and part tolerance is such that a pilot is required to center and start the gage in the hole.

3.2.1.2.2 *Cylindrical Step Plug Gages.* A cylindrical step plug gage is a plain plug which has a surface ground perpendicular to its axis for use in gaging a depth. The specifications for the cylindrical gaging features shall be identical to that for a standard type gage. The following should be considered when designing gages of this type:

(a) The plug must have a chamfer to clear the allowable radius in the bottom of the hole.

(b) The step surface on the gage must be immediately adjacent to the part surface and must be accessible for feel purposes or for use with a straight edge.

(c) The part tolerance on depth should be .005 or greater since the accuracy of inspection depends on feel.

(d) Clearance cuts or slots must be incorporated in the design to clear obstructions.

(e) When the part tolerance exceeds ±1/64 the use of scribe lines is acceptable in lieu of a step. See paragraph 3.5.2.1.

A single step is employed for gaging only one critical limit of a depth, either maximum or minimum. A single step may also be placed on not go gages used for hidden surfaces to indicate whether the gage has entered to or beyond the permissible limit. Two steps are employed when the gaging of both limits of a depth is required. In certain cases where the tolerance on diameter and depth of the hole is very small and the mating part entering the hole is a close fit, it becomes necessary to use both a step plug and a flush pin. The single step on the plug is used to insure that the hole is the proper diameter to its minimum depth and will properly receive the mating part, while the flush pin is used to check the depth limits of the hole. The tolerance on the single step on the plug shall be reversed (minus) to prevent conflict with the flush pin inspection.

3.2.1.2.3 *Recessed Type Plug Gages.* Some dimensional features necessitate the design of plug gages containing various types of slots, cutouts, and counterbores which will clear protrusions located within the hole being gaged. This type plug shall be modified, where possible, from an American Gage Design Standard blank and may be designed to either clear or perform a functional check on the location of the protrusion within the hole.

3.2.1.2.4 *Functional Plug Gages.* Certain part specifications require that a plug of specific diameter and length must pass through the part. Care should be taken to insure that the plug design is made as light as possible and that a convenient method of handling is provided.

3.2.2. *FLAT CYLINDRICAL PLUG GAGES.* This type of gage is essentially the same as a cylindrical plug gage insofar as its gaging application is concerned. When used as a Not Go gage, it provides a more critical inspection due to the reduced area of contact as compared to that of a full circumference. The following features should be considered in design:

(a) An entering chamfer should be used where the part specifications will permit.

(b) Lightening holes should be used on large plugs to reduce weight.

(c) Precision centers should be left to facilitate inspection and reconditioning.

(d) Plugs over 8 inches in diameter may have a strap handle insulated from the gage to ease the inspector's use of the gage.

3.2.2.1 The chief application of flat cylindrical plugs is on large diameter holes where a full cylindrical plug would be impractical due to its weight. Another primary application of the flat cylindrical plug is as a Not Go gage on critical maximum dimensions of holes since it will pick up out-of-roundness beyond the maximum limit which would not be observed using a full cylindrical plug.

3.2.2.2 Depth checking steps may be included in the design of a flat cylindrical plug gage as outlined in paragraph 3.2.1.2.2.

3.2.3 *ADJUSTABLE PLUG GAGES.* Adjustable plug gages are usually applied to low production items when the internal diameter to be inspected is large and the part tolerance is greater than .003. The gage consists of a frame, a set of gaging buttons and adjusting device. Adjustable plugs are standardized in both single and double end types in size ranges from 2½ to 12½ inches approximately. Full details of preferred construction may be found in Commercial Standard CS8, Gage Blanks.

3.2.4 *TAPER PLUG GAGES.* Taper plug gages are used for checking the various dimensional limits of tapered holes such as diameter, depth and angle or taper. When gaging tapered holes, the designer should be extremely cautious to insure that the design will sufficiently control all the part dimensions. In some instances, it may be necessary to use a taper flush pin in conjunction with a plain taper plug.

3.2.4.1 The control of the diameter of a tapered hole is usually attained by grinding steps on one end of the plug gage which indicates the limit of the distance it may enter the hole. When it is necessary to measure the max and min limits of the taper or the angle, two plugs are employed, one plug being made to the maximum angle, and the other to the minimum angle. When gaging the part, the maximum tapered plug must wedge at the top portion of the taper, while the minimum plug should clear at the top portion and wedge at the bottom. The designer should provide for the removal of a quarter section of each plug to aid the inspection in checking whether those conditions prevail.

3.2.4.2 Preference should be given to the datum diameter system of dimensioning in conjunction with the use of a basic taper if the length of the taper is such that the taper is sufficiently controlled by the tolerance zone created. When the length of taper is short, a tolerance on the taper or angle is generally required.

3.2.4.3 Dimensions over rolls may be given in addition to the actual mandatory size control dimensions, but such dimensions should be labeled "Reference" on the drawing. Wear allowance shall not be applied on taper plug gages for tapers over 15° included angle since there is no problem of sliding contact which would cause rapid wear. Also, it is not necessary to chamfer the front end of the plug since there is no problem entering the gage into the part.

3.2.5 FLAT PLUG GAGES. This type of gage is usually utilized in the inspection of the width of a slot or groove. In some instances, the Go member may incorporate the maximum and minimum depth of a slot along with its basic function. Flat plugs are also employed in many fixture type designs.

3.2.5.1 A Go and two Not Go flat plug gages must be employed for a satisfactory dimensional check of a rectangular hole.

3.2.5.2 Flat plug gages should have entering chamfers except where the shallow depth of a part will not permit.

3.2.6 *MULTI-ELEMENT PLUG GAGES.* This gage classification includes all male gages composed of two or more gaging elements on a common axis. If the gage consists of only cylindrical or taper elements, it shall be labeled as such, i.e., Multi-element cylindrical plug gage or Multi-element taper plug gage. If is consists of combinations of these or other types of elements, it shall be referred to as simply a Multi-element plug gage.

3.2.6.1 *Applications.* This type of gage is used primarily to inspect the relationship of two or more internal surfaces. It may be designed on the basis of dependent requirements specified on the drawing or independent requirements on a drawing which may not be gaged ecomically separately.

3.2.6.2 *Design Considerations.* Each surface of the gage is designed to the minimum size of its corresponding female surface less the allowable misalignment per individual surface. In two element gages, the permissible misalignment may be halved and each half subtracted from the minimum part size *if the surfaces are adjacent and of the same length.* If the surfaces are not adjacent or not the same length one diameter must be held to the minimum female size and all the misalignment subtracted from the other diameter to avoid any errors induced by the angular displacement between the two diameters. In gages with more than two elements, it is preferable to reduce each diameter by its individual misalignment. Individual limit gages shall be specified to control the sizes of the various elements of the component.

3.2.6.2.1 On the smaller gages, American Gage Design Standard plug gage blanks and handles should be employed, if possible. The drawing, in any case, should specify that the precision centers on which the gage was manufactured should be left to facilitate acceptance inspection and surveillance.

3.3 RING GAGES. Any fixed gage of circular cross-section that verifies the size of a single male plain cylindrical or tapered surface shall be classed as a ring gage.

3.3.1 *PLAIN RING GAGES.* A plain ring gage is defined as one which verifies the size of a single male plain cylindrical surface. There are several basic design criteria that apply to all plain ring gages.

(a) Ring gages should seldom be used as Not Go gages unless deformation of the part is a factor.

(b) Since large ring gages are awkward and expensive, the use of an adjustable snap gage is preferred for gaging large diameters where the tolerance is not critical or deformation is not a problem.

(c) When the part tolerance is .001 or less, it is advisable to use indicating type gages for all sizes.

(d) Ring gages that are under .075 in diameter require an acceptance check to facilitate checking.

(e) When the part tolerance is .004 or less, or the gage is used for 100% inspection on high production items, or the part material is different (brass, copper, aluminum, etc.) from the gage metal, a surveillance or wear limit check is required which is a standard plain cylindrical plug gage made to the master tolerance in table II. In this case, it may be desirable to fabricate the ring from a wear resistant material such as chrome plated tool steel, high speed steel, carbide, etc.

3.3.1.1 *Military Standard Plain Ring Gages.* There are two Mil-Std catalogs containing plain ring gages. Mil-Std-112 contains Go rings and Mil-Std-113 Not Go rings.

3.3.1.1.1 *Mil-Std-112.* This catalog contains all the Military Standard Go rings. It covers the range from .059 to 2.510 inches inclusive, in increments of .001 and .03125 inches.

3.3.1.1.2 *Mil-Std-113.* This catalog contains all the military Standard Not Go ring gages. It covers the range from .059 to 2.510 inches inclusive in increments of .001 of an inch and includes rings in increments of .0005 for a part tolerance of .0005 covering the range from .059 to .825 of an inch.

3.3.1.2 *Special Ring Gages.* This category includes all plain ring gages which are designed using the general design information pertaining to Mil-Std ring gages, but which possess a unique design feature such as a step or cutout. In designing special ring gages of any type, consideration should be given to the following:

(a) The gaging tolerances and allowances shall be in accordance with the applicable values found in table II.

(b) American Gage Design standard blanks shall be used wherever possible.

(c) The thickness of section shall be kept uniform to prevent deformation in heat treating and, further, the depth of cross-section shall be sufficient to prevent the gaging dimaeter from going out-of-round in excess of the tolerance allowed.

3.3.1.2.1 *Plain Step Ring Gages.* A step ring gage is a plain ring which has a surface ground perpendicular to its axis for use in gaging a length. The specification for the cylindrical gaging features shall be identical to that for a standard type gage. The following should be considered when designing a gage of this type:

(a) The ring shall have a chamfer to clear the allowable fillet on the part.

(b) The step surface on the gage shall be immediately adjacent to the part surface and shall be accessible for feel purposes or for use with a straight edge.

(c) The part tolerance should be .005 or greater since the accuracy of inspection depends on feel.

(d) Clearance cuts or slots shall be incorporated in the design to clear obstructions.

3.3.2 *TAPER RING GAGES.* Taper ring gages are used for checking the various dimensional limits of tapered parts such as diameter, length, angle, or taper. When gaging tapered parts, the designer shall take care to sufficiently control all part dimensions. In some instances, it may be necessary to use a female taper flush pin gage in conjunction with a plain taper ring.

3.3.2.1 Where practical, taper ring gages shall be designed so that American Gage Design standard blanks may be used.

3.3.2.2 The control of the diameter of the tapered protrusion on the part is usually attained by grinding steps on one end of the ring which indicate the limits of the distance the gage may fit on to an acceptable part. When it is necessary to determine the limits of the taper or the angle, two (2) taper rings are employed. One ring is made to the maximum angle and the other is made to the minimum angle, and are employed similar to the taper plugs of para. 3.2.4.1.

3.3.2.3 Preference shall be given to the datum diameter system of dimensioning in conjunction with the use of a basic taper, if the length of taper is such that the taper is sufficiently controlled by the tolerance zone created. When the length of the taper is short, a tolerance on the taper or angle is generally required.

3.3.2.4 Taper rings usually are fitted to a Master taper plug by the blueing transfer method.

3.3.2.5 Wear allowance shall not be applied on taper gages for tapers over 15° included angle as there is a minimum of sliding contact. A chamfer at the large end of the ring is not necessary since taper parts are easily inserted into the gage.

3.4 SNAP GAGES. A snap gage consists of opposing measuring surfaces separated by a spacer or frame and is used for gaging diameters, lengths, and thicknesses. A snap gage is an excellent Not Go gage since ovality below the minimum limit can easily be detected. A snap gage is an adequate Go gage for many purposes; however, a ring gage is preferred if assembly is the prime consideration. There are three general classes of snap gages: adjustable, fixed, and indicating.

3.4.1 *PLAIN ADJUSTABLE SNAP GAGES.* Plain adjustable snap gages with or without extended anvils are used for gaging part diameters, thicknesses and lengths when the part tolerance is .003 or greater. Gages of this type are classified as Mil-Std gages and accordingly no drawings are required. Mil-Std-118 gives a listing of stock numbers for unset plain adjustable snap gages (plain or extended anvils, square or round button type) for size range from 0 to 11.625 inches. This Mil-Std catalog also establishes the method for listing the proper stock number and setting size on the List of Inspection Equipment.

3.4.1.1 *Adjustable Snap Gage-Modified Anvils.* Special part features often require that the snap gage anvils must be modified to a special form. Particular attention shall be given to insure that the upper and lower anvils be held within the proper alignment to insure correct functioning of the gage. It is also necessary to check the location of the screws in the lower anvil to insure that no interference will occur between the required contour of the anvil and the screws. The proper alignment notes between the upper and lower anvils shall be specified as well as the detailed dimensions of the modified anvils. Mil-Std-118 presents a method for classifying a modified adjustable snap gage as a standard gage. This method, however, shall be used only in the event that the modified anvils may be used for inspecting a series of similar dimensions. (Example: thickness of wall at mouth on cartridge cases.) Generally, when a modified anvil is required the modification is such that the likelihood of further use on other parts is improbable and therefore a gage drawing must be prepared depicting the required modification. The setting size in this case shall be specified on the gage drawing and not on the List of Inspection Equipment. The gage drawing shall then be classified as Special.

3.4.1.2 *Adjustable Snap Gage-Blade Type Anvil.* This type gage is a standard commercial product. The gage consists of a C frame on which are mounted adjustable blade anvils. The thickness of standard anvils is either .130 or .183 inches. These thin blades are particularly adaptable for gaging recessed diameters in shafts, the recesses possessing dimensional limits or shapes for which an ordinary adjustable snap gage would not function. Blades of special thicknesses and forms may be designed to suit specific requirements. In designing gages of this type, the proper frame for the given part diameter must be selected and the width and contour of the blade anvils shall be specified or detailed in the event that the anvils deviate from the standard type. This type gage should not be used for part tolerances of less than .003.

3.4.2 *BUILT-UP SNAP GAGES.* Build-up snap gages are used primarily where a fixed type gage is desired and the part tolerance is about .003. Built-up snap gages are also widely used for larger part tolerances where the part shape is such that a standard or extended anvil type adjustable snap cannot be used. The use of built-up snaps should be minimized on low production items.

3.4.2.1 *General Construction Features.* A built-up snap gage usually consists of two hardened steel anvils separated by a soft steel or cast iron spacer, the three pieces being fastened together with socket head screws of a size proportional to the size of the gage. When the gaging dimension is above one inch, the anvils shall be fastened by screws entering from each anvil. The length and width specifications for the anvils shall be governed by the part sizes. The spacer is made from soft machine steel, as this is an aid in maintaining dimensional stability. However, gray cast iron spacers have been recently introduced and due to the even higher degree of dimensional stability, this type of spacer is preferred.

3.4.2.1.1 Built-up snap gages may be of the single end, progressive, or double end type design. The progressive type is considered the most desirable from a standpoint of rapid inspection. However, there are certain instances where the part design is such that a double end type becomes a necessity.

3.4.2.1.2 The Go end of a built-up snap gage shall be identified by a radius on the anvil and the Not Go end shall be identified by a chamfer

3.4.2.2 *Built-up Snap Gages-Separate Receiver Type.* It is often necessary to design a receiver or holder for the part which is used in connection with a built-up snap for gaging length from a datum or a taper, position of shoulder, etc. The receiver is usually designed to slide on the bottom anvil and the limits are established by progressive steps on the upper anvil.

3.4.2.2.1 Receivers of the female type usually require a check gage which simulates the critical form and dimensions of the part. The check gage shall be depicted on a separate drawing.

3.4.2.3 *Built-up Snap Gages-Recessed Anvil Type.* It is often necessary to provide recesses or cavities in the anvils of snap gages to clear protrusions on or in the part gaged. The designer shall take special care to provide clearance at extreme conditions by providing the required chamfers, etc. If possible, sufficient clearance shall be provided so that keys and dowels are not required to maintain alignment.

3.4.2.3.1 Where alignment of the part is to be controlled or is a factor in the gaging of another feature, the upper and lower anvils shall be keyed or doweled to the spacer. A note shall appear on the drawing specifying the misalignment allowed on the assembled gage.

3.4.2.4 *Built-up Snap Gages-Relieved Anvil Type.* Where the part gaged has a small contact surface, it is advisable to reduce the width of anvil to a practical width on which approximately even wear will occur. It is difficult to pick up a small area of wear in a wide anvil and this leads to errors in gage surveillance since a gage block measurement will be governed by the high points or unworn surfaces on the anvils.

3.4.2.5 Carbide inserts may be used on the anvils of built-up snap gages to minimize the effect of wear. The use of inserts is recommended particularly on standardized items where production is high and the component design or material is such as to cause rapid wear on the gage.

3.4.3 *PLATE GAGES OF THE SNAP TYPE.* This type of gage is not easily salvaged and should be employed only where an adjustable snap or built-up type is not adaptable to the particular application. It is made entirely from one piece of steel which is hardened and finish ground to size. A chamfer on the outer corner of the anvil denotes the Not Go gaging side while a radius similarly placed identifies the Go side on the double end type. Gages of this type require wear allowance.

3.5 TEMPLATE GAGES. Template gages are widely used to check profiles, lengths, widths and depths. Gages of this type are economical to manufacture due to their simplicity. In the case of profile gages and certain length types, the gage is simply a measuring stick, and acceptance of the part depends upon the accuracy of the inspector's visual judgment. When gaging complicated profiles, it is suggested that an optical comparator be used in lieu of a template type, particularly if the part is used on a standard item.

3.5.1 GENERAL CONSTRUCTION. Template gages of the small and medium types are usually made from hardened tool steel 1/8 to 3/8 inches thick, the gaging surfaces being ground to the proper size. In some cases, large gages are made from machine steel, the gaging surfaces being case-hardened and ground to size. (Generally, gages are designed to permit the manufacturer to use construction holes to facilitate gang milling and grinding so that several may be made in one set-up.)

3.5.2 *TEMPLATE GAGES FOR DEPTHS & LENGTHS.* This type of gage usually resembles the letter T in shape, the gaging surfaces being the undersides of the cross bar of the T which are ground parallel and in line. Parallel to these surfaces, two steps separated by an undercut, are ground on the base of the T their difference being equal to the part tolerance. Template gages for depth and length do not require wear allowance.

3.5.2.1 When a part has a tolerance of .03 or greater, it is sometimes feasible to use scribe lines to denote the maximum and minimum lengths. This type gage is usually L shaped and is faster in operation but less accurate. Scribe lines shall be .005 maximum wide by .008 maximum deep and should be placed on both sides of the gage.

3.5.3 *TEMPLATE GAGES FOR PROFILES.* This type of gage is used to inspect various profiles and contours. It is made of hardened tool steel ground to the proper profile. Generally, the gage is made to the maximum profile while scribe lines are positioned to indicate the minimum conditions of length. The profile or gaging surface should be chamfered on both sides to produce a thin sighting surface, the desired thickness of the gaging surface *ranging from 1/32 to 1/16 inch.*

3.5.3.1 Profile gages may also be designed using a nominal profile and in this case an acceptable contour is determined simply by vsiual comparison. This type of design should be used only on parts where the contour is of minor importance. In other instances where the contour is relatively important, maximum and minimum profile gages should be employed to insure that the contour is within the desired limit.

3.5.3.1.1 Tolerance on angles should equal 10 percent of the angular tolerance on the part, applied minus on max and plus on min. Tolerance on radii should equal 10 percent of part tolerance. Where no tolerance is shown on angles or radii on the part drawings, the tolerance on the gage will be dependent on function of the parts. Where there is no fit, tolerance on angle will be ±0°5′ and on radii ±5 percent of radius.

3.5.3.2 Profile gages generally require an acceptance check gage. The gage is fitted to the check and is acceptable when the viewing on a comparator shows perfect matching of the profiles. Only one acceptance check is required for each lot of gages.

3.5.3.3 Since profile gages rely on the inspector's visual accuracy in sighting an acceptable contour, they should be used sparingly on complicated profiles. On standardized items, preference should be given to the use of optical projectors in order to facilitate accurate inspection.

3.6 FLUSH PIN GAGES. A flush pin gage is defined as one which utilizes a pin that protrudes or is recessed a known length, moving in relation to a reference surface to indicate acceptability.

3.6.1 *APPLICATIONS.* Flush Pin gages are used for checking dimensional features such as the following:

(a) Depth of holes, either straight or tapered.
(b) Height of bosses, either straight or tapered.
(c) Location and position of holes, bosses, etc.
(d) Perpendicularity.

The application of flush pin gages is generally confined to the gaging of dimensions having a tolerance of .005 or greater. When the part tolerance is under .005, it is preferable to use a dial indicator type gage rather than to rely on the accuracy of the inspector's sense of touch.

3.6.2 *GENERAL CONSTRUCTION FEATURES.* The common type of flush pin consists of a body, movable gaging pin and pin-retaining device. There exists a multiplicity of body styles and retaining devices currently in use. In the interests of standardization, however, the following construction criteria are preferred.

3.6.2.1 *Barrel Type Flush Pin.* These gages are so named because the body is cylindrical in shape. The basic design criteria are:

(a) A cylindrical body having a minimum wall thickness of 5/16 inch, knurled and with two flats, diametrically opposed, provided for marking purposes.
(b) A ratio of length of body to diameter of sliding pin of about 3:1 (3:1 plus component dimension for internal gages).
(c) A retaining device consisting of a buttonhead socket screw, located 1/2 inch from the top face of the body and having the first 1/8 inch of its length machined down to the minor diameter.

3.6.2.2 *Bar Type Flush Pin Gages.* These gages consists of a pin sliding in a bar. The pin may be centered in the bar or placed in any position along the bar. The bar should be basically rectangular in shape with recesses along the sides for easy gripping.

3.6.2 *GENERAL DESIGN CRITERIA.* The following precautions shall be considered when designing flush pin gages:

(a) The end of the pin or bottom of the hole in the body shall be chamfered wherever necessary to clear any chamfer or fillet on the part feature.
(b) The diameter of the pin for external flush pins or diameter of the hole in the body for internal flush pins shall always clear the worst condition relative to the diameter of the part.
(c) All feel surfaces must be easily accessible to the inspector when using the gage.
(d) All feeler edges (both steps on body and top edge of pin) shall be sharp to insure gaging accuracy. A note to this effect shall appear on the drawing.
(e) The movement of the flush pin shall be sufficient to insure that the part can

always be applied to the gage and easily withdrawn after gaging.

3.4.6 *EXTERNAL FLUSH PIN GAGES.* This type of flush pin is used to gage the depth of holes, or similar female dimensions. It consists of the body together with a protruding pin that enters the feature being gaged. The other end of the pin is correlated with the reference steps on the body to indicate whether the part dimension lies within the desired limits.

3.6.4.1 *Flush Pin Gages Entering Thread Cavities.* When a flush pin gage is used to measure the depth of a threaded cavity, the pin must clear the minor diameter. The pin diameter shall be dimensioned to either 40% of the difference between the minor diameter of the part and the mating part, or .002 whichever is the larger. In the event that the mating part is designed with a pilot extending into the threaded cavity, the flusy pin shall have a similar pilot based on the conventional 40% functional rule.

3.6.4.2 *Foush Pin Gages for Depth of Drilled Holes.* The depth of drilled holes is usually dimensioned from the entered surface to the intersection of the cylindrical surface and the drill angle. Unfortunately, drill wear usually creates a varying radius at this intersection. Therefore, flush pins for the depth of drilled holes shall be designed to clear this radius and contact the conical surface below the intersection. This is done by grinding a smaller diameter on the end of the flush pin, maintaining a sharp corner at the bottom. In dimensioning, an amount equal to the additional length from the point of the intersection of the part to the point of contact of the flat bottom flush pin, is added to the gaging sizes. See figure 19.

3.6.4.2.1 Since the gage presents only line contact, it is advisable to use carbide inserts on the bottom of the pin in order to maintain sharp edges.

3.6.5 *INTERNAL FLUSH PIN GAGES.* This type of flush pin is used to gage the height of a boss or other type of protrusion. The gage is designed as above, except that the length of the body is three times the pin diameter, plus the part dimension. For gaging part dimensions up to 5/8 inch, a slot should be cut in the side of the body to permit viewing the contact between part and pin. Above 5/8 inch, a hole should be drilled through the body to permit viewing the same. The lower edges of the receiving hole are chamfered to clear any fillets at the base of the protrusion.

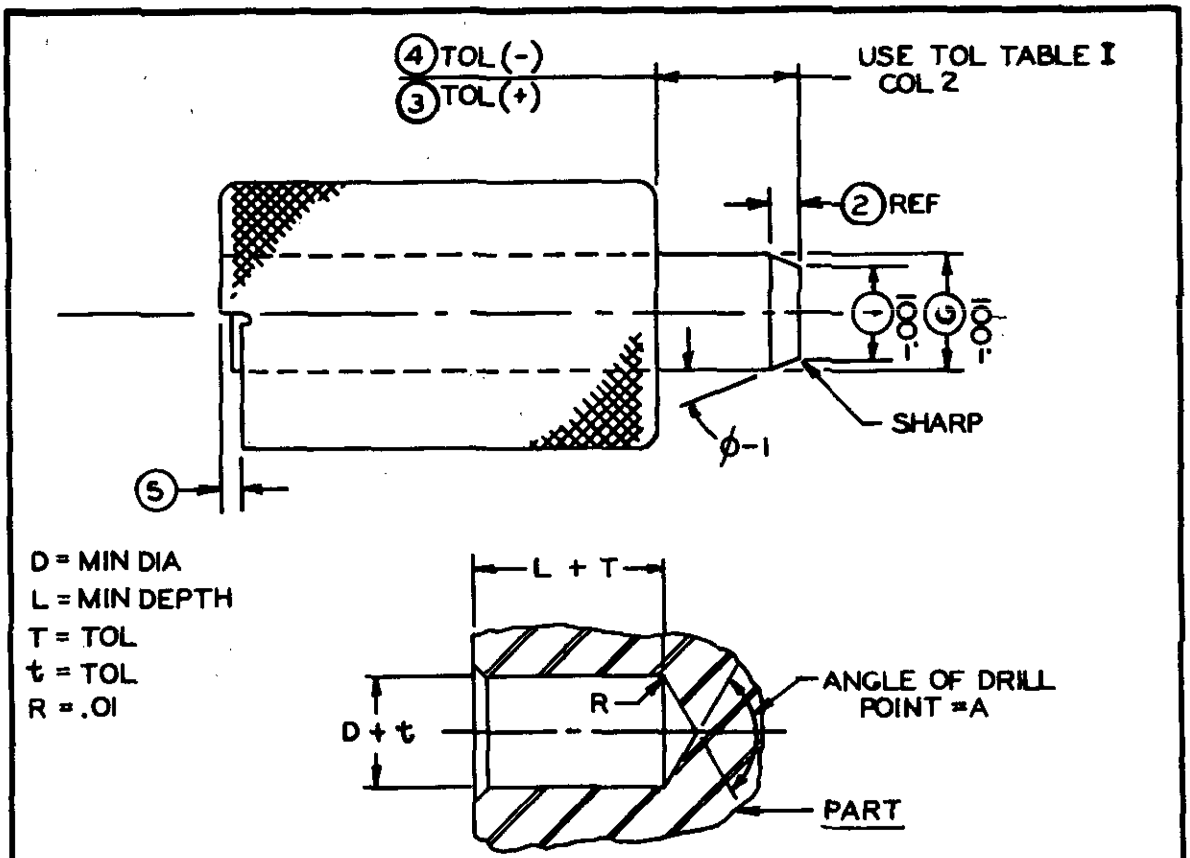
3.6.6 *TAPER FLUSH PIN GAGES.* This type of flush pin is generally used to gate the distance from a surface to a datum diameter in a tapered hole or on a cylindrical tapered boss. The design features of this type of gage are identical to those mentioned in paragraphs 3.6.4 and 3.6.5, except that the sliding pin or the body, as the case may be, is tapered to suit the taper of the hole or boss. The gaging dimensions are given from the base of the body to the datum diameter on the pin or from a datum on the body to the end of the pin. Wherever practical, the gage taper should be dimensioned similar to the part taper and care should be taken to insure that all component variations have been considered. The tolerance on the taper part of the pin or body should be taken in the proper direction to slightly clear the worst possible condition of the part. When gaging some types of taper holes, it is necessary to use a two section taper flush pin in conjunction with a plain taper plug gage to sufficiently control all of the component variations.

3.6.7 *SPRING LOADED TYPE FLUSH PIN GAGES.* The use of spring loaded pins eliminates the need for the inspector to seat the pin before feeling the steps. Spring loaded types should be used primarily on those fixture gages where the number of gaging elements may make it impractical for the operator to seat each pin before feeling the steps.

3.6.8 *MULTIPLE TYPE FLUSH PIN GAGES.* When a part is designed with a counterbore or a protrusion having two different diameters, it is sometimes desirable to check the depths or heights simultaneously. In this instance, a multiple flush pin gage is employed. The design features of this type of gage are similar to the ordinary flush pin except that there is an inner pin sliding within the outer sliding pin and the bottom of this outer sliding pin acts as the gaging surface from which the inner pin measures. There are two sets of steps, one set on the body for the outer pin, and the other set on the inner pin. See figure 20.

3.6.8.1 On occasion, it is necessary to employ the multiple flush pin on tapered holes or protrusions where all the part variations cannot be gaged using the ordinary type of taper flush pin or plug.

3.6.8.2 Multiple flush pin gages are relatively pensive and their use should be confined to standardized items of high production or employed only when the part design precludes the use of ordinary flush pin gages.



FLUSH PIN FORMULA
FOR DRILLED HOLES

FOR 118° DRILL	OTHER ANGLES
Ⓖ = D−.002	Ⓖ = D−.002
① = D−.97R	① = $D-2\left(1-\cos\frac{A}{2}\right)R$
② = .8837 (Ⓖ−①)	② = $\frac{Ⓖ-①}{2\tan\phi}$
③ = L+.2914R	③ = $L+\left(\sin\frac{A}{2}-\tan\phi\right)R$
④ = ③ + T + .3004t	④ = ③ + T + $\frac{.5t}{\tan\frac{A}{2}}$
⑤ = ④ − ③	⑤ = ④ − ③
ø = .25A = 29°30′	ø = .25A

FIGURE 19. *Flush pin formula for drilled holes.*

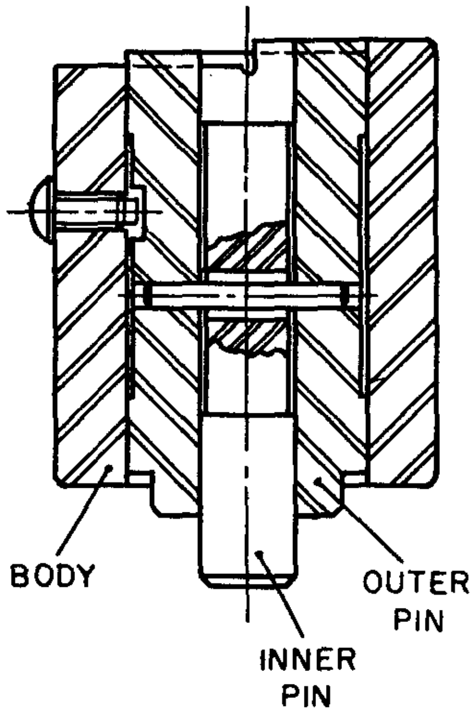


FIGURE 20. *Multiple flush pin.*

3.6.9 *BUILT-UP TYPE FLUSH PIN GAGES.* Some part designs necessitate the use of complex flush pin gages to measure various lengths, depths, thicknesses and locations. One or more flush pin units similar in principle to standard flush pin gages are mounted on a frame or case along with positioning and holding devices to comprise the complete gage. Designs of this particular type are difficult to standardize; therefore, their development depends upon the part design and the gate designer's originality.

3.7 SPANNER GAGES. The term "spanner gages" as used in the following paragraphs refers to gages which are designed to check either the location of plain or threaded holes or protrusions or the spacing of slots.

3.7.1 *GENERAL DESIGN DATA.* The first step in the design of spanner gages is to determine the mating part conditions. The survey must ascertain if the extreme part limit conditions permit proper assembly. The designer must then decide whether to gage the actual or the implied dimensions, particularly with the two pin or two hole type.

3.7.2 *TWO PIN (HOLE) GAGES.* The simplest type of spanner gage involves either two pins or two holes or a combination accurately located with respect to each other. The design data is as follows.

3.7.2.1 The distance between centers of the holes or pins on the gage shall be equivalent to the mean of the part hole or pin spacing. The tolerance on this distance shall be five percent of the part spacing tolerance applied bilaterally ($\pm$.05%). It shall not exceed $\pm$.0005 or be less than $\pm$.0001 in any case.

3.7.2.2 On a male type gage, the diameter of each of the pins shall be equal to the minimum diameter of the part hole minus one-half of the total tolerance on the part hole spacing. The tolerance on the pin diameters shall be the "go" tolerance from Table II applied plus. The part tolerance on the holes shall be used to obtain the required gage tolerance from the tolerance table.

3.7.2.3 In the female type gage, the diameters of the holes shall be equal to the maximum diameter of the part protrusions plus one-half of the total tolerance on the part spacing. The tolerance on the hole diameters shall be the Go tolerance from Table II, applied minus. The part tolerance on the pin shall be used to obtain the required gage tolerance from the table.

3.7.2.4 When a location of a hole or protrusion is given from a surface, the total part spacing tolerance shall be added to the gage hole or subtracted from the gaging pin diameter. Tolerance applied same as above.

3.7.2.5 Generally, where only two holes or protrusions are concerned, sufficient information for gaging is given by the distance between holes and tolerance on holes being specified. However, if the tolerance has been omitted or available tolerance is not sufficient, the gage may be designed using implied dimensions.

3.7.3 *MULTIPLE PIN OR HOLE GAGES.* Multiple pin or hole gages are designed utilizing the same basic data as two pin gages. That is, that the ideal center of the part pin or hole coincides with the ideal center of the gage pin or hole and the gage pin or hole is altered by the amount of mislocation to allow acceptance of any correct diameter pin within the area defined by the locational tolerance.

3.7.3.1 However, in dimensioning this type of gage, difficulties arise. A careful survey of the part dimensioning and tolerancing and that of its mating part must be made. If the part has been dimensioned using the basic location system with a locational tolerance according to MIL-STD-8, it is a relatively simple matter to gage if the part tolerances are not extreme. It is recommended that coordinate location be used despite the increase in accuracy required of the gage.

3.7.4 *BASIC CONSTRUCTION*

3.7.4.1 *Male Spanner Gages.* This gage consists of a holder into which the gaging pins are secured. The holder is usually of soft machine steel to facilitate the precision location needed for the pins. The pins are usually driven in the holder and may or may not be shouldered. The holder will contain knock-out holes for removing the pins. The pins should be designed with chamfers to aid in entering the part. The length of the pins may vary according to the dictates of the individual part. However, when not otherwise limited by the part, a length equal to one and one half times the diameter of the pin is considered good practice.

3.7.4.2 *Female Spanner Gages.* This gage consists of a plate and the necessary bushings to gage the protrusions of the part. The plate is usually made from soft machine steel to facilitate the precision location required for the bushings. The internal diameter of the bushings is ground concentric with the outside diameter and press fitted into the plate. The bushings are made from hardened tool steel and may either be of the headless or head type. It is advisable, wherever possible, to use standard commercial bushings. Their length will determine the thickness of the plate. The bushings will be chamfered to clear any part fillet or radii.

3.8 CALIPER GAGES. Caliper gages are any gages with movable arms (or a combination of fixed and movable arms) that transfer a part feature inserted between or placed over them to an indicating mechanism.

3.8.1 *DESIGN CONSIDERATIONS.* The major considerations in the design of caliper gages are the rigidity of the arms, the alignment of the calipering points with each other and with the surface to be gaged, the accuracy of the pivot and finally the relationship between the lengths of the gaging arms and those of the indicating arms.

3.9 COMPARATOR GAGES. A comparator gage has been defined as any gage which utilizes an indicating device to directly contact the work and indicate its departure from a preset size with a minimum of auxiliary devices.

3.9.1 *CONSTRUCTION.* As illustrated, most comparators consist of a sturdy base and column, together with an arm riding on the column carrying the indicating device or its sensing element. Either the top surface of the base is finished square with the indicating device or an anvil with a lapped upper surface is provided. The anvil is usually serrated to reduce the amount of surface to be lapped and resistance to sliding motion of the part. The indicating device used on the comparators may be air, electric, mechanical, or optical. An optical projector is not classed as a comparator. See figure 21.

3.10 RECEIVER GAGES. Receiver gages are precisely what the name implies. They *receive* the part and verify its dimensions. The name shall be applied only to gages which consist predominantly of internal surfaces or portions of surfaces arranged to verify part dimensions. Gages consisting of exclusively external surfaces are dealt with under paragraph 3.2.6, Multi-Element Plug Gages.

3.10.1 *APPLICATION.* This type of gage is used primarily to inspect the interrelationship of two or more external surfaces. It may be designed on the basis of either dependent requirements specified on the part drawing or independent requirements which cannot be gaged economically by direct indication.

3.10.2 *DESIGN CONSIDERATIONS.* Each surface of the gage is designed using the maximum size of its corresponding part surface plus the allowable misalignment per individual surface. In gages with only two gaging surfaces which are also adjacent, half of the allowable misalignment may be added to each maximum part dimensions. If there are more than two gaging surfaces of if the surfaces are not adjacent, then one surface is held to the maximum size of its corresponding part surface and all the allowable misalignment added to the maximum size of the other surface. When thus designed, the gage will insure that the parts are within the specified limits of alignment when the individual part sizes are maximum. (Max metal condition)

3.10.3 *GENERAL CONSTRUCTION.* Gages containing only two shallow gaging diameters should utilize American Gage Design Standard solid ring gage blanks, if possible. Gages with more than two surfaces or long gaging surfaces may be manufactured in one piece if they are not too large, but preferably should be constructed in sections that are precisely fitted into a holder unit. Sectional con-

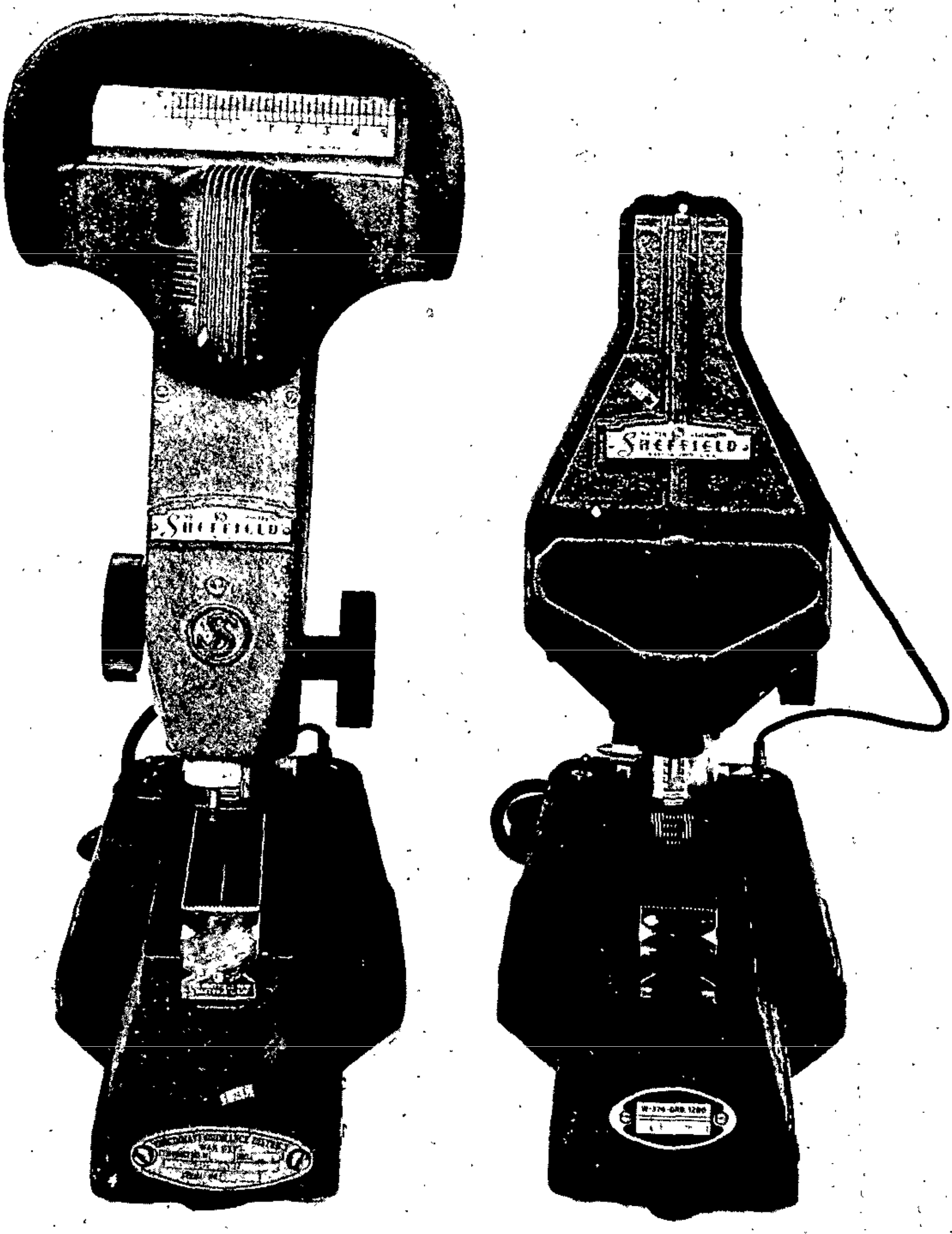


FIGURE 21. *Comparator gages.*

struction facilitates manufacture, inspection, surveillance, and repair or modification. Caution must be exercised to maintain reasonable uniformity of section throughout the design of both solid and sectional type receiver gages to prevent distortion during heat treating.

3.10.4 *CHECK GAGES.* The problem of acceptance and subsequent surveillance inspection of receiver type gages must be considered. A check plug shold be designed for all gages which cannot be conveniently set up for measurement.

3.10.4.1 The check plug shall be shown on a separate drawing. The gage shall be marked "ACCEPTANCE CHECK FOR 7XXXXXX2". The required gage sizes will be shown on the elements of the check plug. The ring can be accepted as being dimensionally correct if it fits the check when inspected with the Prussian Blue transfer process.

3.10.4.2 In some instances, smaller receiver gages can be designed to eliminate the use of a check plug gage. This is accomplished by finish grinding the outside diameter and then finishing the inside diameters concentric with it. Using the outside diameter as a reference surface on which the gage may be rotated, the gage checker can measure the inside diameters and verify their concentricity by use of a dial indicator.

3.11 FIXTURE GAGES. Any gage consisting predominantly of devices arranged to verify the features of a part shall be labeled a fixture gage.

3.11.1 *GENERAL CONSTRUCTION.* Fixture gages vary in type and method of construction depending upon the nature of the part, the function or functions being checked, and the gage designer's originality. Generally, fixture gages usually consist of the following parts or elements: (a) a base, (b) locating pins, blocks, clamps, (c) indicating devices, flush pins or dial indicators, (d) necessary part handling aids for the inspector such as positioning or ejecting devices.

3.11.1.1 Some types of fixture gages require the use of masters for setting of the gage prior to checking a group of parts This setting master usually simulates the part but is not necessarily an exact duplicate of the part.

3.11.1.2 Gages should be designed to hold the part or locate it in a manner as similar to its functional location or function as possible. In addition, fixture gages should be designed to check the part in accordance with the dimensional specifications rather than to the particular method of manufacture. Care should be taken in analyzing the parts to be gaged so that the correct locating and bedding points will be chosen.

3.11.1.3 Where close dimensional limits must be maintained, welded construction should be used with caution.

3.11.2 *ECONOMY IN MANUFACTURE.* A fixture gage is a specialized type of gage which usually is applied to only one part. Its size and dimensional accuracy is such that the cost of the gage is usually rather expensive. Therefore, the following points should be considered to effect the greatest economy.

3.11.2.1 The part being gaged should be a standardized item warranting the design of a complicated fixture gage.

3.11.2.2 An investigation should be made to assure that a commercial gage is not available which could be modified to suit the given part at a reasonable cost.

3.11.2.3 When a fixture gage is designed, the cost of the gage should be amortized in a saving of inspection time. Therefore, the designer must design a gage that is easy to operate incorporating quick operating and positive gaging features.

3.11.2.4 When a fixture gage is needed to gate an experimental item, the designer should, if possible, provide an improvised method of inspection using standard measuring equipment with one or two specially made adapters to facilitate positioning or locating, if necessary.

3.11.3 *OPERATING MECHANISMS.* The gage designer may minimize the part inspection time by employing any of the following basic mechanisms:

- (a) Quick acting cams for locating or locking.
- (b) Spring loaded pins and plungers.
- (c) Multiple lead screws.
- (d) Levers
- (e) Hydraulic or air cylinders for lifting or moving the part into position.

3.11.4 *REPLACEMENT ELMENTS.* In designing fixture gages, an analysis must be made of the different gaging elements to ascertain which particular parts are subject to wear and will eventually need replacement. The gage must be designed so that these parts can be easily replaced, involving a minimum amount of time and expense without destroying the required accuracy of the gage. Thread plugs and thread rings used on fixture gages are excellent examples and provisions must be made for their replacement. In some isolated cases, one fixture gage may be designed to suit two or more similar parts by the use of replaceable or interchangeable elements. (See paragraph 2.3.4.)

3.12 INDICATING TYPE GAGES.

3.12.1 *APPLICATION.* Most types of basic gages such as snaps, flush pins, length gages, etc., can be designed using indicators instead of fixed anvils or profiles. This conversion in design is preferred under the following conditions:

(a) When the part tolerance is relatively small (under .005) and the specific type gage utilizes feel or sight, an indicator can often be substituted to improve accuracy.

(b) On low production or experimental items, indicating type gages may be used to inspect several parts having similar dimensions which fall within the range of the indicator, thereby eliminating the need for several fixed gages.

3.12.2 *TYPES OF INDICATORS.* There are various indicating type gages available commercially. The most common are mechanical dial indicators and air-pressure activated indicators.

3.12.2.1 Mechanical Dial Indicators. Mechanical dial indicators have been standardized with respect to range, accuracy and mounting dimensions. The pertinent information may be found in MIL–I–18422.

3.12.2.1.1 The range of the indicator shall exceed the component tolerance and also be sufficiently large to enable easy entry and removal of components from the gage.

3.12.2.1.2 The graduations on the dial shall be such that ample circumferential spacing exists between the maximum and minimum limits. A good empirical rule is that the range of the indicator be approximately eight (8) times the component tolerance.

3.12.2.1.3 The proper type of indicator back shall be selected to facilitate simple and economical mounting of the indicator and provide the desired adjustment in positioning. "Back" type mountings are preferred to "stem" mountings, since improper clamping may bind the spindle.

3.12.2.1.4 When applying indicators to heavy or cumbersome components, it is advisable to apply some intermediate gaging device to act as a shock absorber. Guards around the indicator to prevent damage are also advisable.

3.12.2.1.5 When designing gages utilizing mechanical dial indicators, it shall be kept in mind that there are considerable variations in various commercial indicators that nevertheless meet all AGD specifications. If the specific application will only accept a certain indicator, it shall be so specified on the drawing. This condition shall be avoided as much as possible.

3.12.2.2 *Air Pressure Indicators.* There are two general types of air pressure indicators, differing primarily in the method of indication. Both use the flow characteristics of air through orifices. However, one method uses a float suspended in a tapered tube to indicate the relative velocity and thus the comparative size, while the other uses a differential bellows, bourdon tupe or other mechanical sensing device to indicate on a dial similar to that of a mechanical dial indicator. The float and differential types appear of equal merit. The flow (or tube) utilizes two masters (not necessarily the part limits), one to set the zero set, the other to establish the magnification. The differential type has a fixed magnification and may be set with a single master. See figure 22.

3.12.3 *Setting Masters.* Setting masters for simple dimensions may be plugs, rings or set master disks as shown in Commercial Standard CS8, Gage Blanks. The form of the setting master should approximate

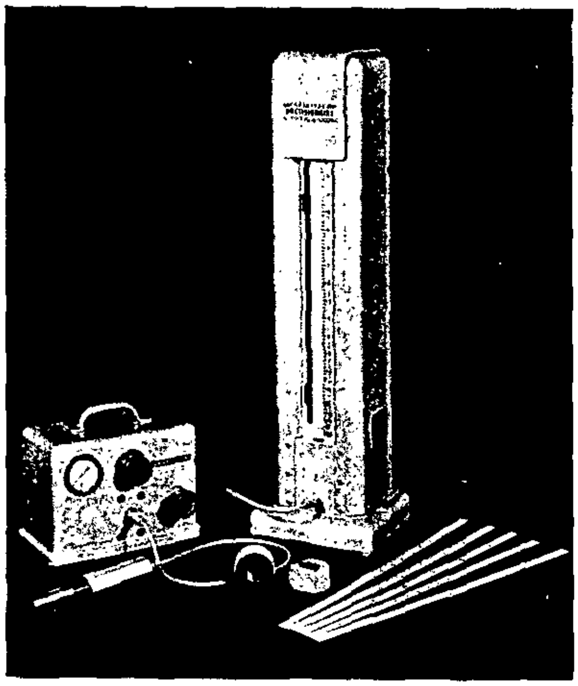


FIGURE 22. *Dial and column type air pressure indicators.*

the form of the piece being inspected. It is preferable that both a maximum and minimum master be used for each application. The indicator is set to one limit and the other limit checked to prove out the magnification. Inaccuracies of magnification can be compensated for by ruling new lines on the dial face.

3.12.3.1 Except for very tight tolerances or an extremely critical limit, it is not necessary to specify masters for the exact tolerance limits, the nearest thousandth generally being satisfactory. Further, the tolerancing of such set masters should be bilateral, so they may be used for a limit in either direction, high or low. The tolerance should be half the Master tolerance from Table II applied bilaterally. Furthermore, since masters generally have their exact sizes recorded in acceptance or calibration, the indicator can be set to this size, thus giving a high order of accuracy regardless of the direction of tolerance or its magnitude.

3.12.3.2 In cases of a liberal tolerance or a Max or Min limit, a single master may be used to set the desired limit at zero and the accuracy of the indicator mechanism is used to establish the limits of tolerance.

CHAPTER 4. INTERRUPTED DIAMETERS

4.1 INTRODUCTION. This section contains the pertinent design data for interrupted diameters such as threads, serrations and splines.

4.1.1 *GENERAL.* Broadly speaking, gages for interruped diameters are gages to insure interchangeability. Usually, a multi-element "Go" gage that simulates the mating part determines if the part being inspected will assemble with any acceptable mating part, and one or more single element "Not Go" gages check critical dimensions (such as pitch diameter) to insure that they are within acceptable limits.

4.2 UNIFIED AND AMERICAN NATIONAL THREADS.

4.2.1 *GENERAL.* The two most common thread forms are the 60° Unified form that has been developed as an international standard and the American National form.

4.2.1.1 *Standardization.* Due to the wide application of the basic thread form the gages have reached a high degree of standardization. The specific series—UNC, UNF, UNEF, 8UN, 12UN, and 16UN have been cataloged as Military Standards. The design data for gages for threads of special diameters, pitches and lengths of engagement has also been standardized and is presented in Handbook H28. A discussion of the gaging approach and policy is contained in this section.

4.2.2 *GAGES FOR INTERNAL THREADS.*

4.2.2.1 *Go Thread Plug Gages.* A Go thread plug is designed to check the minimum pitch diameter, the clearance at the major diameter, the lead, and the flank angle all simultaneously. When a Go gage enters the part, assembly of the inspected thread with any acceptable external thread is assured with only the minor diameter of the part requiring further inspection.

4.2.2.1.1 Go Thread Plug Gages for thread sizes .150 or below shall have the male precision centers left on the gaging members. On all Go thread plugs with a nominal thread size above .150, a slot called a chip groove shall be cut through the first three or four threads at the entering end of the plug. Other type chip grooves in accordance with commercial practice such as the longitudinal groove extending the complete length of the gaging member will be considered as acceptable. This shall apply to all male threaded gages including those used to gage concentricity, alignment, and similar functions. The slot shall be cut parallel to the axis of the thread and shall in all cases extend below the root of the thread. The preferred dimensions for the width, depth, etc., will be found in MIL–STD 114. One chip groove is required at the front end of the gaging mumber, unless the gaging member is reversible which requires a chip groove at each end.

This slot is to serve as a reservoir for collecting foreign matter that might damage the thread flanks. It is definitely not intended to function as a tap for cleaning out burred threads.

4.2.2.1.2 On gages without a chip groove the partial thread at the front end of the gaging member shall be removed to a blunt start to avoid feather edges. On gages with a chip groove, the partial thread preceding the chip groove shall be completely removed to a depth at least equal to the minor diameter of the thread. Not more than one complete turn of the thread shall be removed to the point where the full thread form is obtained. On gages of 28 threads per inch and finer, a 60° chamfer from the axis of the gage is permitted in lieu of removal of the partial thread. Gages that have male precision centers left on the gaging members perform the same function as the 60° chamfer.

4.2.2.2 *Not Go Thread Plug.* A Not Go thread plug is designed to check only one element of the thread, the pitch diameter. The thread form on the gage is truncated at the crest and cleared at the root so that the flank makes contact on a limited area of the part thread flank. This is to determine if the pitch diameter has exceeded the maximum limit.

4.2.2.3 The conventional method of inspecting the limits of the minor diameter of an internal thread utilizes plain plug gages. A Go plug gage insures against undersize minor diameters and the Not Go plug insures that there is sufficient depth of thread.

4.2.2.4 *Depth Requirements.* A large percentage of part tapped hole specifications include a requirement for minimum length or depth of full form thread. Occasionally, a maximum length of full form thread is confused with the specification for depth of tap drill or bore diameter. The depth shall be considered to be to the centerline of a full form thread space on the part internal thread unless otherwise specified.

4.2.2.4.1 The conventional method of gaging this depth is with a step or flat added to the Go thread plug gage. On applications where more than twenty-five percent of the circumference is removed, other methods should be considered since maximum salvageability of the thread plug is always desired. One possibility is the use of hardened lock nuts with their faces ground square with the axis of the thread.

4.2.2.4.2 When the step or flat method is applied, it is cut on the threaded cylinder at 90° with the axis and to a depth sufficient to provide for comparison of the part with the gage by either feeling with a fingernail or by the use of a straightedge. The step shall be placed circumferentially so that at least one half of the full form of the tread remains at the center of the flat. Unless the depth requirement is an exact multiple of the pitch, the thread start at the full form will not fall on the centerline of the step. If both a max and a min step are desired, they should be placed 90° apart.

4.2.2.4.3 When a Go thread plug gage is designed to include a depth requirement, the gage shall be classified as Special. If the gage is a Unified or American National Standard thread, the design data for the major diameter, pitch diameter, and root clearance, etc., shall to taken from the appropriate Mil-Std.

4.2.2.5 *Handles.* All thread plug designs are to be single end and the handle should be in accordance with American Gage Design Commercial Standard CS8. Aluminum handles shall be used for all thread plugs. AGD standard thread blanks should be specified wherever possible.

4.2.2.5.1 The Not Go tri-lock blank shall be specified for Go thread plugs in sizes above 1.510 and with pitches finer than 16 threads per inch unless a special requirement necessitates the use of the longer Go blank.

4.2.2.5.2 The Not Go taper lock blank shall be specified for Go thread plug gages which have depth steps whenever the blank has sufficient length to allow for grinding a flat on the back face of the plug.

4.2.2.6 *Segment Type Thread Plugs.* The operation of screwing solid thread plug gages in and out of the part is a time-consuming and monotonous operation. Several types of retractable segment thread plugs have been developed to eliminate this operation and reduce inspection time. The segment type gage is constructed so that the expanded position of the spring loaded segments is indicated by a dial indicator.

4.2.2.6.1 The expanding type gage is not satisfactory for inspecting both the maximum metal (go) and minimum metal (not go) limits simultaneously. This is due to the fact that standard gaging practice requires a smaller truncation on the major diameter of the Go member than on the Not Go member to insure thorough inspection. Therefore, segment type gages must be supplied in pairs for a complete inspection, i.e., one gage for each limit. The gage truncations and root clearance should follow standard thread plug gage practice.

4.2.2.6.2 A solid type thread ring gage is recommended for setting segment type plug gages. A thread check plug is required for the manufacturing and acceptance inspection of the setting ring gage. A separate drawing shall be prepared for each unit.

4.2.2.6.3 The initial cost of a complete set of segment type plug gages for an internal thread is relatively high and, therefore, this type of gaging should be employed only on standardized high production types of materiel so that the cost can be readily amortized by subsequent savings in inspection.

4.2.2.7 *Roll Thread Plug, Bar Type.* This type of gage utilizes two thread rolls of small diameter which are mounted on the spring loaded telescoping center bar which serves to expand and set the rolls firmly in the part being inspected. A gaging button is mounted on each member of the telescoping center bar. Acceptability of the part is determined by trying either a Go or Not Go feeler plug or both between the buttons depending on the design of the rolls. The same general principles as outlined in 4.2.2.6.1 apply to roll thread plug gages.

4.2.2.7.1 The bar type roll thread gage may be specified for gaging threaded holes 7" in diameter or larger. Gaging rolls can be made to check 60° form, Whitworth, Acme, Buttress and other special forms. The thread form on the thread roll is ground as a cylinder rather than on the true helix and, therefore, cannot be successfully applied to threads having a large helix angle (7° or greater) or to multiple threads.

4.2.2.7.2 This type of gage will afford sufficient accuracy for most large diameter applications if the gage is used carefully. Since the cost of the gage is relatively low, it is especially applicable to low production items. The gages can be salvaged easily since the rolls are replaceable.

4.2.3 GAGES FOR EXTERNAL THREADS. Thread ring gages are the most conventional means of checking external threads such as those found on a screw.

4.2.3.1 *Go Thread Ring.* A Go thread ring is designed to check the maximum pitch diameter, the clearance at the minor diameter, the lead and the flank angle simultaneously. When an external thread on a part enters a Go ring gage completely, assembly with the mating internal thread is assured with only the major diameter of the part requiring further inspection.

4.2.3.1.1 *Chip Grooves.* Chip grooves are not applied on thread ring gages. The design of the American Gage Design Standard adjustable type blank includes three (3) slots which serve as chip grooves.

4.2.3.2 *Not Go Thread Ring.* A Not Go thread ring is designed to check only one element, the pitch diameter, to insure that it is not below the minimum limit. For this reason, the thread form on the ring gage is truncated at the minor diameter and cleared at the root so that the gage only makes contact upon the central portion of the part thread flanks. The clearance at the root may be omitted on thread ring gages for 28 pitch and finer since it is impractical to provide clearance on fine pitches.

4.2.3.3 *Thread Ring Gages, Types.* Thread ring gages can be successfully produced in either the solid or American Gage Design Standard adjustable types. The term "adjustable" must be considered with caution. The gage may be adjusted up to .0005. However, this adjustment is used only insofar as it is necessary to obtain a proper feel on the setting plug.

4.2.3.3.1 *Gage Blanks.* American Gage Design Standard thread ring blanks should be specified wherever possible.

4.2.3.4 *Thread Setting Plug Gages.* Thread setting plug gages are required for the manufacture, acceptance inspection, and subsequent surveillance of solid and adjustable type thread rings, roll thread snap, segment type snaps, and other indicating type gages.

4.2.3.4.1 All thread setting plugs including those used for thread ring elements on fixture gages shall be designed having both a full form and a truncated major diameter, except when a setting plug is required for a blind thread ring element on a fixture gage, in which case a full form major diameter setting plug shall be designed.

4.2.3.5 *Thread Ring Minor Diameter Acceptance Plugs.* Thread ring gages having nominal diameters under .375 generally cannot be measured in all laboratories due to limitations of the measuring equipment. Therefore, it is necessary to inspect the minor diameter after the thread ring has been properly set to the thread setting plug. Two plain plug gages are required for adequate inspection.

4.2.3.5.1 A separate drawing shall be prepared for each gaging element provided the desired size is not listed in MIL-STDS 116 and 117. The gage shall be known as an Acceptance Check. Note that the gagemaker's tolerance is in a minus direction on the Go element and in a plus direction on the Not Go element, the reverse of conventional gaging practice.

4.2.3.6 *Major Diameter Adjustable Snaps.* The most conventional method of inspecting the limits of the major diameter of external threads is by the use of adjustable snap gages. The Go portion insures against oversize major diameters and the Not Go portion insures that there is sufficient depth of thread.

4.2.3.6.1 MIL-STD-118 lists the various stock numbers for unset plain adjustable snap gages. It is preferred that the square button type (Models MC or C) be used for gaging the major diameter. The method shown in the Standard for specifying the proper stock number, setting size, etc., shall be followed.

4.2.3.7 *Length Requirement.* Occassionally, an external thread specification will include a requirement for minimum length of full form thread. The length shall be considered to be to the center line of a full form thread space on the component external thread, unless otherwise specified.

4.2.3.7.1 The rear face of the Go thread ring blank may be ground square with the axis if the length inspected closely approximates the length of either a thick or thin blank. If the length specified is considerably less than the thickness of a standard blank, the gage may be counterbored from one side and the opposite face ground square with the thread axis to provide a surface for comparison of the part to the gage by feel with the fingernail or by use of a straight edge. The leading thread on the thread ring must be convoluted (removed) to a full thread form.

4.2.3.7.2 Care must be exercised to insure that the cross-section of the finished ring gage is not so irregular that distortion will occur when hardening.

4.2.3.7.3 When a thread ring gage is designed to include a length requirement, the gage shall be classified as Special. If the gage is a Unified or American National Standard thread, the design data for the major diameter, pitch diameter, minor diameter and root clearance, etc., shall be taken from the appropriate Mil-Std.

4.2.3.8 *Thread Ring Gage, Segment Type.* The operation of screwing thread ring gages on and off a part is time-consuming and monotonous. Several types of segment thread rings have been developed to eliminate this operation and reduce inspection time. The segment type ring gage is constructed so that contact is obtained on approximately 75% of the thread circumference and approximates thread ring gaging action. The segments are mounted on pivots to allow fast, one pass gaging of the full length of thread.

4.2.3.8.1 The segment type gage is more expensive than standard ring gages but the cost can usually be amortized from the savings in inspection time.

4.2.3.9 *Roll Thread Snap Gages.* This type of gage utilizes two thread rolls of small diameter mounted on opposite sides of a "C" frame. Where both the Go and Not Go limits are to be inspected, a set of rolls is mounted for each function. The thread form on the rolls must be truncated and effectively cleared in accordance with normal ring gage practice.

4.2.3.9.1 Gaging rolls can be made to check not only the 60° Form, but Whitworth, Acme, Buttress, and other special forms. The thread form is ground as a cylinder rather than on a true helix and, therefore, cannot be successfully applied to threads having a large helix angle (7° or greater) or to multiple threads.

4.2.3.9.2 This type of gage will afford sufficient accuracy for a large percentage of applications but must be specified with caution.

4.2.3.9.3 When roll thread snap gages are specified for high production items, it is good practice to also supply a thread ring gage for use in spot checking.

4.2.4 *TOLERANCES AND ALLOWANCES.*

4.2.4.1 Tolerances for both Unified and American National forms are in accordance with H28, Screw Thread Standards for Federal Serivices.

4.2.4.2 Standard tolerances for thread plug and ring gages are of three classes:

(1) "W" tolerances which represent the highest commercial grade of accuracy and are applicable to the lead and flank angle of all setting plugs regardless of class. "W" tolerances may also be applied to pitch diameters if the class of fit warrants it.

(2) "X" tolerances are larger than "W" tolerances and are an economical compromise among such factors as gage cost, amount of part tolerance consumed by gage tolerance, etc. "X" tolerances are generally applicable to all inspection gages and to pitch diameters of setting plugs.

(3) "Y" tolerances include a wear allowance and are applicable on thread plug and ring gages where a little extra gage life is desired.

4.2.4.3 Tolerances on lead are specified as an allowable variation between any two threads not farther apart than the length of a standard gage omitting one full turn at each end. In the case of setting plugs, the length shall be that of the thread in the mating thread ring. On truncated setting plugs, any lead error shall be the same on the full form portion as on the truncated portion and shall be uniform within .0001 over any portion equivalent in length to that of the mating thread ring.

4.2.4.4 Tolerances are specified on the flank angle rather than the included angle to insure that the thread form is perpendicular to the axis of the thread.

4.2.4.5 Tolerances on lead, flank angle, and pitch diameter are not cumulative; that is, the tolerance on any one element may not be exceeded even though the errors in the other two elements are smaller than the respective tolerances.

4.2.4.6 Thread gages for UNC, UNF, UNEF, 8UN, 12UN, and 16UN threads are classified as Military Standards. In the event that the part specifications for an NS thread are such that a Mil-Std gage element can be used, the applicable Mil-Std stock number shall be referenced on the supply list and an appropriate note added as an aid to inspection personnel. (Mil-Std XXXXXXX is applicable to Go P.D. for XXX-XXNS-X Thread.)

4.2.5 *IDENTIFICATION DATA*

4.2.5.1 The identification data block for thread gages shall include complete thread designation as to nominal size, threads per inch, thread series, class of fit, and product pitch diameter size. In specifying the nominal thread size, pitch diameter, etc., the decimal form shall be used.

When a thread gage is designed to inspect an additional dimensional feature such as depth, out-of-squareness, etc., this information shall be included in the identification data block together with the complete thread designation as outlined above.

4.2.5.2 The data on Not Go gages for UNS and NS threads shall also include the length of engagement (LE) to which gage applies; for example:

1.5000-32NS-2
NOT GO PD 1.4851
LE 1.5

This is necessary as a result of the varying tolerances applied to the different ranges of length of engagement. Since the tolerances for Unified threads are based on a particular number of pitches and applied to all lengths of engagement up to 1½ diameters, it will not be necessary to indicate the particular range in the thread designation.

4.2.5.3 When the thread data given on the part drawing is not in accordance with the tables in H28, the following will apply:

(1) When a product has a non-standard (not in accordance with H28) major or minor diameter, the Go and Not Go pitch diameter thread gages will be designed according to standard thread data providing the major or minor diameters clear the part.

(2) When the product thread data dictates that a non-standard major or minor diameter on the gage is necessary to provide clearance, or the pitch diameter of the product is a non-standard size, then the gage for the element and limit that is not standard should be marked NON STD in place of the usual class of thread. As an example, the correct upper limit of the pitch diameter of a 1.50-32NS-2B product thread is 1.4849. For reasons of design, a pitch diameter tolerance of .0083 is used making the upper limit 1.488. The Not Go plug gage for this element and limit should be marked:

1.50-32NS-NON STD
NOT GO PD 1.488

4.2.6 *GAGES FOR MULTIPLE THREADS.* A multiple thread is defined as one that has a lead which is an integral multiple of the pitch.

4.2.6.1 In designing gages for multiple threads, the designer is cautioned to make a thorough investigation of all features of the thread before proceeding with the design. In general, the design data for the major, pitch, and minor diameters, root clearance, chip grooves, and tolerance on half angle is identical with single pitch threads. In addition, the pitch and lead of the thread must also be specified. Multiple lead threads will be classified Special, since it is highly desirable to maintain a reference to the applicable component parts.

4.2.6.2 The thread starts at both ends of the gage should have the thread removed to a full form. Note that this will not require the removal of a full turn as is the case for a single pitch thread gage. A thread having a lead which is twice the pitch will have the thread convoluted for a half turn and will require two chip grooves (go thread plug) instead of one.

4.2.6.3 In designing not go thread gage elements for multiple threads, it is desirable to design gages which have only a single-thread start but with the proper lead, in order to facilitate the inspection of each thread start individually. The length of thread should be such as to provide 1¼ turns if practical as to an aid in measurement. This method of design facilitates an economical and accurate inspection.

4.2.6.4 The data block shall contain the complete thread designation as specified in paragraph 4.2.5 and shall also include the lead and pitch.

4.2.6.5 The label "MULTIPLE THREAD" shall be placed in a conspicuous position on the drawing in ¼" high letters.

4.3 OTHER THREAD FORMS

4.3.1 *PIPE THREADS.* American Standard pipe threads are 60° threads designed on the same order as the Unified and American National Threads previously described. Some are different only in the truncation while others differ in both the truncation and the fact that they are cut upon a cone rather than a cylinder.

4.3.1.1 *Taper Pipe Threads.* Taper pipe threads are 60° form threads cut on a cylinder with a taper of 1 in 16, or .75 inch per foot, measured on the diameter and along the axis. There are two basic pipe thread series differing primarily in the degree of truncation of the thread.

4.3.1.1.1 *NPT Pipe Threads.* The American Standard taper pipe thread, designated as NPT, is designed for low pressure application and requires the use of a sealing compound to give a leak-proof joint. In consequence, the gaging approach is rather simple. A taper thread plug gage for the internal threads and a taper thread ring gage for the external threads are sufficient. A taper thread plug and plain taper plug are also required for the manufacture and acceptance inspection of the taper thread ring. Steps are cut in the thread plug and ring gages to indicate the limits that the gages may enter into or upon the part threads.

4.3.1.1.2 *NPTF Pipe Threads.* NPTF or Dry Seal taper pipe threads are designed for use without a sealer. The threads are so designed that when mated hand tight the crests and roots of the threads are just touching. When wrench-tight, the crests and roots are crushed together giving a metal to metal seal. To provide this series of actions, close control of the taper of the threads and of the truncation of the crests is imperative.

4.3.1.1.2.1 *Gaging Internal Threads.* Internal threads are gaged utilizing two taper thread plugs and one plain taper step plug. The two taper thread plug's lengths and diameters are so related that one checks primarily the lower end of the taper on the component and the other checks the upper end, thus giving a more accurate check of the taper than a single plug. Steps are provided on the plugs to aid in evaluating the component condition. These steps are provided at the basic condition and a turn and a half either side of basic. The two gages must enter the part to or near the corresponding steps in order to have an acceptable part. The plain taper step plug also has steps which correspond to those on the taper thread plugs so that all three gages must enter previously determined amounts for an acceptable part. The approach to gaging external taper pipe threads is the same as that outlined for internal threads except that two taper thread rings and a plain taper step ring are employed. Further, it is necessary to provide a plain taper plug and taper thread plug for each thread ring and a plain taper plug for the plain taper step ring for purposes of manufacture, acceptance and surveillance.

4.3.2 *Acme Threads.* The design data for regular and Stub Acme thread gages is available in Handbook H28, Screw Thread Standards for Federal Services. Condensation of the design data for Stub Acme gages has not been accomplished; therefore, H28 shall be used. Design data for the General Purpose thread and the Centralizing thread has been condensed and is presented here. The three classes of general purpose threads have clearances on all diameters for free movement and may be used in assemblies where the screw is contained in a bearing or bearings and the nut is rigidly fixed. The five classes of centralizing threads have a limited clearance at major diameter of screw and nut so that bearing at major diameter maintains approximate alignment of the thread axis. For any combination of these five classes of screws and nuts, some backlash or end play will be obtained. If this is objectionable, one of three practices has been used as follows:

(1) The nut is split parallel with the axis and lapped to fit the screw.

(2) The nut is tapped first and the screw is machined to fit the nut.

(3) The nut is split perpendicularly to the axis and the two parts are adjusted to bear on the opposite flanks of the screw.

The gage design data for these eight classifications of Acme threads follow. Unless otherwise noted, all design values will be extracted from table X.

4.4 INVOLUTE SPLINES AND SERRATIONS. Involute splines and serrations are multiple keys in the general form of internal and external involute gear teeth, as used to prevent relative rotation of cylindrically fitted machine parts. The form of the tooth is made an involute primarily because it is self-locating in finding a full side bearing under load, and can be manufactured by the same machine used to generate involute gears. For purposes of gaging, the terms Spline and Serration can be used interchangeably. Therefore, wherever the term spline is used, it also pertains to serrations.

4.4.1 *INVOLUTE SPLINE GAGING.* The two main objectives in the inspection of involute splines and serrations are: (a) the assurance of interchangeable assembly by control of effective fit, achieved by use of composite gages; and (b) the dimensional control of parts, obtained by checking the space width or tooth thickness, major and minor diameter.

PITCH	P/4	P/6	.435P	.24P	.28P	.02P		3P	P/10	MAJOR & MINOR DIA TOLS	PITCH DIA TOLS CLASS 2	PITCH DIA TOLS CLASSES 3 TO 6	HALF ANGLE TOL	
1	2	3	4	5	6	7	THDS PER INCH	8	9	10	11	12	13	14
.06250	.01562	.01040	.02719	.01500	.01750	.00125	16	.18750	.0062	.001	.0006	.0005	0° 10'	.005
.07143	.01786	.01190	.03107	.01714	.02000	.00143	14	.21429	.0083	.001	.0006	.0005	0° 10'	.005
.08333	.02083	.01388	.03625	.01999	.02333	.00167	12	.24999	.0083	.001	.0006	.0006	0° 10'	.005
.10000	.02500	.01666	.04350	.02400	.02800	.00200	10	.30000	.0100	.002	.0007	.0006	0° 10'	.010
.12500	.03125	.02080	.05438	.03000	.03500	.00250	8	.37500	.0125	.002	.0008	.0007	0° 8'	.010
.16667	.04167	.02777	.07250	.04000	.04667	.00333	6	.50001	.0167	.002	.0009	.0007	0° 8'	.010
.20000	.05000	.03333	.08700	.04800	.05600	.00400	5	.60000	.0200	.002	.0010	.0008	0° 8'	.010
.25000	.06250	.04166	.10875	.06000	.07000	.00500	4	.75000	.0250	.002	.0011	.0008	0° 8'	.010
.33333	.08333	.05555	.14499	.07999	.09333	.00666	3	.99999	.0333	.002	.0013	.0008	0° 6'	.010
.40000	.10000	.06666	.17400	.09600	.11200	.00800	2 1/2	1.20000	.0400	.002	.0014	.0009	0° 6'	.010
.50000	.12500	.08333	.21750	.12000	.14000	.01000	2	1.50000	.0500	.002	.0015	.0010	0° 6'	.010
.66667	.16667	.11111	.29000	.16000	.18666	.01333	1 1/2	2.00001	.0667	.002	.0018	.0010	0° 5'	.010
.75000	.18750	.12500	.32625	.18000	.21000	.01500	1 1/3	2.25000	.0750	.002	.0018	.0010	0° 5'	.010
1.00000	.25000	.16666	.43500	.24000	.28000	.0200	1	3.000	.1000	.002	.0021	.0010	0° 5'	.010

.029 TO & INCL .825 DIAS	.825 TO & INCL 1.510 DIAS	1.510 TO & INCL 2.510 DIAS	2.510 TO & INCL 4.510 DIAS	4.510 TO & INCL 6.510 DIAS	6.510 TO & INCL 9.010 DIAS	9.010 TO & INCL 12.010 DIAS
15	16	17	18	19	20	21
.0001	.00012	.00016	.0002	.00025	.00032	.0004

LENGTH OF THREADS	CLASS 2	CLASS 3,4,5,6	MULTIPLE THDS CLASS 2	MULTIPLE THDS CLASS 3,4,5,6
	22	23	24	25
UP TO 1"	.0003	.0002	.00045	.0003
ABOVE 1" TO 3"	.0004	.0003	.0006	.00045
ABOVE 3" TO 5"	.0005	.0004	.00075	.0006
ABOVE 5" TO 10"	.0007	.0006	.00105	.0009

TABLE X. *Gage design values for Acme threads.*

Nominal Major Diameter of Screw		Length of "go" ring gage (max)	Amount pitch dia of "go" ring shall be less than max pitch dia of screw
Above	To and Incl	1	2
Inches	Inches		Inch
0	1	2 diameters	
1	1 1/8	2 inches	0.0012
1 1/8	1 1/4	2 inches	.0012
1 1/4	1 3/8	2 inches	.0015
1 3/8	1 1/2	2 inches	.0015
1 1/2	1 3/4	2 inches	.0015
1 3/4	2	2 inches	.0019
2	2 1/4	2 1/2 inches	.0019
2 1/4	2 1/2	2 1/2 inches	.0019
2 1/2	2 3/4	2 1/2 inches	.0019
2 3/4	3	3 inches	.0019
3	4	3 inches	.0027
4	5	3 inches	.0039

NOTE: - The above compensation is based on a length of engagement of two diameters and on a lead error in the product not exceeding the following values (in inches)

0.0003 in length of 1/2 inch or less
.0004 in length over 1/2 to 1 1/2 inches
.0005 in length over 1 1/2 to 3 inches
.0007 in length over 3 to 6 inches
.0010 in length over 6 to 10 inches

The lengths noted in col. 1 are a compromise for reasons of economy or limitations of manufacture. To insure positive interchangeability gage lengths should approximate the product length of engagement.

TABLE XI. *Pitch diameter compensation for adjusted lengths of Go Thread Ring Gages for centralizing and general purpose threads.*

NOMINAL SIZE RANGE		PITCH DIAMETER ALLOWANCES ON EXTERNAL THREADS, GENERAL PURPOSE AND CENTRALIZING.		
		CLASSES 2G, 2C, & 5C .008 $\sqrt{D}$	CLASSES 3G, 3C & 6C .006 $\sqrt{D}$	CLASSES 4G, 4C .004 $\sqrt{D}$
Above	To and Incl.	1	2	3
0	3/16	.0024	.0018	.0012
3/16	5/16	.0040	.0030	.0020
5/16	7/16	.0049	.0037	.0024
7/16	9/16	.0057	.0042	.0028
9/16	11/16	.0063	.0047	.0032
11/16	13/16	.0069	.0052	.0035
13/16	15/16	.0075	.0056	.0037
15/16	1 1/16	.0080	.0060	.0040
1 1/16	1 3/16	.0085	.0064	.0042
1 3/16	1 5/16	.0089	.0067	.0045
1 5/16	1 7/16	.0094	.0070	.0047
1 7/16	1 9/16	.0098	.0073	.0049
1 9/16	1 7/8	.0105	.0079	.0052
1 7/8	2 1/8	.0113	.0085	.0057
2 1/8	2 3/8	.0120	.0090	.0060
2 3/8	2 5/8	.0126	.0095	.0063
2 5/8	2 7/8	.0133	.0099	.0066
2 7/8	3 1/4	.0140	.0105	.0070
3 1/4	3 3/4	.0150	.0112	.0075
3 3/4	4 1/4	.0160	.0120	.0080
4 1/4	4 3/4	.0170	.0127	.0085
4 3/4	5 1/2	.0181	.0136	.0091

[1]An increase of 10 percent in the allowance is recommended for each inch, or fraction thereof, that the length of engagement exceeds 2 diameters. The values in columns 1, 2 and 3 are to be used for any size within the nominal size range. These values are calculated from the mean of the nominal size range.

TABLE XII. *Pitch diameter allowances on external threads, general purpose and centralizing.*

"GO" Thread Plug Gages

A. CENTRALIZING ACME THREADS

1. Major Diameter	= Minimum Major Dia. of Nut Tolerance—Figure in col. 15, 16, 17, 18, 19, 20, or 21 (apply plus)
2. Width Crest Flat	= Figure in Col 6 (both corners at the crest shall be chamfered equally at an angle of 45° with axis of thread) Tolerance—Figure in col 7 (apply minus) NOTE: Crest Flat "Must be Central"
3. Pitch Diameter	= Minimum Pitch Dia. Nut Tolerance—Figure in Col 11 or 12 (apply plus)
4. Minor Diameter	= Minimum Minor Dia. Nut (−) minus .010 (MUST CLEAR)
5. Length	= Approximately the length of engagement, but not exceeding twice the nominal Major unless otherwise specified.
6. Tolerance on Half Angle	= Figure in Col 13 (apply plus & minus)
7. Variation in Lead	= Figure in Col 22, 23, 24 or 25

B. GENERAL PURPOSE ACME THREADS

1. Major Diameter	= Minimum Major Nut (−) minus figure in Col 14 Tolerance = Figure in Col 10 (apply plus)
2. Pitch Diameter	= Minimum Pitch Dia. Nut Tolerance = Figure in Col 11 or 12 (apply plus)
3. Minor Diameter	= Minimum Minor Dia. Nut (−) minus .010 (MUST CLEAR)
4. Length	= Approximately the length of engagement but not exceeding twice the nominal Major Dia. unless otherwise specified
5. Tolerance on Half Angle	= Figure in Col 13 (apply plus & minus)
6. Variation in Lead	= Figure in Col 22, 23, 24, 25

"Not Go" Major Dia. Thd Plug Gages for Centralizing Acme Thread

1. Major Diameter	= Maximum Major Dia. Nut Tolerance—Figure in Col 15, 16, 17, 18, 19, 20, or 21 (apply minus)
2. Pitch Diameter	= Maximum Pitch Dia. of the Class 4c *screw* (for Classes 2c, 3c and 4c) or maximum pitch diameter of the Class 6c screw (for Classes 5c and 6c) Tolerance—Twice the figure in col 12 (apply minus)
3. Width Crest Flat	= Figure in Col 5 (both corners at the crest shall be chamfered equally at an angle of 45° with axis of thread) Tolerance—Figure in Col 7 (apply minus) NOTE: Crest Flat "Must be Central"
4. Minor Diameter	= Minimum Minor Dia. Nut (−) minus .01 (MUST CLEAR)
5. Length	= 3P min Round off to nearest 1/64"* 4P max
6. Tolerance on Half Angle	= Figure in Col 13 (apply plus and minus)
7. Variation in Lead	= Figure in Col 22, 23, 24, 25

"Not Go" Pitch Diameter Thd Plug Gages for General Purpose & Centralizing Acme Thds

1. Major Diameter	= Maximum Major Dia. Screw—Minus figure in Col 2 Tolerance—Figure in Col 10 (apply minus)
2. Pitch Diameter	= Maximum Pitch Dia. Nut Tolerance—Figure in Col 11 (apply minus)
3. Minor Diameter	= Minimum Minor Dia. Nut (−) minus .010 (MUST CLEAR)
4. Root Clearance (Optional)	= Figure in Col 4 Max.
5. Length	= 3P Min Round off to nearest 1/64"* 4P Max
6. Tolerance on Half Angle	= Figure in Col 13 (apply plus & minus)
7. Variation in Lead	= Figure in Col 22, 23, 24, 25

"Go" Thread Ring or Snap Gage Centralizing Acme Threads

1. Major Diameter	= Maximum Major Dia. screw (+) plus .010 must clear
2. Pitch Diameter	= Fit to setting plug
3. Minor Diameter	= Minimum Minor Diameter of the Nut (−) minus: Classes 2c & 5c = Col 1, Table XII Classes 3c & 6c = Col 2, Table XII Class 4c = Col 3, Table XII *Tolerance—Figure in Col 10 (apply minus)*

*When a multiple thread is involved, the not go thread plug shall be of such a length as to provide at least 1 full turn of thread.

4. Length	= Approximately the length of engagement but not exceeding Col 1, Table XI
5. Tolerance on Half Angle	= Figure in Col 13 (apply plus & Minus)
6. Variation in Lead	= Figure in Col 22, 23, 24, 25

"Go" Thread Setting Plug
Centralizing Acme Threads

1. Major Diameter—Full	= Maximum Major diameter screw Tolerance—Figure in Col 10 (apply plus)
Trunc	= Maximum major diameter screw (−) minus Figure in Col 3. Tolerance—Figure in Col 10 (apply minus)
2. Pitch Diameter	= If the length of engagement exceeds the length of the ring gage, the pitch diameter shall be less than *Maximum pitch diameter* of the screw by the amount shown in Col 2, Table XI. Tolerance—Figure in Col 11 or 12 (apply minus)
3. Minor Diameter	= Shall clear Minimum minor dia. of go thread ring or snap
4. Length	= Shall be approximately twice the length of the go thread ring or thread snap
5. Tolerance on Half Angle	= Figure in Col 13 (apply plus & minus)
6. Variation in Lead	= Figure in Col 22, 23, 24, 25

"Go" Thread Ring or Snap Gage
General Purpose Acme Threads

1. Major Diameter	= Maximum Major Dia. screw (+) plus .01 (MUST CLEAR)
2. Pitch Diameter	= Fit to setting plus
3. Minor Diameter	= Maximum Minor Dia. screw (+) plus figure in Col 14 Tolerance—Figure in col 10 (apply minus)
4. Length	= Approximately the length of engagement, but not exceeding the length specified in Col 1, Table XI
5. Tolerance on Half Angle	= Figure in Col 13 (apply plus & minus)
6. Variation in Lead	= Figure in Col 22, 23, 24, 25

"Go" Thread Setting Plugs
General Purpose Acme Threads

1. Major Diameter—Full	= Maximum Major Dia. screw Tolerance—Figure in Col 10 (apply plus)
Trunc	= Maximum Major Dia. screw (−) figure in Col 3. Tolerance—Figure in Col 10 (apply minus)
2. Pitch Diameter	= Maximum Pitch Dia. screw Tolerance—Figure in Col 11 or 12 (apply minus)
3. Minor Diameter	= Clear minimum minor diameter of "go" thread ring or snap
4. Length	= Approximately twice the length of the go thread ring or snap
5. Tolerance on Half Angle	= Figure in Col 13 (apply plus & minus)
6. Variation in Lead	= Figure in Col 22, 23, 24, 25

"Not Go" Thread Ring or Snap
General Purpose & Centralizing Thread

1. Major Diameter	= Maximum major dia. screw (+) plus .01 (MUST CLEAR)
2. Pitch Diameter	= Fit to setting plug
3. Minor Diameter	= Min. minor dia. of nut (+) plus figure in Col 2 Tolerance—Figure in Col 10 (apply plus)
4. Length	= 3P Min Round off to nearest 1/64" 4P Max
5. Root Clearance (Optional)	= Figure in Col 4 maximum
5. Tolerance on Half Angle	= Figure in Col 12 (apply plus & minus)
7. Variation in Lead	= Figure in Col 22, 23, 24, 25

"Not Go" Thread Setting Plug
General Purpose & Centralizing Thread

1. Major Diameter	= Maximum major dia. screw Tolerance—Figure in Col 10 (apply plus)
Trunc	= Maximum major dia. screw (−) minus Figure in Col 3 Tolerance—Figure in Col 10 (apply minus)
2. Pitch Diameter	= Minimum Pitch Diameter xcrew Tolerance—Figure in Col 11 or 12 (apply plus)

3. Minor Diameter = Shall clear minimum minor dia. of the not go thd ring gage
4. Length = Shall be approximately twice the length of the not go thd ring or thread snap gage.
5. Tolerance on Half Angle = Figure in Col 13 (apply plus & minus)
6. Variation in Lead = Figure in Col 22, 23, 24, 25

"Go" and "Not Go" Plain Plug Gages
Minor Dia. General Purposes & Centralizing Nut

1. Go Diameter = Minimum Minor Dia. Nut
   Tolerance—Figure in Col 15, 16, 17, 18, 19, 20, or 21 (apply plus)
2. Not Go Diameter = Maximum Minor Dia. Nut
   Tolerance—Figure in Col 15, 16, 17, 18, 19, 20, or 21 (apply minus)

"Go" and "Not Go" Snaps
Major Dia. General Purpose Acme Screw

1. Go Diameter = Maximum Major Dia. screw
   Tolerance—Figure in Col 10 (apply minus)
2. Not Go Diameter = Minimum Major Dia. screw
   Tolerance—Figure in Col 10 (apply plus)

"Go" and "Not Go" Snaps
Major Dia. Centralizing Acme Screw

1. Go Diameter = Maximum Major Dia. screw
   Tolerance—Figure in Col 15, 16, 17, 18, 19, 20, or 21 (apply minus)
2. Not Go Diameter = Minimum Major Dia. screw
   Tolerance—Figure in Col 15, 16, 17, 18, 19, 20, or 21 (apply plus)

4.4.2 *DEFINITION OF TERMS.* The following definitions are given for the more important terms pertaining to involute splines and spline gages. They are the same, wherever possible, as those in the latest A.S.A. B5.15 Involute Splines, Serrations and Inspection.

4.4.2.1 *Effective Space Width.* The effective space width of an internal spline is equal to the circular tooth thickness on the pitch circle of an imaginary perfect external spline which would fit the internal spline without looseness or interference.

4.4.2.2 *Effective Tooth Thickness.* The effective tooth thickness of an external spline is equal to the circular space width on the pitch circle of an imaginary perfect internal spline which would fit the external spline without looseness or interference.

4.4.2.3 Effective Clearance (Positive or negative) between two splined parts is equal to the effective space width of the internal spline minus the effective tooth thickness of the mating external spline. Positive effective clearance indicates rotary motion, while negative effective clearance indicates an interference or press fit condition.

4.4.2.4 *Effective Fits.* The fit between two mating splined members depends on the effective space width of the internal spline and the effective tooth thickness of the external spline. If these two effective dimensions are equal, a metal-to-metal fit at two or more spots could exist. If the effective space width is greater than the effective tooth thickness, then there will be clearance between mating splines. If the effective space width is smaller than the effective tooth thickness, this condition could result in interference or a press fit between mating splines.

4.4.2.5 *Allowable Errors.* The following allowable errors are unavoidable errors produced by machine and cutting tool inaccuracies during the machining operation. Distortion from heat treatment may cause additional errors.

4.4.2.5.1 Total Index Error is the greatest difference in any two teeth (adjacent or otherwise) between the actual and the perfect tooth spacing on the same circle. Measurements are taken from one point selected as a reference, to the corresponding points on the same circle on all other teeth, and will be affected by involute error and out-of-roundness.

4.4.2.5.2 *Profile Error.* Profile error is the deviation from the specified tooth profile. It is positive in the direction of maximum material and negative in the direction of minimum material.

4.4.2.5.3 *Parallelism Error.* Parallelism error is the deviation from a specified direction of the spline teeth on the pitch cylinder. It is usually measured by traversing a dial indicator along the tooth face, normal to the pitch line, and parallel to the axis of the spline. This error should be specified on the product drawing. However, since it is usually controlled within close tolerance, it should be disregarded in determining the error allowance.

4.4.2.5.4 OUT-OF-ROUNDNESS is the deviation of the spline from a true circular configuration.

4.4.2.5.5 *Effective Error.* The effective error is the accumulated effect of the spline errors on the fit with the mating part.

4.4.2.6 *Error Allowance.* Error allowance is the permisible effective error. Experience has shown that the effect of individual spline errors on the fit (effective error) is less than their total. Therefore, instead of using the total of all the errors, the error allowance is 60 percent of the sum of twice the positive profile error, the total index error and the parallelism error for the length of engagement.

4.4.2.6.1 *Machining Tolerance.* Machining tolerance is the permissible variation in actual space width or actual tooth thickness.

4.4.2.6.2 *Total Tolerance.* Total Tolerance is the machining tolerance plus the error allowance.

4.4.2.7 Actual Space Width is the circular width on the pitch circle of any single space. It is determined by measurement between pins, paddle plug or any other method which measures the actual distance across the space, directly or indirectly. Since there are errors present in the internal spline, the actual space width must be made larger than the effective space width by the effect of these errors. In short, the actual space width is equal to the effective space width plus the error allowance.

4.4.2.8 Actual Tooth Thickness is the circular thickness on the pitch circle of any single tooth. It is determined by measuring over pins, calipers, snap gage, or any other method which measures the actual distance across the tooth, directly or indirectly. Since errors are present in the external spline, the actual tooth thickness must be made less than the effective tooth thickness by the amount of the effect of these errors. In short, the actual tooth thickness is equal to the effective tooth thickness minus the error allowance.

4.4.2.9 Nominal Clearance between two splined members is equal to the actual space width of the internal spline minus the actual tooth thickness of the external spline. It does not define the fit between mating members, because of the effect of errors.

4.4.3 *COMPLETE PRODUCT SPECIFICATIONS.* In order to design gages properly, proper product specifications must be recognized to determine if they are adequate or correct. The spline gage designer is cautioned to check whether the tables in A.S.A B5.15 Involute Splines, Serrations, and Inspection have been used to design the product.

4.4.3.1 *Complete Product Specifications for an Internal Spline.* The following items are considered to be the proper specifications for the Internal Spline:

Type of Fit
Number of teeth
Diametral Pitch
Pressure Angle
Base Circle Dia. Ref
Total Index Error Max (Any two teeth)
Involute Profile Error T.I.R.
Out-of-Roundness
Max Parallelism Error
X.XXXX Max. Meas. Between .XXXX Dia Pins Ref
X.XXXX+.XXXX Minor Dai.
X.XXXX+.XXXX Major Dai.
X.XXXX Ref. Pitch Dia.
X.XXXX Form Dia.
Max. Actual Circular Space Width
Min. Effective Circular Space Width
Length of Engagement

4.4.3.2 *Complete Product Specifications for an External Spline.* The following items are considered to be the proper specifications for the External Spline:

Type of Fit
Number of Teeth
Diametral Pitch
Pressure Angle
Base Circle Dia. Ref
Total Index Error Max (Any two teeth)
Involute Profile Error T.I.R.
Out-of-Roundness
Max Parallelism Error
X.XXXX—.XXXX Minor Dia.
X.XXXX—.XXXX Major Dia.
X.XXXX Ref. Pitch Dia.
X.XXXX Form Dia.
Min. Actual Circular Tooth Thickness
Max. Effective Circular Tooth Thickness
Length of Engagement

4.4.3.3 *Standard Products.* If the dimensions of the spline product were taken from standards, the spline product is considered to be standard and gages can be designed as outlined in the text.

4.4.3.4 *Non-Standard Components.* If the dimensions of the spline component were not taken from standards, but are dimensioned in accordance with the concept of the standard, i.e.; effective size, dimensional size and allowable errors shown, the procedure followed in designing the gages in the same as for standard products. However, care must be taken in making appropriate changes wherever necessary.

4.4.4 *INCOMPLETELY DIMENSIONED PRODUCTS.* If the product dimensions were not taken from standards and show only the pin measurements with no reference to effective size or actual size, then the determination of gaging should be based on the following procedure.

4.4.4.1 *Incompletely Dimensioned Internal Product.* In dealing with an internal spline having given the maximum and minimum measurement between pins, corresponding space widths should be calculated. These sizes should be interpreted as the maximum and minimum actual space widths. If no allowable errors are tabulated on the product drawing, error allowances should be tentatively applied and submitted to Product Engineering for coordination and approval. Upon approval, the error allowances are subtracted from the minimum actual space width. This becomes the minimum effective space width.

4.4.4.2 *Incompletely Dimensioned External Product.* When the external product has shown a maximum and minimum measurement over pins, the corresponding tooth thickness should be calculated. The spread or tolerance on this tooth thickness should be interpreted as the machining tolerance for the external tooth. Interpret the maximum tooth thickness as determined from the maximum effective tooth thickness. If no allowable errors are tabulated on the product drawing, error allowances should be tentatively applied and submitted to Product Engineering for coordination and approval. Upon approval, subtract the error allowance from the maximum effective tooth thickness to determine the maximum actual tooth thickness. Subtract the machining tolerance from the maximum actual tooth thickness to establish the minimum actual tooth thickness. The old measurement over pins is discarded and a new measurement computed corresponding to the actual sizes.

4.4.4.3 *Engineering Coordination.* It is assumed that the Engineering in designing the spline has provided for a certain type of fit; however, the probability exists that if no error allowance was given, the effective fit concept was not considered. Therefore, any change that is made to use the effective fit must be thoroughly coordinated with the Product Engineer in order that reconsideration of the spline fit can be made. This is particularly necessary when changes alter the fit from the original dimensional clearance fit to an effective interference fit.

4.4.5 **NOMENCLATURE.** The nomenclature followed is the same wherever possible as that in the latest A.S.A. B5-15 Involute Splines, Serrations and Inspection.

4.4.6 *GAGES FOR INTERNAL INVOLUTE SPLINES.* To effectively gage an internal spline to assure proper fit and interchangeability, a set of three gages is required, Go Composite Plug, Go Paddle Plug and Not Go Paddle Plug. Paddle Plugs are also known as Sector Plugs.

4.4.6.1 Go Composite Plug Gage is designed to check the minimum effective space width of the internal spline. The gage has a full complement of teeth and checks as much profile as will be required by the mate. This gage is recommended without exception.

4.4.6.2 Go Paddle Plug Gage is designed to check the minimum actual space width. The gage has all of its teeth removed except two pairs located diametrically opposite each other. The major diameter is truncated, and the outside form of the teeth relieved to minimize the effect of the allowable errors. This gage is recommended as a final inspection gage to be used only for the evaluation or rejection by Go Composite Plug Gage. It is seldom needed for broached splines having a rather fixed tooth thickness, except to evaluate the rejections of the Go Composite Plug due to fillet interference. Frequently, it is used as a machining gage or for control of machine settings.

4.4.6.3 Not Go Paddle Plug Gage is designed to check the maximum actual space width. This gage is recommended without exception.

4.4.7 *GAGES FOR EXTERNAL INVOLUTE SPLINES.* To effectively gage an external spline to assure proper fit and interchangeability, a set of five gages is required: A Go Composite Ring, a Tapered Tooth Master Plug, a Go Snap, a Not Go Snap and a Setting Master.

4.4.7.1 Go Composite Ring Gage is designed to check the maximum effective tooth thickness of the external spline. The gage has a full complement of teeth and checks as much profile as will be required by the mate. This gage is recommended without exception.

4.4.7.2 *Tapered Tooth Master.* This gage is never used to check the product. However, it is useful in the manufacture of the Go Composite Ring Gage. This gage is of the plug type with a full complement of teeth. One side of each tooth is tapered slightly to vary the tooth thickness. The opposite sides are non-tapered providing a full length contact with the ring gage. This provides a fit range and discard limit on the gage. These masters are for new ring gage acceptance and for determining when the ring is worn to the high limit of the part. The ring is fitted as a section on the master which incorporates a wear allowance on the ring. The ring gage is checked periodically for wear with the tapered tooth master, and when the ring passes over the discard limit on the large end of the master, it should be replaced with a new ring. The major diameter of the master is not tapered. Tapered tooth masters are recommended wherever a ring gage is used, to assure the correct effective relation between the ring gage and the plug gage used for the mating part and to assure replacement of ring gages of a like effective size.

4.4.7.3 *Snap Gages.* A snap gage is a gage arranged with opposing measuring surfaces separated by a spacer or frame. It is designed to check the actual tooth thickness of an external spline. The Go Snap Gage checks maximum actual tooth thickness. This gage is recommended as a final inspection gage to be used for evaluation of rejection by Go Composite Ring Gages. It is also used frequently as a machining gage or for control of machine settings. The Not Go Snap Gage checks minimum actual tooth thickness. This gage is recommended without exception.

4.4.7.3.1 *Roller Type Snap Gages.* The roller type snap gage is preferred wherever possible because of the many advantages over the other types of snap gages. The rollers are easily manufactured and do not have to be held to close tolerance since they are set to a setting master and adjusted quickly by a sensitive eccentric. Slight changes in tolerances on the product can be easily accommodated by adjusting the eccentric to a new setting master. The gaging surfaces of the rollers are straight sided and do not require special machines to manufacture. The wear life of the gage is greatly increased due to the increased gaging surface on the flank of the roller, since wear is distributed over the roller circumference. The disadvantage of this type of gage, is that it cannot be used wherever the spline is close to a shoulder of flange which would prevent the roller from checking a sufficient length of spline.

4.4.7.3.2 *Built-Up and Solid Type Snap Gages.* The built up or solid type snap gage is used wherever it is necessary to gage close to a shoulder or flange. Disadvantages of these types of gages are that they must be ground to extremely close limits during manufacture, and the wear life is greatly reduced because of its small gaging surfaces.

4.4.7.3.2.1 Built-Up Type Snap Gages are used if the major diameter of the component is less than 1.500 inches. The built-up type, as distinguished from the solid type, is split in the center and held together with screws and a key.

4.4.7.3.2.2 Solid Type Snap Gages are used on products whose major diameter is greater than 1.500 inches. The measuring surfaces of these gages are integral with the frame.

4.4.7.4 *Setting Master for Go and Not Go Snap Gages.* This gage is never used to check the component. Setting masters are used exclusively to set the Go and Not Go Roller Snap Gages. The gage is of the plug type having two sets of teeth, one for setting the Go Snap and the other for setting the Not Go Snap. For splines having ten teeth or less, setting masters become special problems and must be dealt with as such. The gage is required for setting the snap gages and detecting wear on them. This gage is recommended, without exception, whenever roller snap gages are used.

4.4.8 *GAGE BLANKS.*

4.4.8.1 *Standard Gage Blanks.* Standard gage blanks are to be used wherever possible. Standard designs for certain types of spline gage blanks are available in the report of the American Gage Design Committee, U.S. Department of Commerce Commercial Standard CS-8-61, "Gage Blanks". In some instances, rather than design special gages, the standard design is modified to suit the particular gaging problem.

4.4.8.2 *Special Gage Blanks.* Special gage blanks are designed for gages for which no standard existed or where it is impossible to modify any existing design.

4.4.9 *MACHINING TOLERANCE AND ALLOWABLE ERRORS FOR GAGES.*

4.4.9.1 *Machining Tolerance.* The machining tolerance for gages is the allowable variation in tooth thickness or space width permitted in the manufacture of the gages. Since the Go Composite Ring Gage is fitted to the Tapered Tooth Master Plug no tolerance is required on the measurement between pins. The tolerance on measurement over pins should never be less than .0002 except for serrations having a diametral pitch finer than 48/96, when closer tolerances must be used. The sign of the tolerance is always plus for the Go Composite Plugs plus and minus for the Go Paddle Plugs and minus for the Not Go Paddle Plugs. The Tapered Tooth Master tolerance is plus on the large end and minus on the small end. The Setting Master Tolerance is plus and minus for the Go set of teeth and plus for the Not Go set of teeh.

4.4.9.2 *Allowable Errors for Gages.* The allowable errors encountered in manufacturing the component will also be encountered in manufacturing the gage. These errors must be specified on the gage drawing. They are kept as small as is feasible to control the accuracy of the gage and yet not make the cost of the gage prohibitive.

4.4.10 *MEASURING PINS*

4.4.10.1 *Determining Proper Measuring Pins.* Since the measuring pins used for gages are not the same as the measuring pin used on the component, the gage designer must compute the pin diameter to have contact occur as close to the pitch diameter as possible. For standard splines constants have been established which when divided by the diametral pitch determine the pin diameter required for the gage. If the spline is non-standard, the gage designer must compute the pin diameter from various formulas available so that contact will occur at a diameter near but outside the pitch diameter on the plug gage and near but inside the pitch diameter on the ring gage. The designer is cautioned to use the tooth thickness or space width corresponding to the diameter at which contact is to occur in determining the measuring pin diameter for non-standard splines.

4.4.10.2 *Selection of Measuring Pin.* The selection of the measuring pin is made from the Table of Recommended Standard Measuring Pins. It is recommended to always select the next larger pin to the computed diameter. In all cases, it is inadvisable to use flattened pins as they are awkward to use and wear more readily.

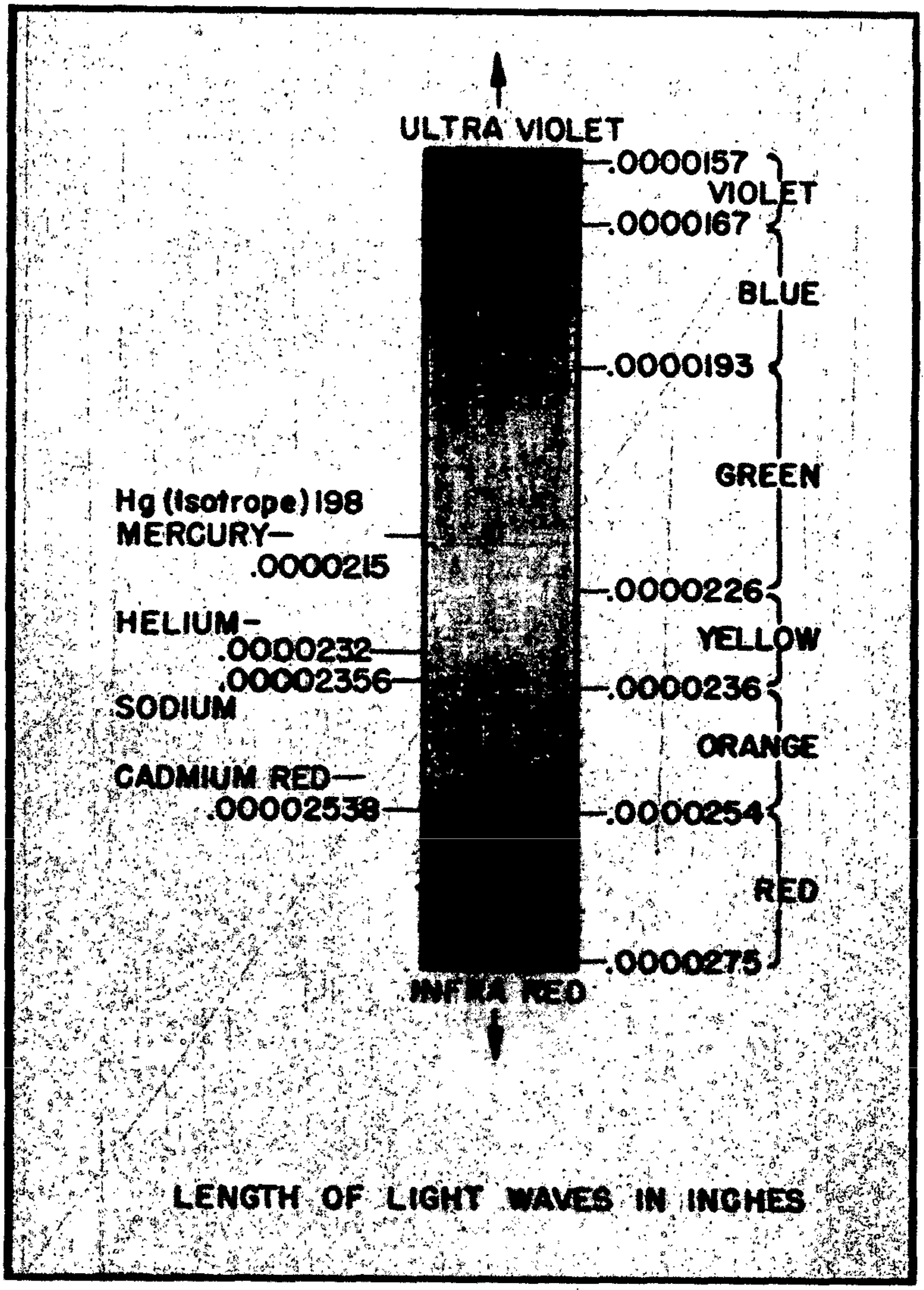


FIGURE 23. *Length of light waves in inches.*

CHAPTER 5. OPTICS IN INSPECTION

5.1 INTRODUCTION. Light is a most versatile tool in inspection. It may be employed as auxiliary illumination in visual inspection or run through the illumination in visual inspection or run through the optical system of a microscope or projector to provide a magnified image of the part. Parallel (or collimated) rays of light may be used to establish reference lines and planes while the patters from waves interfering with each other may be used as an ultra precise measuring tool through interferometry. Finally the ultimate standard in our system of dimensional measurement, the inch, is defined in terms of a precise number of wavelengths of a particular color type of light.

5.1.1 *GENERAL NATURE OF LIGHT.* Light is a type of electromagnetic vibration and as such appears to travel in waves. Further, light is just one small segment of the entire electromagnetic spectrum which ranges from powerline frequencies through radio waves, infra red, then light followed by x-rays and Gamma Rays. Visible light is that series of wavelengths from .0000157 to .0000275 inches. This series is arbitrarily divided into six broad areas—viloet, blue, green, yellow, orange, and red. Since the colors blend continuously, this can only be approximate. Figure 23 represents the visible spectrum and the wavelength for each color.

5.1.2 *GENERAL LAWS OF GEOMETRICAL OPTICS.* Light obeys certain fundamental laws which the equipment and processes outlined on the following pages employ to the best advantage.

(a) Law of Rectilinear Propagation. Light travels at a constant speed in a straight line in a medium of constant density.

(b) Law of Reflection. In passing from a medium of lesser density to one of greater density, light is deviated toward the normal. In passing from a medium of greater density to one of lesser density, light is deviated away from the normal.

(c) Law of Reflection. The angle of reflection is equal to the angle of incidence and lies on the opposite side of the normal; the angle of incidence being the angle formed between the rays striking the surface and the normal.

5.2 MIRRORS. The simplest form of optical system is the plane mirror which provides a reversed image that appears to be as far behind the mirror as the object is in front of it. See Figure 24. Mirrors are used in inspection to view inaccessible areas and in autocollimation.

5.3 THE SIMPLE MAGNIFIER. Referring to Figure 26, it is shown that the simple mangifier produces an image that is magnified and on the same side of the lens as the object; also, it is unreversed. The single mangifier is subject to both chromatic and spherical aberration; i.e., except over a narrow range the colors and shape of the image are distorted. However, within its limits, it is an excellent production and inspection aid in that it can be used

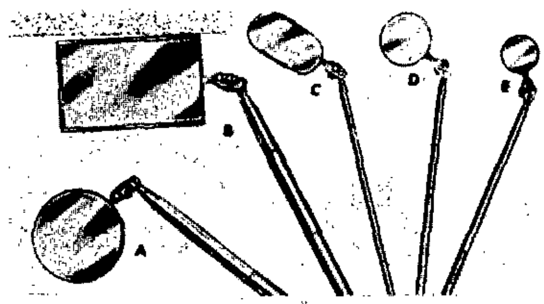


FIGURE 24. *Inspection mirrors.*

FIGURE 25. *Bench magnifier.*

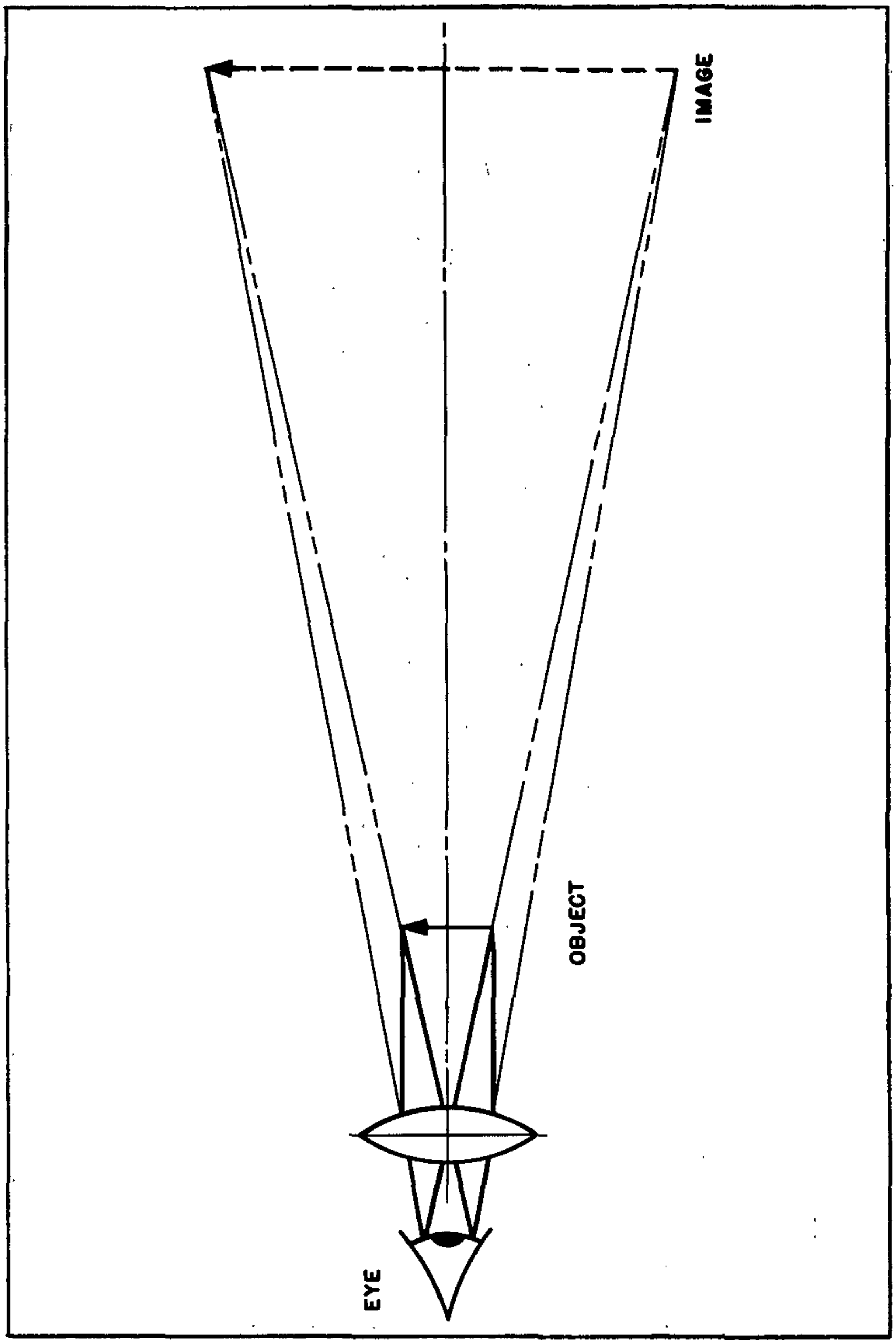


FIGURE 26. *Simple magnifier.*

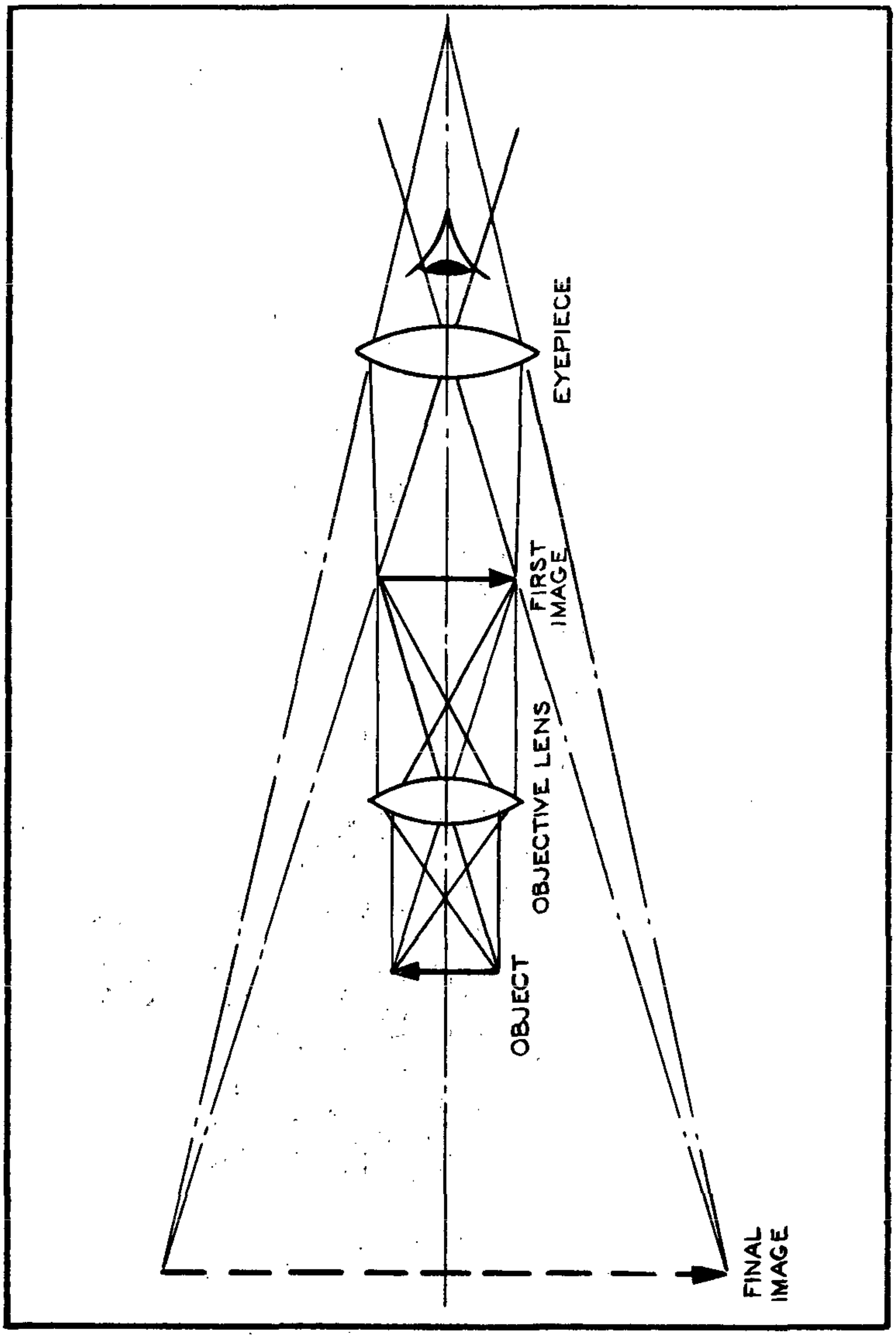


FIGURE 27. *Microscope.*

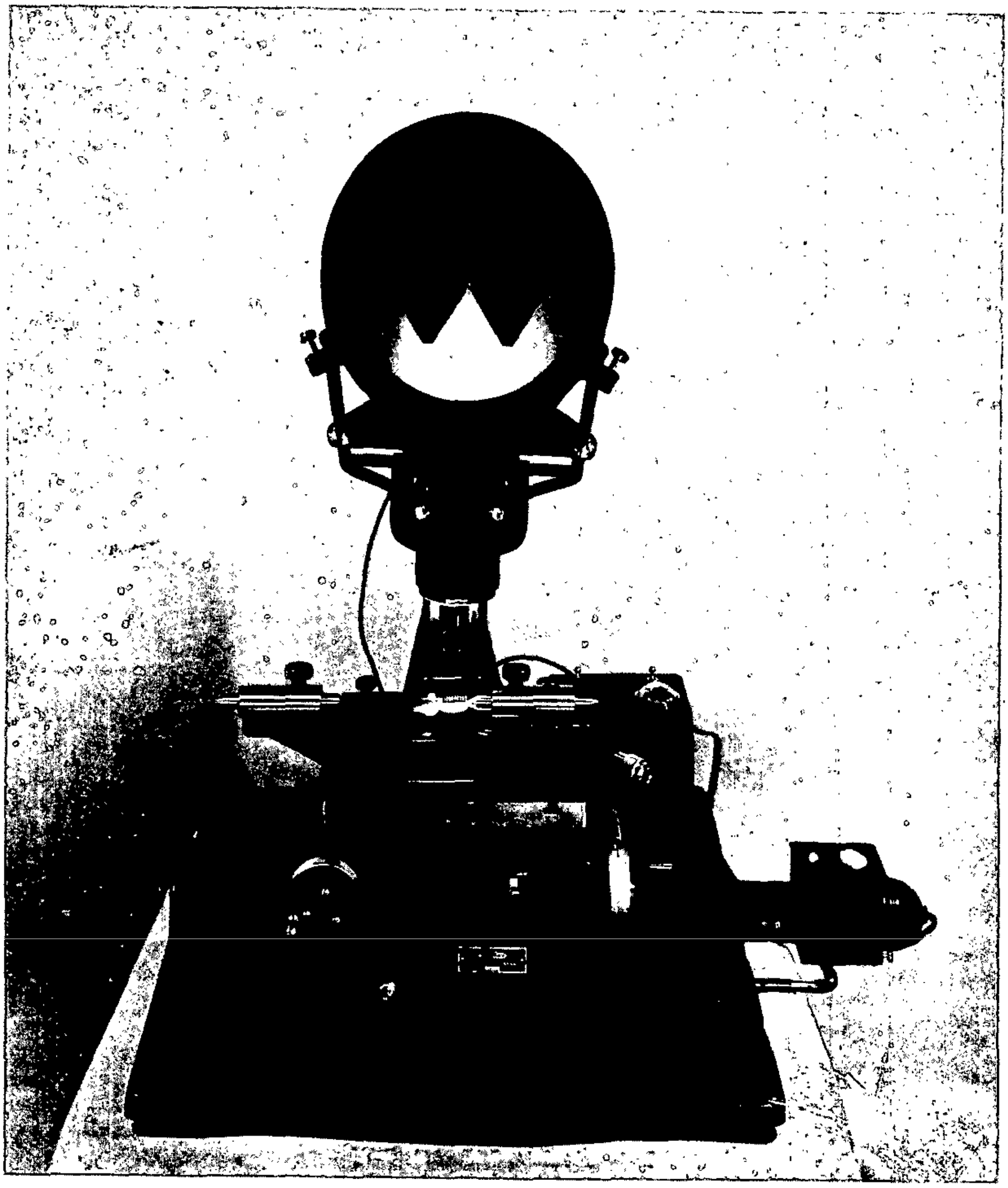


FIGURE 28. *Toolmaker's microscope.*

to view visual defects more clearly, to aid in scale reading and to facilitate handling of small parts. A typical application is shown in figure 25, a bench magnifier.

5.4 THE MICROSCOPE. Whenever high magnification is desired, the microscope is used. It consists of two converging lens (in practice, lens systems), an objective lens of very short focal length and an eyepiece of moderate focal length. The objective lens forms within the tube of the instrument a somwhat magnified real image of the object. This image is magnified by the eyepiece which serves here as a simple magnifier. Thus, the final image, seen by the eye, is virtual, inverted and greatly magnified. By placing a graduated reticle at the site of the real image, it is examined by the eye piece along with the real image, so a direct measurement of distance, angle or form may be made. See figure 27.

5.4.1 *MICROSCOPES* employed in inspection are of two general types—work shop and toolmakers' which vary primarily in the degree of accuracy available, with the toolmakers' being more accurate. The work shop microscope generally would have a magnification of 10X while the toolmakers' would range from 10X to 100X in addition to having a table which moves on coordinate slides with micrometer adjustment. Some toolmakers' miscroscopes can be fitted with a projection head in the lower powers so that the image may be viewed at eye level on a screen. See figure 28.

5.5 TELESCOPES. A refracting telescope provides a magnified image of a distant object. Referring to Figure 29, two basic lenses are used, an objective lens and an eyelens. A distant object "O" sends rays of light through the objective "M". These rays are focused at "f" and then after passing through the eyepiece "L" emerge in a parallel beam, enabling the eye "E" of an observer to see an inverted image of "O". The two lenses are spaced a distance equal to the sum of their focal lengths and the magnification is equal to the focal length of the objective divided by the focal length of the eyelens.

5.5.1 *BASIC OPTICAL CHARACTERISTICS OF A TELESCOPE.* There are four optical characteristics of a telescope which should be defined here.

5.5.1.1 *Power.* The magnifying power of a telescope is the ratio of the apparent size of the object as seen by the unaided eye to the apparent size of the image seen in the eyepiece of the instrument when both are at infinity. As mentioned previously, it is also equal to the dividend of the focal lengths. If the ratio of image sizes is 30.1, the telescope is said to have a magnification of 30 which is written as 30X or spoken of as 30 power. (Occasionally, it may be referred to as 30 diameters.)

5.5.1.2 *Range.* The range of a telescope is that distance within which an object can be clearly defined or focused. For example, the average alignment type telescope can be sharply focused over a range of from eighteen (18) inches to infinity. An object less than eighteen (18) inches from the objective lens cannot be sharply focused.

5.5.1.3 *Resolution.* The ability of a telescope to distinguish between two adjacent points is termed its resolving power. It is generally expressed in terms of the minimum angle at which the two points can be independently identified (or resolved). The average telescope used for alignment purposes is rated at 3½ seconds. If two points on an object are being viewed which make a smaller angle than the angle of resolution, the image in the telescope will only show one point.

5.5.1.4 *Field of View.* This is defined as the open or visible space the viewer can see through the telecope when it is stationary. It is the maximum angle subtended by any two objects which can be viewed simultaneously. It is generally expressed as "so many yards at 1000 yards", but for optical measurement, it is more likely to be expressed in degrees between rays. An average alignment telescope would have a one degree angle between rays at thirty power. As the magnification of the eyepiece increases, the true field of view goes down, everything else being held equal.

5.5.2 *TELESCOPE CONSTRUCTION.* The major parts of telescopes used in inspection are the objective, the eyepiece, the focusing lens, and the reticle (which together form the lens system); the mount, the eyepiece mounting and the focusing mechanism.

5.5.2.1 *The Lens System.* In the lens system, the objective gathers and focuses the light from the object. At the focal point is placed a glass disc with cross-lines etched into it. The eye lens views this reticle and object image and provides an enlarged image for the observer. If then appears that the cross-lines are superimposed upon the object.

5.5.2.2 *The Mount.* The mount is a sturdy tube which holds the lens system and related mechanisms in proper alignment.

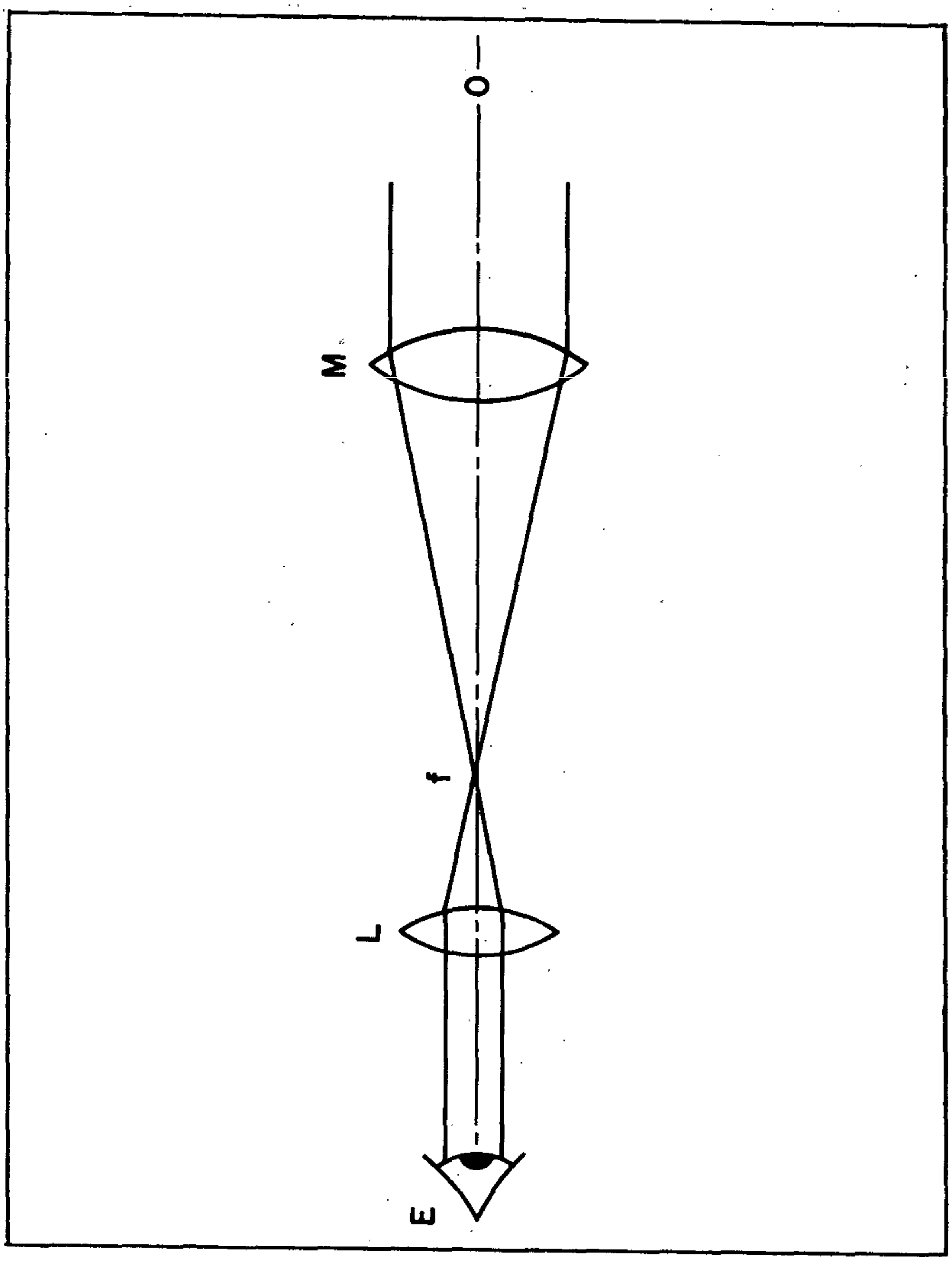


FIGURE 29. *Telescope.*

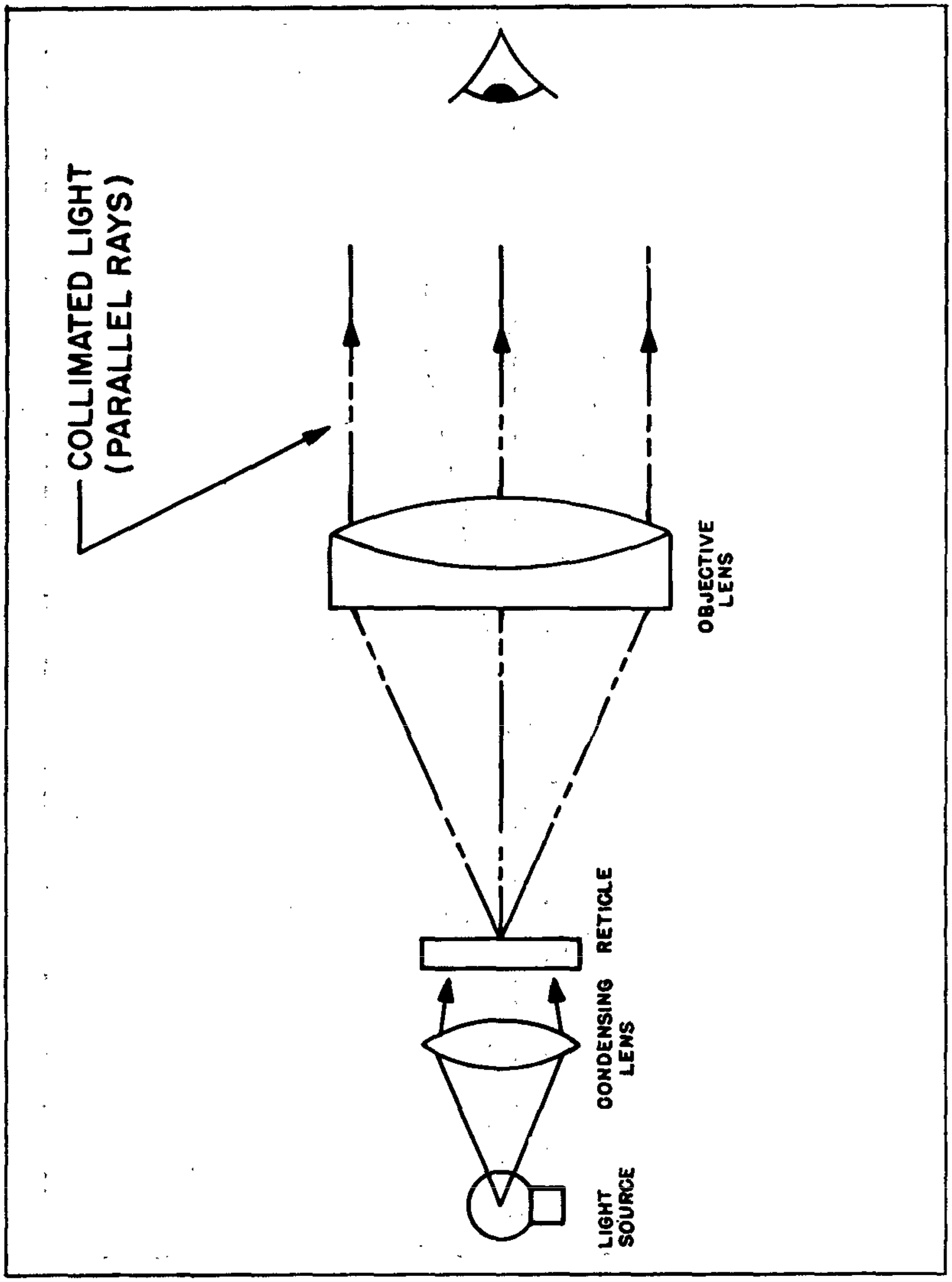


FIGURE 30. *Collimator.*

5.5.2.3 *The Eyepiece Mounting.* It holds the eye lens in the proper relation to the rest of the system and provides an adjustment to be used to compensate for variations in human eyesight, for close focusing on the cross-lines of the reticle. In an instrument with a reticle, either the objective lens or both eyepiece and reticle must be adjusted to maintain focus on nearby objects.

5.6 COLLIMATION

5.6.1 *GENERAL.* The basic collimator is an optical instrument that is derived from the telescope. Light from a distant object enters the telescope objective lens in the form of parallel rays of light. These rays are then converged to a point on a reticle placed at the principal focus of the objective lens. A reverse process is performed in the collimator diagrammed in Figure 30. A light source illuminates the reticle placed in the principal focus of the objective lens. Light rays from the reticle are collimated (rendered parallel) by the objective lens. The image of the reticle appears at infinity. The collimator is used as an instrument in the inspection of optics and as a target in optical tooling, some phases of which are discussed in par. 5.7.

5.6.2 *AUTO-COLLIMATION.* By combining a telescope and a collimator into one instrument, auto-collimation is possible. Auto-collimation is achieved by sighting the instrument into a plane mirror that reflects the rays coming out of the objective lens back through the instrument. The perpendicularity of the mirror with respect to the axis of the auto-collimator may be ascertained by viewing together the reticle of the auto-collimator and the reflected image superimposed thereon. The eyepiece of the instrument is used to examine accurately the degree of superposition.

5.6.3 *CONSTRUCTION OF THE AUTO-COLLIMATOR.* With reference to Figure 31, a simple auto-collimator is comprised of:

A. Reticle
B. Objective Lens
C. Semi-Reflector
D. Eye lens
E. Field Lens
F. Light Source

5.6.3.1 The reticle "A" is usually made of optical glass with finely etched cross-lines. Sometimes additional graduations may be included to indicate the amount of deviation, as shown in Figure 32.

5.6.3.2 The Objective "B" renders the image of the reticle "A" into parallel rays of light. When a reflecting surface is placed at any position perpendicular to these rays, they will be reflected back through the objective lens and refocused on the reticle surface.

5.6.3.3 Semi-Reflector "C" is a partially-coated plane plate glass mirror that reflects the light from the bulb of the light source into the lens system.

5.6.3.4 The Eye Lens "D" magnifies the reticle pattern and the real image formed by the reflected rays seen on the Reticle "A".

5.6.3.5 The illuminating Source "F" may vary from a 6 volt bulb built into the instrument to a high powered separate external source concentrated on the reflector "C".

5.6.4 *THEORY OF THE AUTO-COLLIMATOR.* In any reflected ray of light, the angle it strikes the reflecting surface equals the angle it leaves the surface. Therefore, referring to Figure 31 again, the angle formed between the projected rays and the reflected rays will be twice the angle θ which the reflecting surface is tilted from the vertical. The position of the returned image on the reticle with respect to the graduations themselves will be an amount equal to the tangent of 2θ times the focal length (f) of the objective lens. Therefore, by graduating the reticle as in figure 32, the angle θ of the reflecting surface can be determined.

5.6.4.1 *Determination of Accuracy.* Since, as explained above, the distance X is (f) (tan 2θ), if the desired accuracy is one minute of arc, and assuming an objective "B" focal length of 10″ the spacing of the graduations would be 10X tangent of 2 minutes or .0058 inches. By using a longer focal length of objective lenses, the linear spacing of the graduations may be increased thus permitting the measurement of smaller angles than 1 minute of arc. However, the length of the tube must not become unwieldy. Increasing the power of the eyepiece also increases accuracy and sensitivity but reduces the field of view thus limiting the range of the graduated scale. Vibration of the instrument also tends to limit the accuracy of observation in the smaller angles. Under the best laboratory conditions, accuracies of .1 second of arc are possible; under average working conditions, one-half minute is more practical.

5.6.4.2 *Advantages of Parallel Light.* In using the auto-collimator, the parallelism of the projected rays of light means that the instrument can be used at any distance from a reflecting surface without refocusing or may be rotated about its axis. The only ill effect of long distances upon the function of

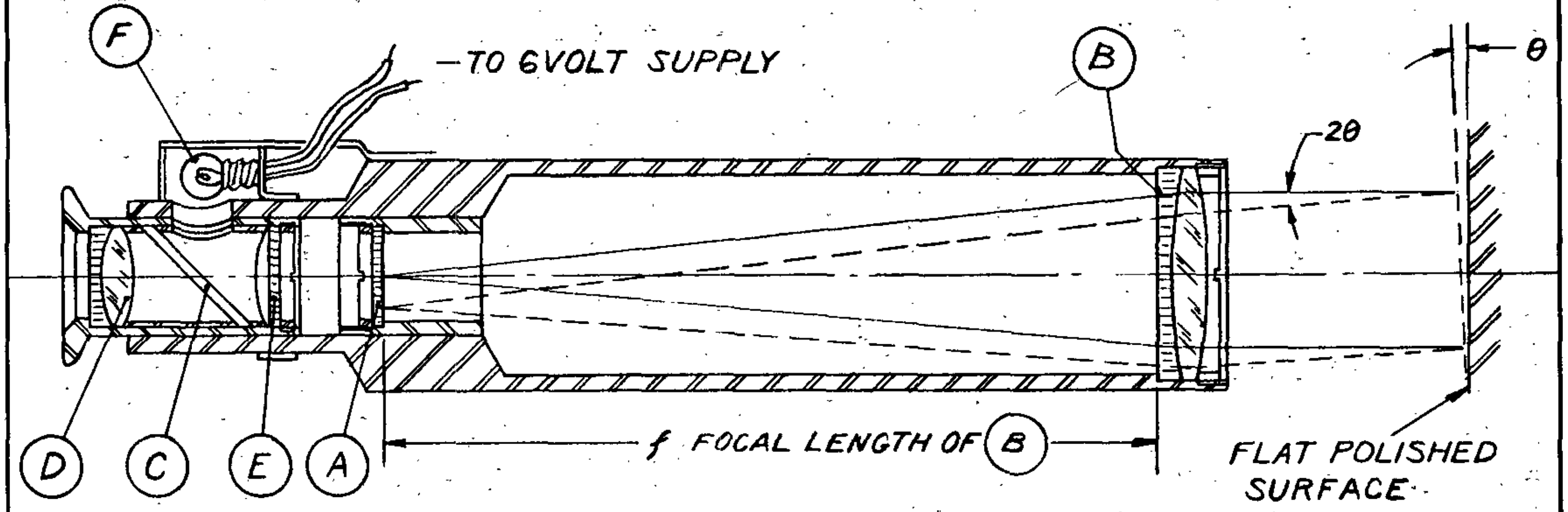


FIGURE 31. THE AUTO-COLLIMATOR

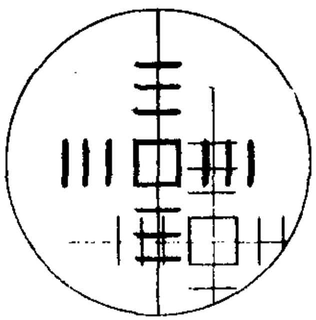


FIGURE 32. EXAMPLE OF RETICLE (A) SHOWING REFLECTED IMAGE DISPLACED DUE TO ANGLE θ

FIGURE 31. *Auto-collimator.*

FIGURE 32. *Reticle showing a displaced image.*

the instrument would come from loss of clarity due to entrance of stray light or the falling out of light intensity as the square of the distance.

5.6.5 *REFINEMENTS OF DESIGN.* The basic auto-collimator, as discussed above, is the most versatile and easily adaptable version. However, there are variations of design which may provide greater accuracy at a sacrifice of mobility, as discussed below.

5.6.5.1 *Micrometer Eyepiece.* In figure 33(a) is an instrument similar to the basic instrument, except that a micrometer eyepiece is used to view the images. Instead of reading the displacement directly on the reticle, it is measured by the eyepiece. The eyepiece has a fixed cross-line together with a movable cross-line actuated by a micrometer screw. In setting up, the fixed cross-line of the eyepiece is set on the cross-line in the reticle. The micrometer dial is then turned until the movable cross-line coincides with the reflected image. The amount of displacement is then read on the micrometer drum which can be so graduated as to read small increments of angle directly. The range of displacement is limited by the field of view of the micrometer which will be quite less than the regular eyepiece. Micrometer eyepieces for standard auto-collimators are easily obtainable commercial items.

5.6.5.2 *Microscope Eyepiece.* To achieve still greater accuracies, a microscope may be used as an eyepiece. The field of view is now so limited that nearly all displacements would be outside of it. Therefore, the complete microscope is mounted on a micrometer actuated cross slide. A fine cross hair in the microscope is lined up with the collimator reticle cross-line and then the micrometer drum is rotated until the cross hair is lined up with the reflected image. The difference in readings is the equivalent angle of deviation. Again the micrometer drum may be graduated in very small increments of angle. Further, the microscope allows more precise alignment of the eyepiece cross hair and reticle cross-line. See figure 33(b)

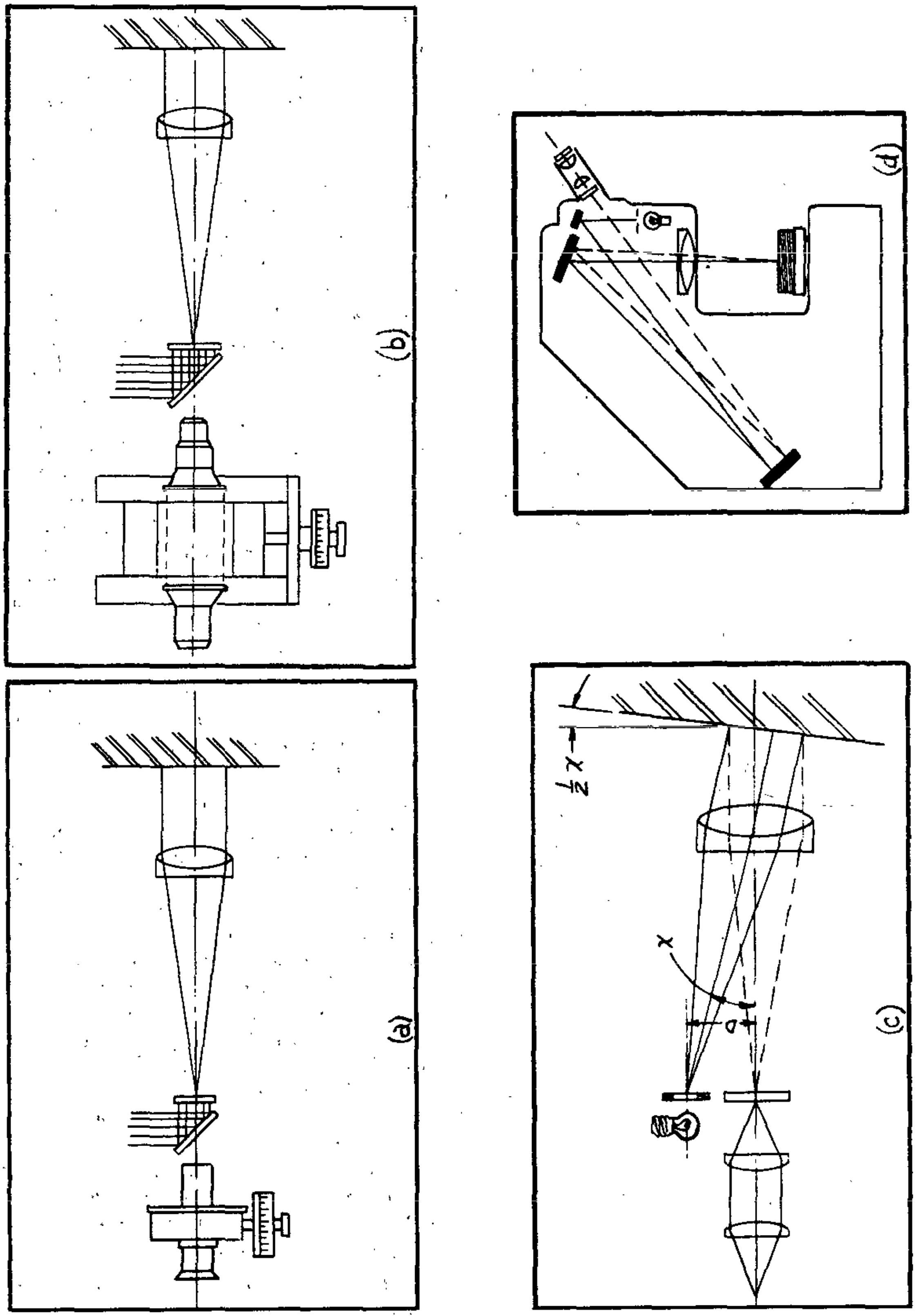
5.6.5.3 *Off-Axis Pinhole Type.* Figure 33(c) illustrates a refinement in the transmitted image. The light source is now injected into the system through a partially reflecting mirror but is off the axis of the telescope. Light is concentrated on an extremely small hole (about .015 diameter) or fine slit located from the objective lens a distance equal to the focal length of that lens. The reticle is still graduated similar to figure 32. For best optical performance, the displacement of slit and reticle "D" should be as small as practicable. Due to the distance "D", the light rays must travel through angle X. When the reflecting surface is perpendicular to the bisector of angle X, the returning light rays of the hole or slit will form an image in the center of the graduated reticle. This system has a distinct advantage in that the returning image is a simple, sharply defined, spot or line of light. This eliminates reading the displacement of two complex patterns since the line or spot can easily be viewed against the basic reticle pattern.

5.6.5.4 *Fixture Type Collimator.* Using the previous principle together with a greatly increased focal length objective the fixture type collimator is evolved. To keep the instrument compact, three mirrors are used to fold the long light path into the frame casting. An adjustable table can be provided to increase the versatility of the instrument. It is very useful for checking parallelism of glass surfaces (surface of optical flats) since the light is reflected from the top and bottom surfaces simultaneously and the displacement of the two reflected images can be obtained directly. By the provision of holding devices for the table, angularity of geometrical figures may be easily checked. See figure 33(d).

5.6.6 *APPLICATION OF THE AUTO-COLLIMATOR.* The following paragraphs illustrate some typed and basic applications of the auto-collimator to general measurement.

5.6.6.1 *Angle Comparison.* Figure 34 shows the auto-collimator being used to compare an angle with the corresponding angle of a master. Ninety degrees is illustrated but practically any angle could be so checked. The axis of the auto-collimator is made perpendicular to the surface of the master angle by adjusting its position until the reflected image of the reticle is lined up with the reticle itself, as seen through the eyepiece. The master angle is then removed and replaced by the angle being tested. An error in the angle of the test piece will thus displace the reflected image. If the master and test piece can both be contained within the field of view of the instrument, it is well to leave the master in position to serve as a constant check. For average work a good surface plate will do as a work holder, but for a high degree of accuracy, both pieces should be wrung to an optically flat surface.

5.6.6.2 *Direct Angle Check.* An angle may be tested by viewing the reflections from one of the



a. Micrometer eyepiece type. b. Sliding microscope type. c. Off-axis pinhole or slit type. d. Fixture type.

FIGURE 33. *Various types of auto-collimators.*

faces and from an optical flat with which the other face is in contact. Figure 35 shows the arrangement for right angles. Two images are formed in the instrument, one by light rays that strike the flat first and the other by rays that strike the face of the test piece first. If the angle is precisely 90° the two sets of rays are parallel and the images coincide. With an angular error of θ, the two sets of rays form an angle equal to 4θ, the images showing a corresponding separation. This method is very convenient, since the instruments may be pointed down at any convenient angle and the holding plate adjusted till both images are in the field of view. This method can be used to measure any simple submultiple of 180 degrees. For even portions of 90° (45° and 22.5°) the same freedom of elevation of the telescope is present as for the 90°; however, for other angles such as 30°, 60°, 75°, the axis of the instrument must be parallel to the bisector of the test angle or the beams will not return into the telescope.

5.6.6.3 *Indirect Angle Checks.* Checking unpolished surfaces presents a problem. One method of doing this is illustrated in Figure 36. A plane mirror is laid on the inclined surface to be measured and the base is set on a polished flat. Two images will be produced as in the method of par. 5.6.6.2 but the rays which strike the flat first are reflected from the mirror back to the flat, then to the mirror, and back to the instrument so that they are deflected four times the error in the test plane. The same holds true for the rays which strike the mirror surface first so that the two images in the instrument will show a separation corresponding to 8 times the error in angle of the test surface.

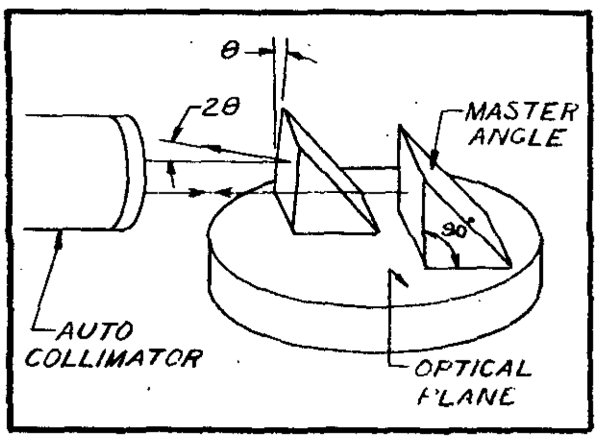


FIGURE 34. *Angle comparison for 09°.*

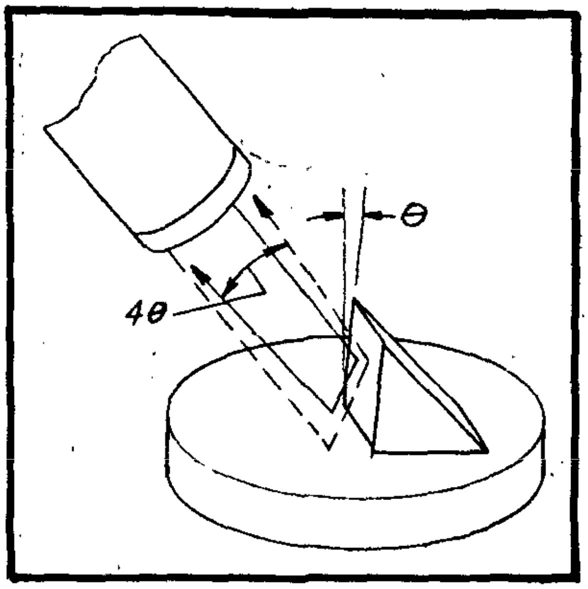


FIGURE 35. *Direct angle check for 90°.*

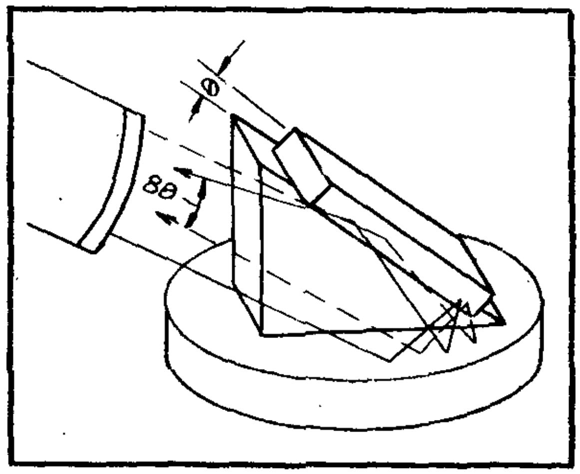


FIGURE 36. *Indirect angle check.*

5.6.6.4 *Checking with a Sine-Bar.* A sine bar may be used to extend the application oı the auto-collimator. In figure 37, the telescope is first adjusted perpendicular to the base plate then the upper surface of the sine bar is set to the complement of the angle to be verified. Deviations from this basic angle are recorded on the auto-collimator's scale. Duplicate pieces can be checked rapidly by this method. Another method is to set the sine bar to the basic angle in question, place it on a surface plate and adjust the auto-collimator normal to the inclined surface of the sine bar. It is moved aside and the

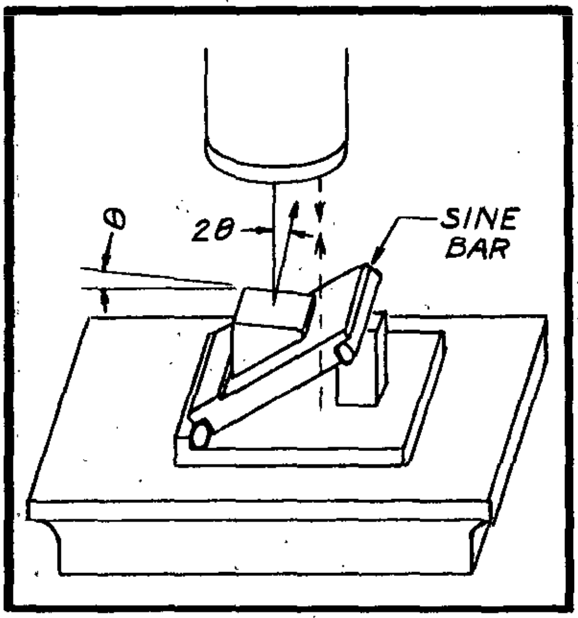


FIGURE 37. *Checking with a sine bar.*

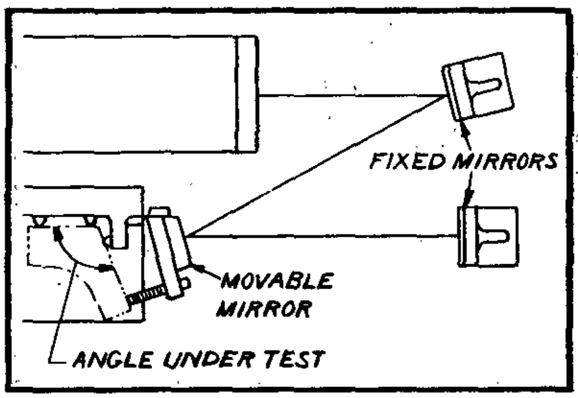


FIGURE 38. *Optical lever.*

pieces to be checked are placed on the surface plate for comparison. This method also lends itself to production checking.

5.6.6.5 *The Optical Lever.* The method in figure 38 can be used for either of two purposes. It can be used to check unpolished surfaces or it can be used to gain magnification. In production inspection, a cradle with a movable mirror to contact the surface in question should be used.

5.6.6.6 *Straightness or Flatness Checks.* Straightness of planes (or flatness) may be checked by using a vertical reflecting surface mounted on a movable saddle, as in figure 39. The deviation from a true surface in any plane may be read from the auto-collimator scale. Saddle plates may be designed for almost any type of surface, such as Vee ways, surface plates, straight edges, etc.

5.6.6.7 *Parallelism.* To check parallelism, the parts are placed one upon the other and the reflected images from the surfaces to be compared are viewed in the auto-collimator. It is often more convenient to have the instrument in a horizontal plane, especially if the parts in question must be set vertically, so the set-up in figure 40 is employed. Here, the use of parallel light permits viewing two images traveling over distances which differ by twice the length of the top piece, yet they both are in focus.

5.6.6.8 *Axial Squareness.* To check the squareness of an end face with the longitudinal axix of a cylindrical piece, rotate the piece in Vee blocks as shown in figure 41, noting the amount of deviation of the reflected reticled. To check a rectangular piece, turn on each side and note the amount and direction of each deviation.

5.6.7 *APPLICATION OF THE INSTRUMENT TO THE INSPECTION OF OPTICS.* All exterior and interior surfaces of optical prisms, wedges, windows and mirrors can be conveniently checked by all the methods indicated for metal parts. The prime advantage of using an auto-collimator rests in the fact that internal reflecting surfaces may be checked. For example, the 90° angle of a right angle prism may be checked by the method shown in figure 42. The auto-collimator would be directed at the hypotenuse face. An optical flat is not needed here as in the case where metal parts are checked and therefore contact error is eliminated. For an error of θ in a 90° angle, an angle of $4N\theta$ will be returned to the instrument, where N = index of refraction of glass. Care must be exercised relative to the reticles used by various manufacturers of auto-collimators, inasmuch as some are compensated to allow for the double error and others must be compensated for by the operator.

5.6 OPTICAL TOOLING. The use of telescopes, collimators, auto-collimators and various accessories in a combined approach to dimensional inspection is referred to as optical tooling. It could also be referred to as the art of applying the principlec of surveying and optics to dimensional inspection. While generally employed in the inspection of large products, it is flexible enough to be applied to almost any type of precision measurement job. For the purpose of this handbook, optical tooling may

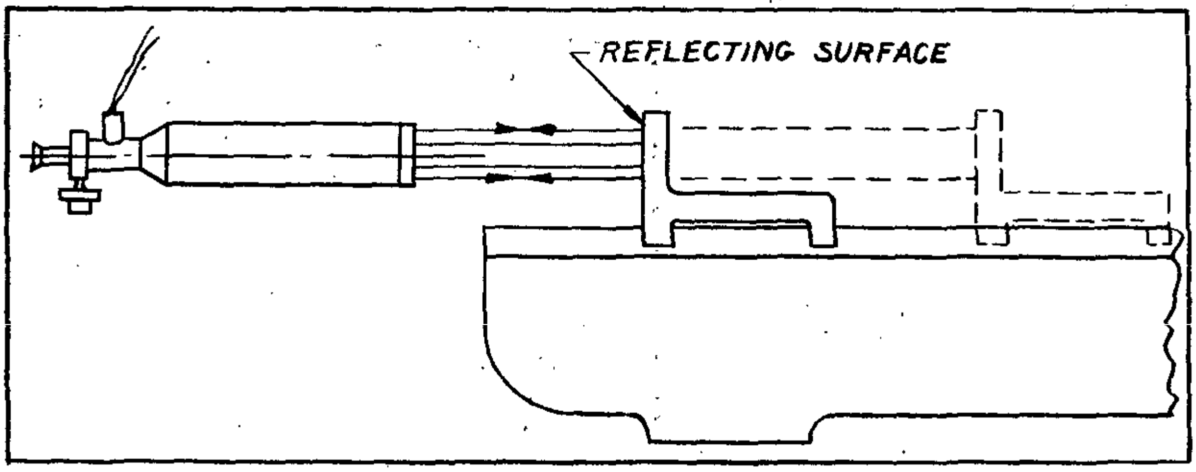


FIGURE 39. *Straightness or flatness test.*

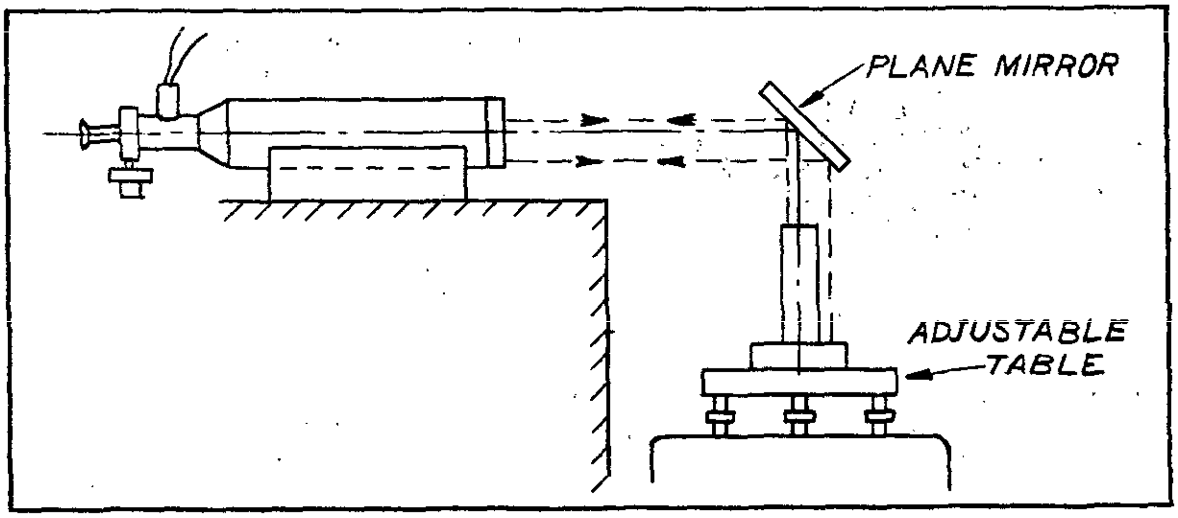


FIGURE 40. *Parallelism test.*

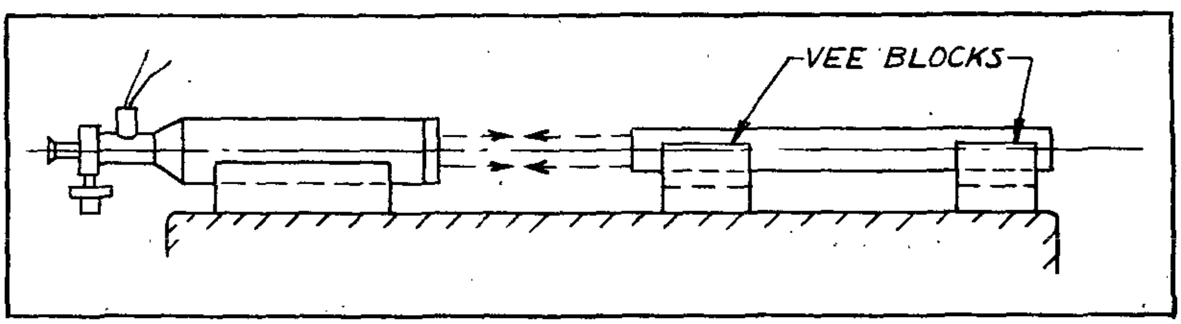


FIGURE 41. *Squareness test.*

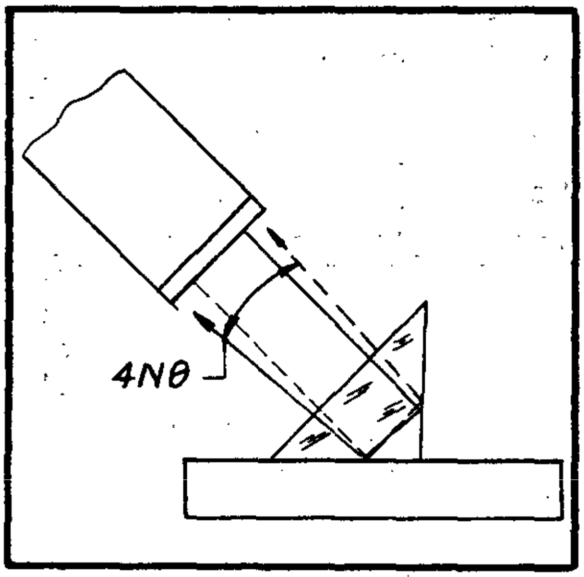


FIGURE 42. *Inspection of a 90° prism.*

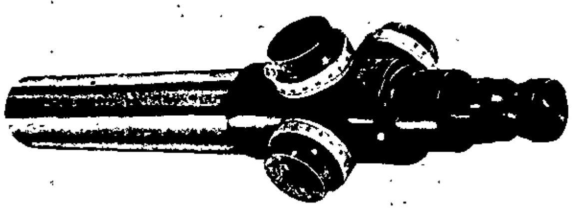


FIGURE 43. *Alignment telescope with micrometers.*

vary from a simple alignment telescope and target to a massive layout involving several telescopes, tooling bars and stands, targets, etc., covering a considerable area.

5.7.1 *TYPES OF EQUIPMENT.* A varied selection of optical devices and accessories are available. The more common will be listed here.

5.7.1.1 *The Alignment Telescope.* The alignment telescope (see figure 43) is one of the most basic instruments that is used in optical tooling. Its main purpose is to establish a precise reference line of sight. However, with the use of various accessories listed under 5.7.2, it may perform many other functions such as measurements; autocollimation; projection; etc.

5.7.1.1.1 *Description.* The telescope mount (tube which holds the lens system) is made of hardened stabilized tool steel with a hard chrome surface. The outside diameter is ground to a standard 2.2498 inches and is concentric with the optical axis of the instrument. Most alignment telescopes contain built-in micrometers for measurement of vertical and horizontal displacement. The micrometers are direct reading to .001 in., numbered every .010 in. and have a range of from .0 to ±.050 in. The reticle may be glass with a crossline pattern or simply cross-wires. An eyepiece is provided to compensate for variations in human eyesight and for keeping the reticle in focus when the main focus of the instrument is changed. A built-in autoreflection target is usually provided on the rear face of the objective lens.

5.7.1.1.2 *Magnifying Power and Range.* Basically, it is a variable power telescope with a resolution of about 3 seconds and a magnification of approximately 4X to 6X at minimum focusing range and from 30X to 60X (depending on manufacturer) at infinity. Focusing ranges vary with the manufacturer. Most instruments have a focusing range of about 18 inches to infinity, with at least one type capable of focusing all the way from infinity down to actual contact with the end of the telescope.

5.7.1.2 *The Alignment Collimator.* The alignment collimator as used in optical tooling is a target instrument for setting up a precise reference line of sight, as opposed to a viewing instrument, i.e., it does not possess an eyepiece. It is also used for checking and adjusting other optical tooling instruments. See figure 45.

5.7.1.2.1 *Description.* The alignment collimator consists of a hardened stabilized tool steel tube ground to a standard outside diameter of 2.2498 in., concentric with the optical axis. A displacement or alignment reticle pattern is centered on the rear surface of the collimator objective lens. An infinity or titlt reticle is placed at the principal focus of the objective lens, generally 10 inches, see figure 46. The tilt reticle is usually graduated every 30 seconds in four directions from zero as in figure 47. The centers of the tilt and displacement reticles are on the optical axis of the instrument. The tilt reticle is illuminated by a low voltage, removable lamp unit.

5.7.1.2.2 *Operation.* In operation, the tilt reticle is illuminated and the rays of light from this reticle emerge in a parallel beam. If an alignment telescope is focused at infinity and placed in this beam, the tilt reticle of the collimator can be made to appear in the telescope. The graduations on the tilt reticle allow a direct reading of the angle that the optical axes of the collimator and the telescope make with each other. By superimposing the tilt reticle of the collimator onto the telescope reticle,

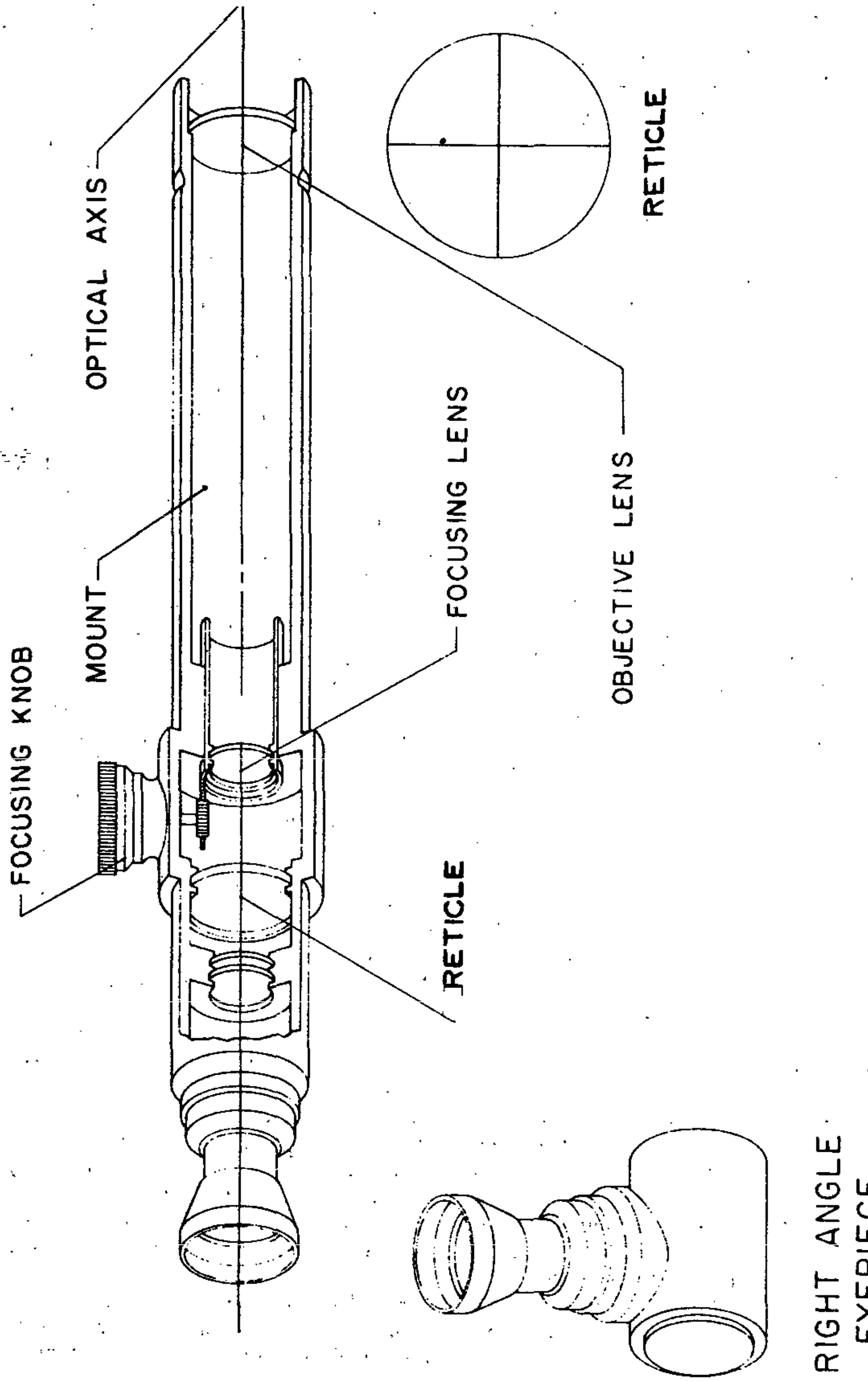


FIGURE 44. *Alignment telescope construction.*

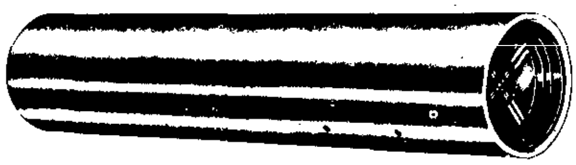


FIGURE 45. *Alignment collimator.*

collimation is accomplished; that is, the optical axes of the two instruments are parallel but they may be displaced by an unknown amount.

5.7.1.2.3 *Collineation.* If the telescope is now focused on the collimator displacement reticle, the amount of displacement can be read directly and the two instruments can be brought into collineation (common optical axes) thereby establishing a straight reference line of sight between the two instruments from which other lines of sight or measurements may be taken. See diagram, figure 48.

5.7.1.3 *The Jig Transit and Optical Transit Square.* The jig transit in Figure 49 and optical transit square are two somewhat similar instruments designed to do practically the same thing, which is:

(a) To establish a precise right angle plane with the optical reference line of sight determined by the alignment telescope.

(b) To take accurate measurements of linear dimensions when used with a tooling bar and other accessories. These two instruments do have different features and will be discussed separately.

5.7.1.3.1 *The Jig Transit.* The jig transit is basically an alignment telescope in a yoke. The yoke is constructed so that the telescope may be rotated 360° in a vertical and horizontal plane. In some makes the yoke has a hollow vertical axis through which the telescope may view a scale placed on the tooling bar (see par. 5.7.1.6.1), in others, the readings are taken from a vernier scale attached to the carriage mount. Provision is made for mounting an optically flat front-surface mirror on the horizontal axle of the telescope, exactly parallel to the telescope's line of sight. This permits the use of auto-collimation or auto-reflection (see par. 5.7.2.2) from it to establish a precise right angle line of sight. The telescope has a focusing range from 8 inches to infinity. Magnification varies from 20X at 8 inches to 30X at infinity. The field of view at infinity focus is 1°10′.

5.6.1.3.2 *The Optical Transit Square.* The transit square is also basically an alignment telescope in a yoke. The vertical axis in this case is solid; measurements are taken from a vernier and scale attached to the tooling bar and carriage. The horizontal axle of the telescope is hollow and sealed at each end with windows; one window is clear, and the other is optically flat and partially coated on the inside surface to make it a semi-reflecting mirror. The mirror, as in the jig transit, is exactly parallel to the telescope's line of sight. Auto-collimation and auto-reflection are performed in the same manner as with the jig transit to establish a right angle line of sight. One advantage of the optical transit square is that the hollow axle design permits a series of instruments to be used on the same optical reference line.

5.7.1.4 *The Tilting Level.* The tilting level is an extremely accurate instrument for precise leveling in optical tooling. Basically, it is a 30X telescope with a resolving power of 4 seconds. The focusing range is from 6 feet to infinity. It provides an erect image, which is a time-saver in that the operator is not subject to mistakes in direction. A 2½X coincidence type split bubble level is mounted exactly parallel to the line of sight. A tilt of one second of arc (approximately .0015 in. at 25 feet) is plainly visible in the level window. A tilting wheel under the eyepiece is used to set the telescope level. The tilting level should be equipped with an optical micrometer so that accurate readings may be taken with respect to the leveling points. See figure 50.

5.7.1.5 *Targets.* There is a wide variety of commercial targets available, ranging from simple cross-lines to elaborate etched grids from which displacement can be read directly. Five types will be discussed here, as shown in figure 51.

5.7.1.5.1 *Alignment Targets.* Alignment targets give a point of reference and usually consist of paired black lines of different thicknesses and spacing. It has been found that an observer can center a telescope reticle in the white space between two black lines much more accurately than he can place the reticle on a single black line. The observer chooses the set of lines with the smallest spacing that will still clearly show white spaces on either side of center.

5.7.1.5.2 *Displacement Targets.* The displacement target gives a point of reference and also has horizontal and vertical scales to measure displace-

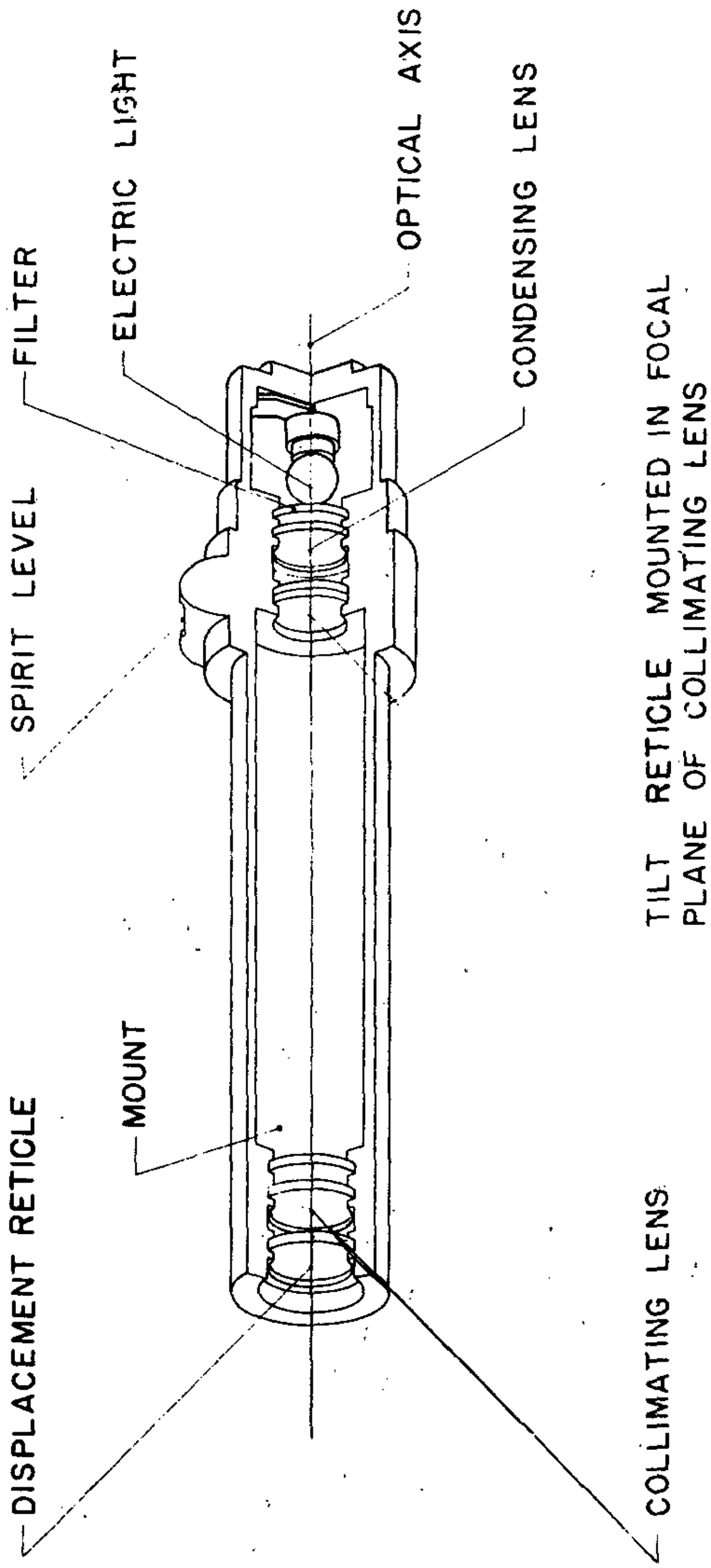


FIGURE 46. *Collimator construction.*

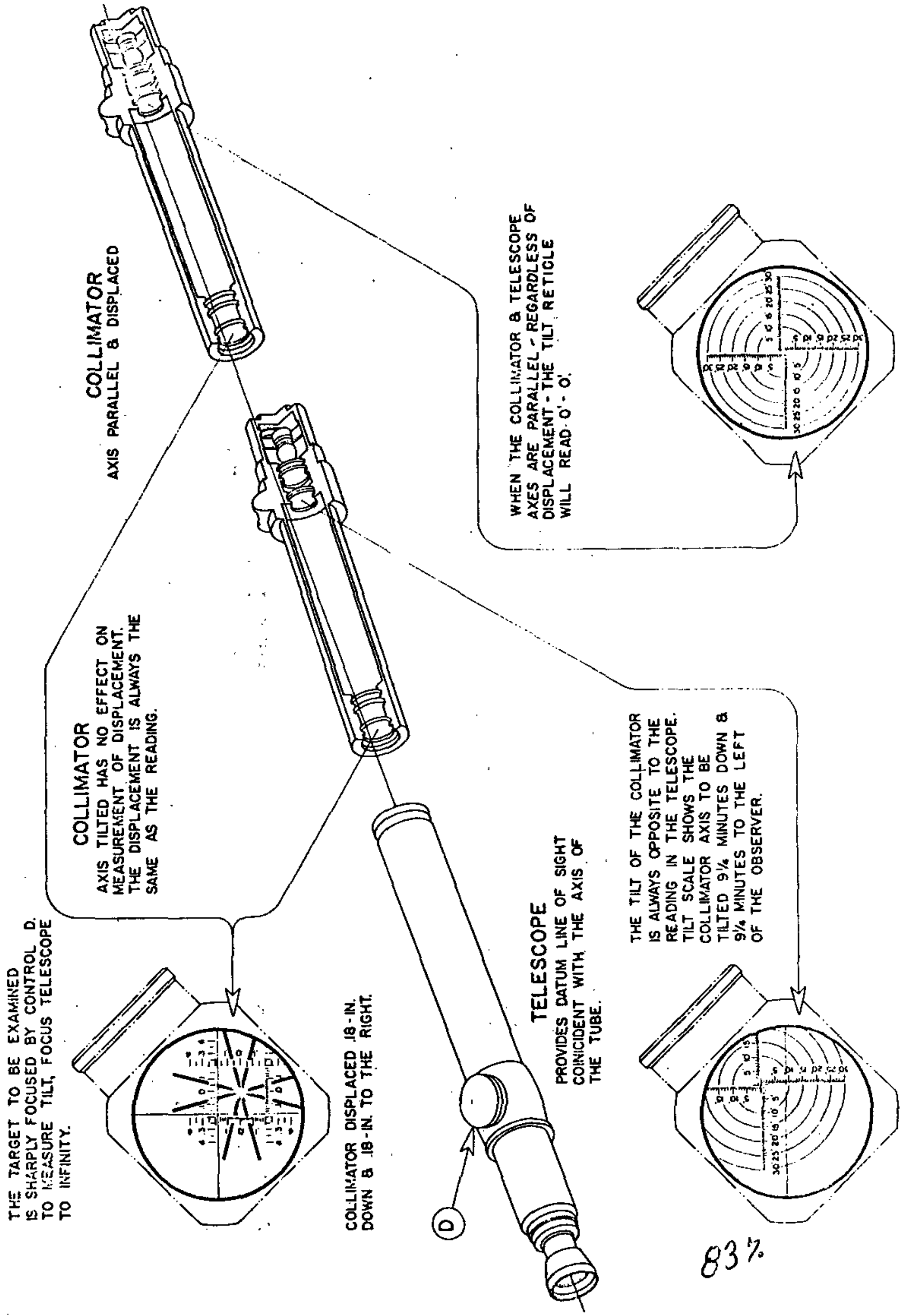


FIGURE 47. *Measuring tilt and displacement with a collimator and telescope.*

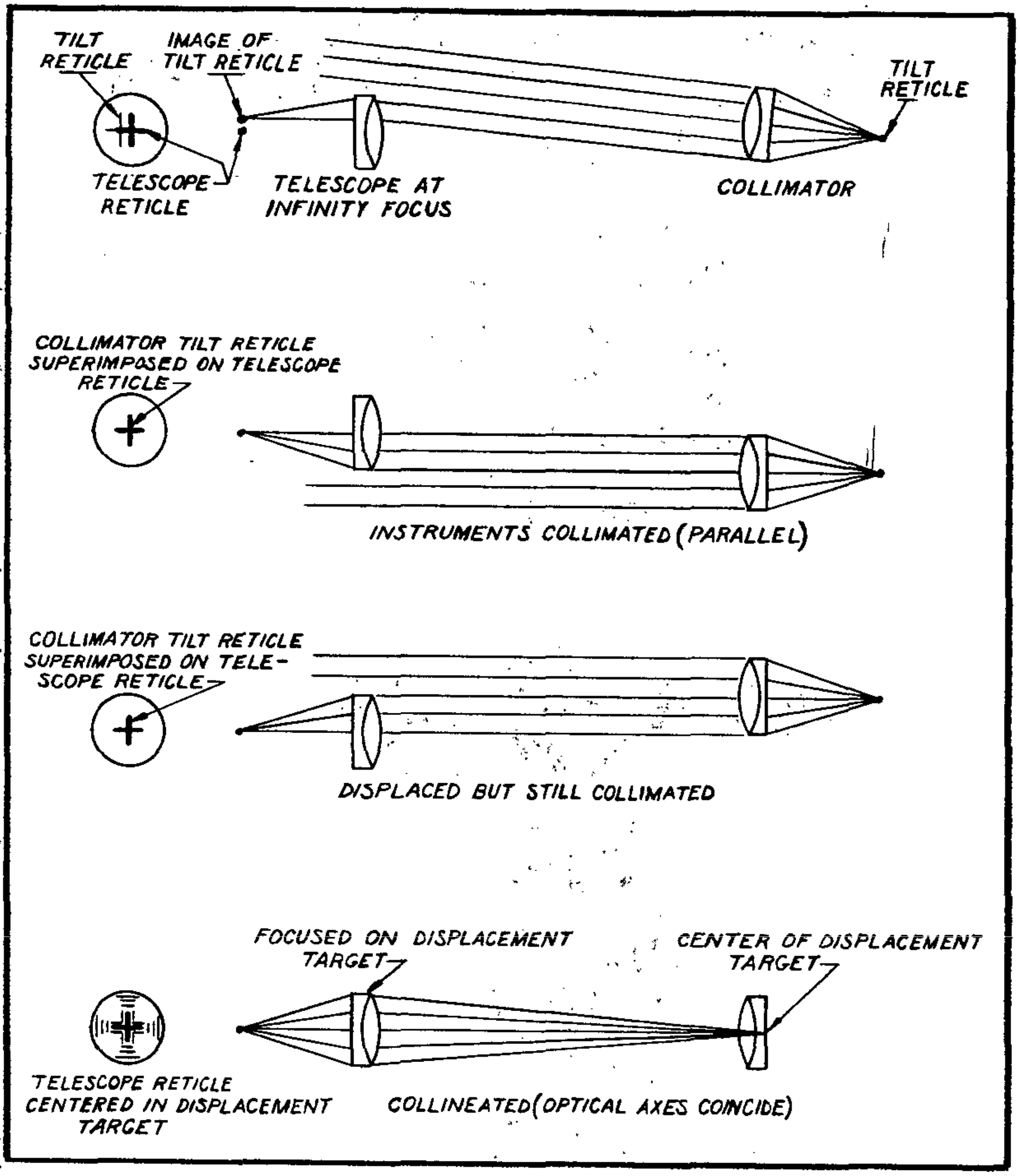


FIGURE 48. *Diagram of collimator and telescope.*

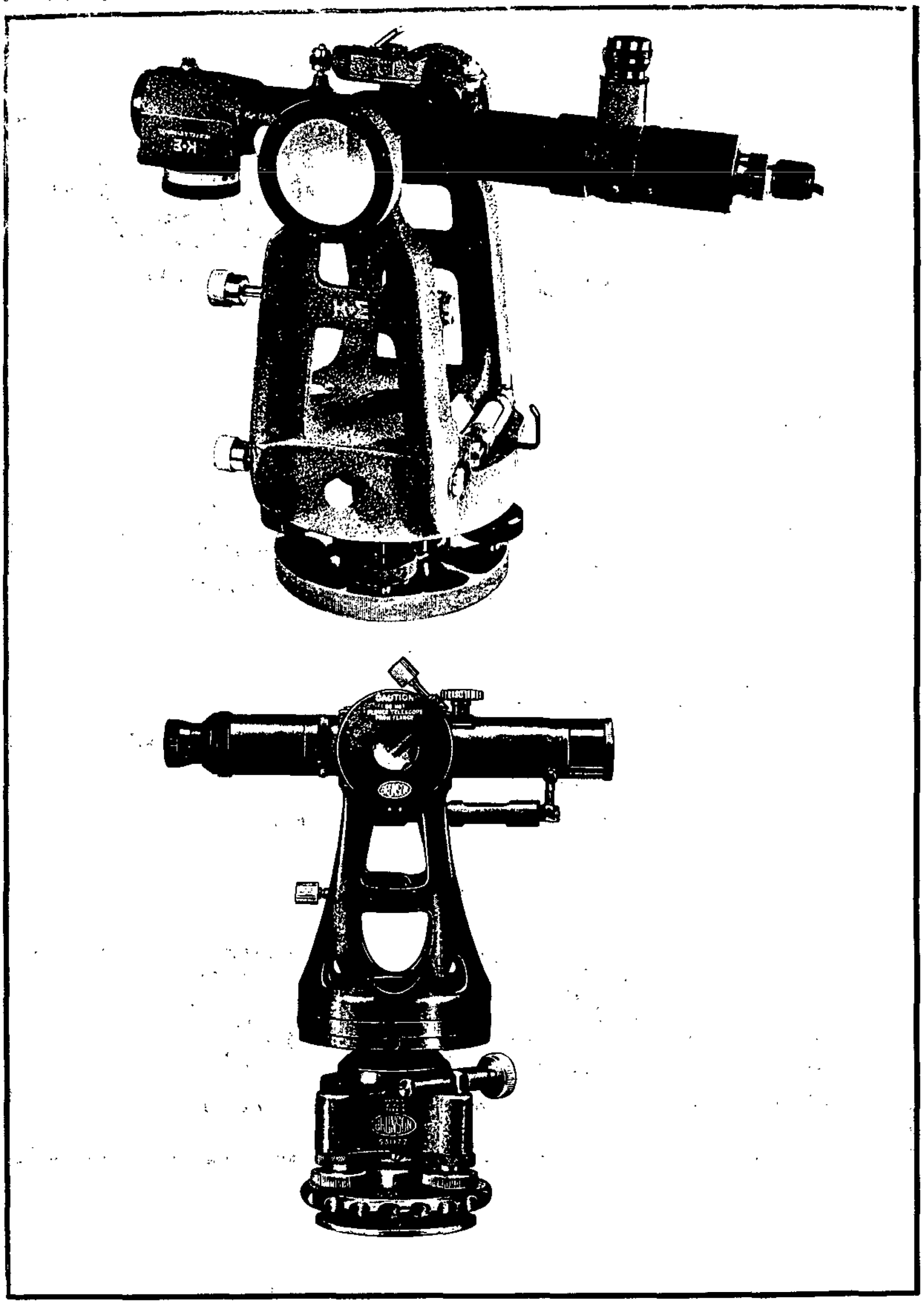


FIGURE 49. *Jig transits.*

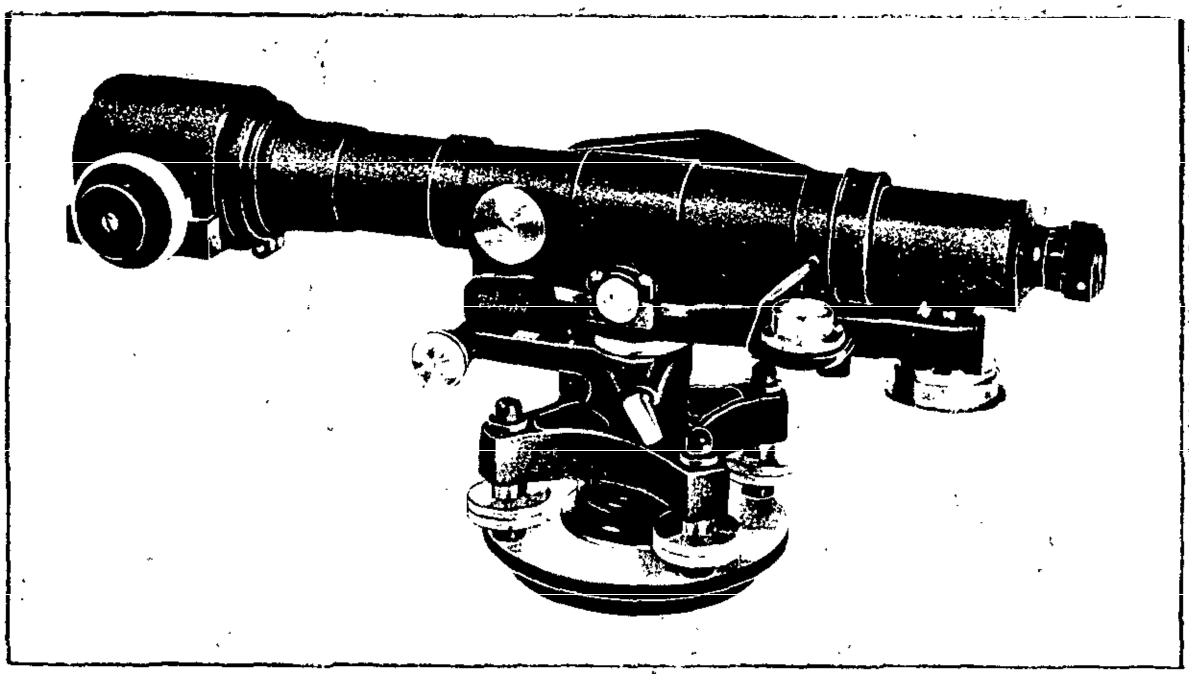


FIGURE 50. *Tilting level.*

ments from the line of sight up to .300 inch. It is usually mounted in a hardened steel ring.

5.7.1.5.3 *Auto-Reflection Targets.* The auto-reflection targets are used on the front of sighting telescopes to give a reference point on the line of sight for auto-reflection. The paired-line principle is used, but the pattern is based on somewhat wider spaces than the alignment target.

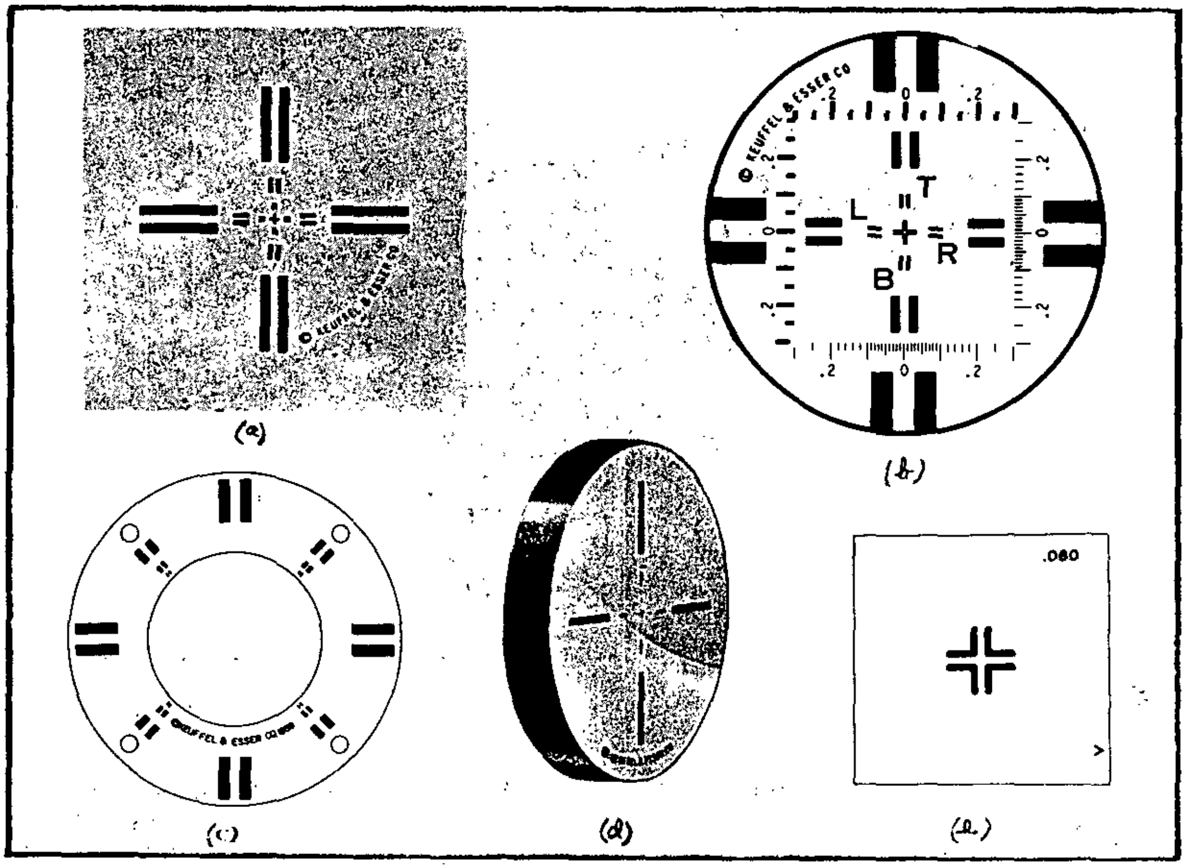
5.7.1.5.4 *Mirror Targets.* The mirror target consists of an alignment target pattern cut in the silvering of a front surface mirror. It is used to give a point of reference and also, by auto-reflection and auto-collimation, to control the tilt of the object on which it is mounted. The pattern is modified because it is illuminated from the back and therefore presents lines of light color against a dark background.

5.7.1.5.5 *Double Line Targets.* Targets are of the paired line principle and are engraved on white plastic plaques and filled with black. The white spacing can be from .005 to .100 inch. By choosing target line spacing on the basis of the range at which they will be used, targets at key points indicate proper tolerance. Distance and line spacing are predetermined so that equal white areas on either side of centerline will show that measurements are within tolerance.

5.7.1.5.6 If it is desired, a special purpose target may be designed giving limits of displacement for quick inspection or reading various functions quickly. Cost can increase quickly as the markings become more complex or highly accurate, so prudence is indicated. On short production runs or those of lesser accuracy, improvised targets may be employed.

5.7.1.6 *Tooling Bars and Instrument Stands.*

5.7.1.6.1 *Horizontal Tooling Bar.* A horizontal tooling bar basically consists of an aluminum track of box-like cross-section upon which is fastened a full length steel index bar having precision drill bushings spaced every 10 inches. A carriage, on which an instrument (such as a jig transit) is mounted, traverses the length of the bar on machined ways and is capable of being locked in place. A ten inch scale with a precision ground plug fits into the drill bushings of the index bar, which in conjunction with a vernier on the carriage or a sight through the mount, permits horizontal linear measurements to .001 inch accuracy. The height of the tooling bar can be regulated by adjustable mobile stands. Tooling bars come in various lengths, from 10 feet to about 30 feet and individual sections can be connected to give any desired length. See figure 52.



a. Alignment target. b. Displacement target. c. Auto-reflection target. d. Mirror target. e. Double-line target.

FIGURE 51. *Targets.*

5.7.1.6.2 *Vertical Tooling Bar.* The vertical tooling bar in Figure 53 makes it possible to measure linear distances in the vertical dimension to an accuracy of .001 inch. The construction is almost the same as the horizontal bar, except that the carriage is counter-balanced for ease of movement and is also spring-loaded to assure continual contact with the ways. The bar is supported by three radial arms, each of which contains casters and leveling screws. Two levels, mounted at 90° to one another, indicate when the tooling bar is vertical. Measurements are taken in the same manner as on the horizontal tooling bar.

5.7.1.6.3 *Instrument Stands.* Instrument stands are used to provide a rigid, mobile support for almost any type of optical instrument. The height is adjustable from about 44 inches to 72 inches by means of a capstan wheel with rack and pinion. A clamp locks the telescoping cylindrical column at the desired height. A cross-slide may be mounted on top of the center column to permit a limited lateral adjustment (2¼ in. to 4¾ in. depending on manufacturer). The cross-slide is fully rotatable through 360°. The stand is supported by three radial arms, each of which contains casters and leveling screws. See figure 54.

5.7.2 ACCESSORIES.

5.7.2.1 *Optical Micrometer.* An optical micrometer as in figure 55, is an attachment that may be used on Tilting Levels, Jig Transits and Optical Transit Squares for very precise measurements, alignment, or leveling. It works on the principle of refraction of light rays. When a light ray enters a disc of optical glass with flat parallel faces, at any angle other than perpendicular, it is refracted or bent a predictable amount according to the law of refraction. When the ray leaves the glass, it is again refracted so that it proceeds at its original

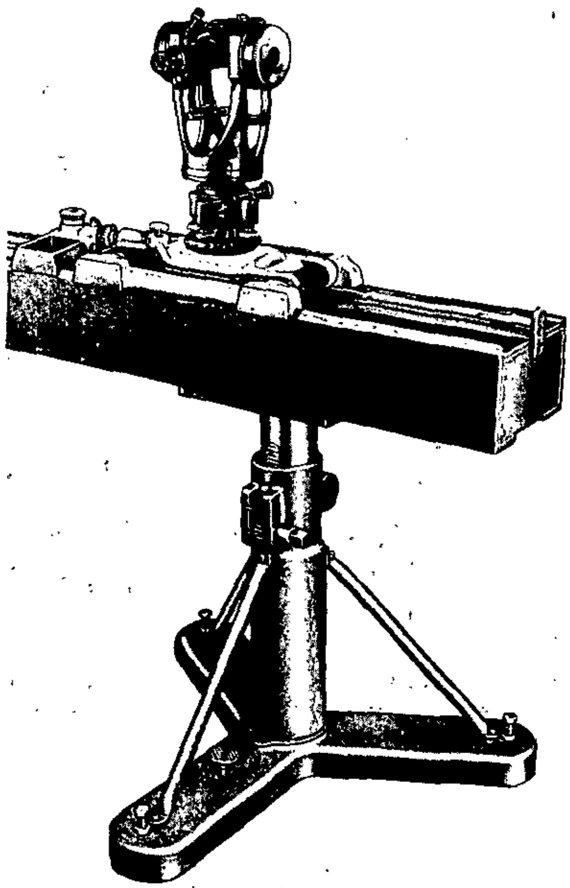


FIGURE 52. *Horizontal tooling bar.*

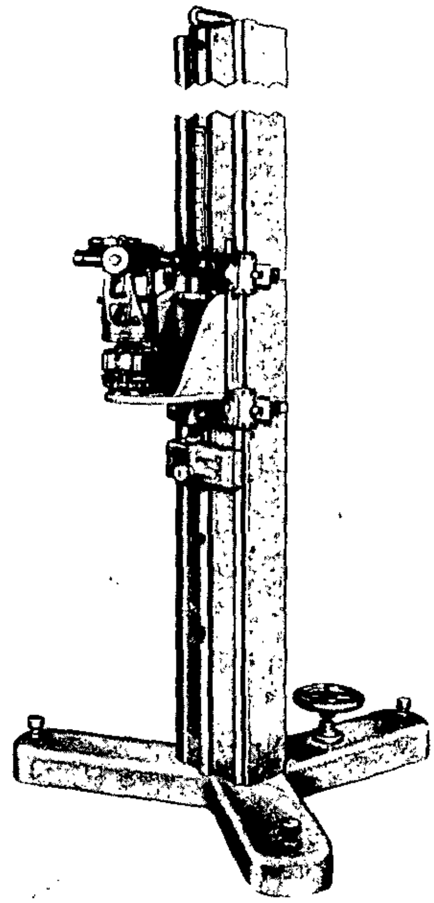


FIGURE 53. *Vertical tooling bar.*

angle, but displaced a certain amount. The optical mircometer takes advantage of this property of light by controlling the amount of tilt of disc of optical glass with a graduated drum. When the drum is turned a precise amount, the line of sight is moved parallel to itself a proportionate amount as in figure 56. The micrometer drum is graduated directly to .001 in., numbered every .010 in. and has a range of from .0 to ±.100 in. The micrometer may be positioned to measure either horizontal or vertical displacement.

5.7.2.2 *Auto-Collimation Unit.* By illuminating the reticles of alignment telescopes, alignment collimators, and transits, auto-collimation and auto-reflection is made possible, thereby increasing the usefulness of these instruments. The various manufacturers achieve this result in different ways. In some instruments, the unit is built in but the light source is removable. In others, figure 57, the unit is complete with an eyepiece that is interchangeable with the eyepiece of the instrument. Most of the units have a rheostat for controlling the amount of light to the reticle.

5.7.2.2.1 *Auto-Reflection.* Auto-reflection is used to position a plane or surface perpendicular to a reference light of sight. An instrument with an auto-reflection target on the end (mounted on the barrel or on the inside surface of the objective lens) and an auto-collimation unit or other means of illuminating the reticle, is needed. The instrument, with its reticle illuminated, is sighted into a mirror placed at some convenient distance and focused on the reflected target image. If there is an error in the perpendicularity of the mirror to the line of sight, the target image will be displaced with respect to the instrument's reticle. By manipulation of the mirror, the target image may be moved until it is

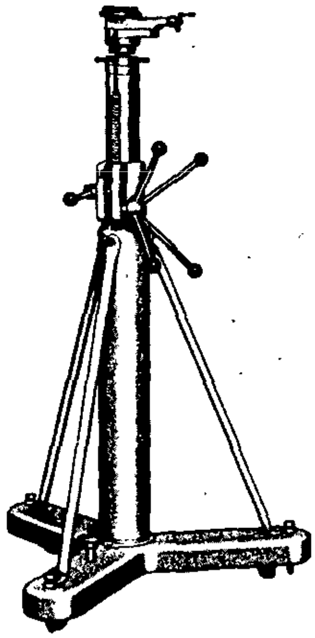


FIGURE 54. *Instrument stand*

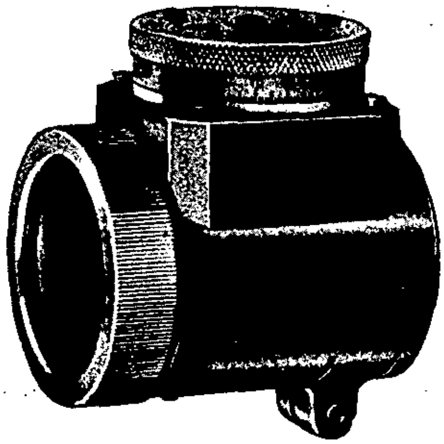


FIGURE 55. *Optical micrometer.*

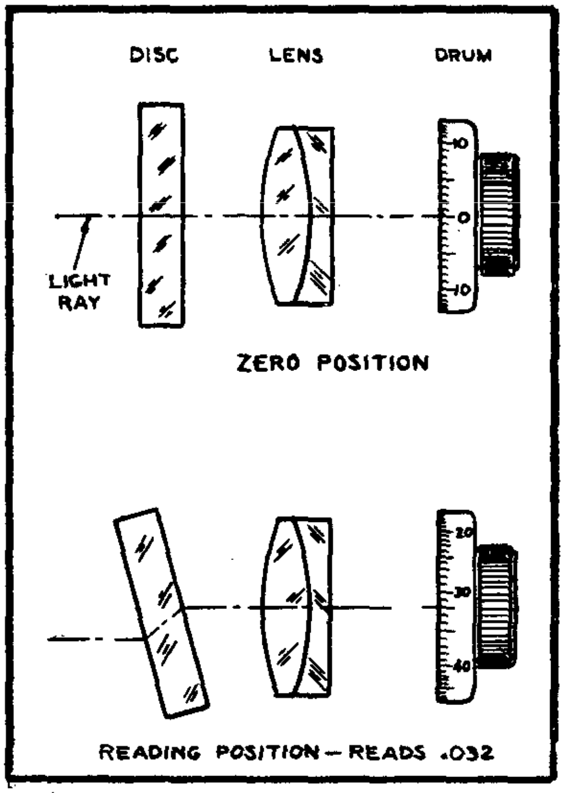


FIGURE 56. *Principle of the optical micrometer.*

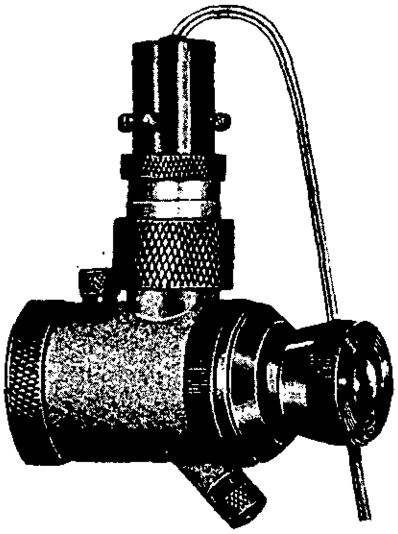


FIGURE 57. *Auto-collimation unit.*

centered on the reticle. The line of sight is now reflected back on itself, proving perpendicularity between the mirror and the line of sight. The principle of auto-reflection is illustrated in figure 58.

5.7.2.2.2 *Auto-Collimation.* Auto-collimation is similar to auto-reflection but more accurate. In auto-reflection, the instrument is focused at a finite distance, i.e., twice the distance from the target to the mirror, therefore any observational error in centering the target image on the reticle is equivalent to a perpendicularity error of the mirror and is a function of the distance from the instrument to the mirror. In auto-collimation is in auto-reflection, the instrument's reticle is illuminated and the mirror

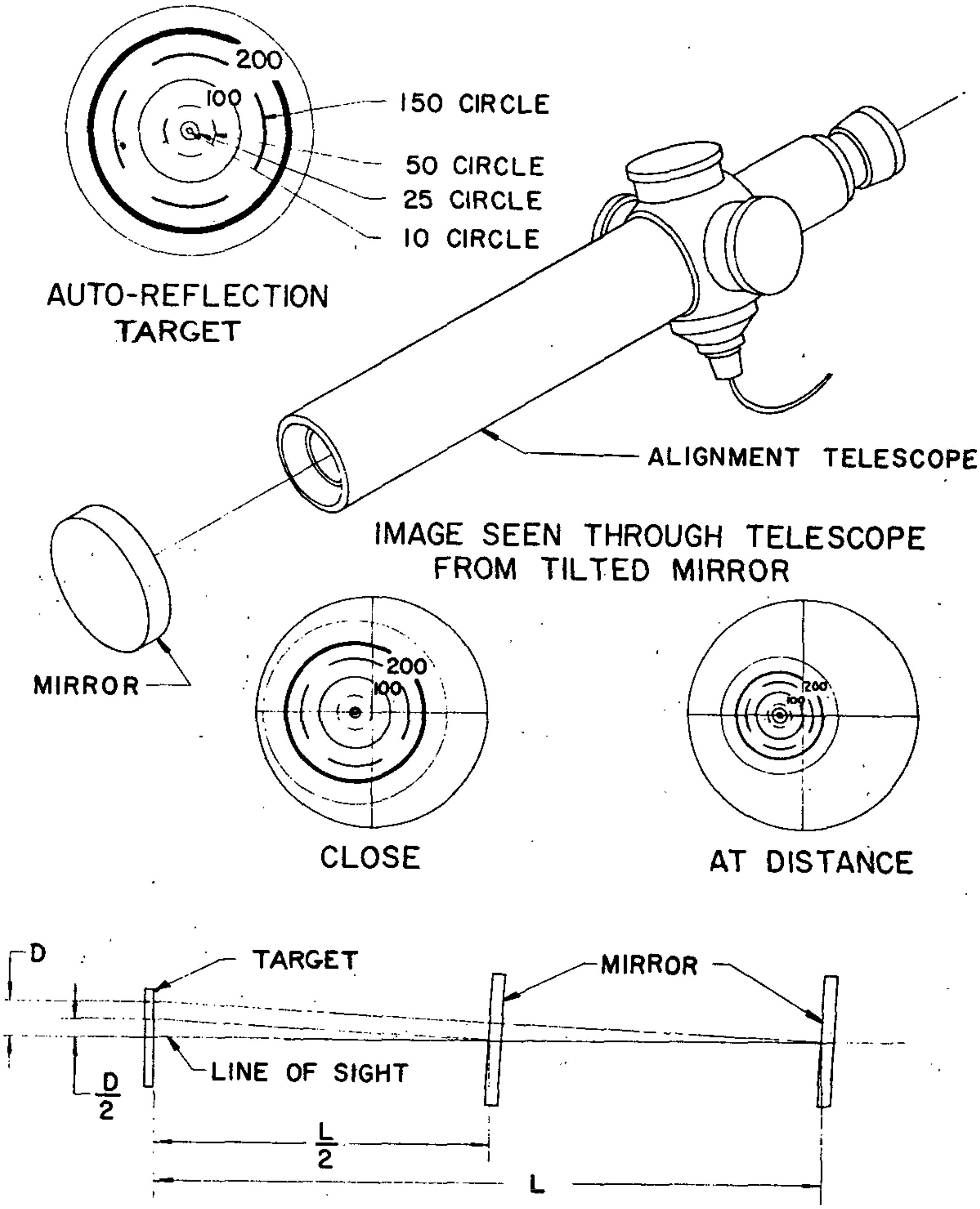


FIGURE 58. *Auto-reflection principle.*

is placed at some convenient distance but the instrument is focused at infinity which makes it an auto-collimator, bringing the instrument's reticle into focus. Sighting into the reflection of the instrument's reticle is the same as sighting into another collimator and the distance to the mirror is no longer a factor as explained previously in par. 5.6.4.

5.7.2.3 *Protection Eyepiece.* The projection unit (shown in figure 59) is used in place of the standard eyepiece of transits and telescopes so that the reticle pattern may be projected into the object being worked on. It is generally desirable to use a projection reticle that has been specially designed for projection. This reticle has fine lines for close work and heavier lines for longer shots. Reticle patterns can be projected 25 feet or more. Some types of projection units have a device which permits projection and normal vision through the instrument.

5.7.2.4 *Right Angle Eyepiece.* The right angle, or elbow eyepiece, is interchangeable with the eyepieces of most optical tooling instruments. This eyepiece is used for very low set-ups or working close to walls, columns, or other obstructions. It also makes it possible to use the transit to conveniently take sights at any high angle, including directly overhead. The right angle eyepiece is fully rotatable through 360° for sighting from any perpendicular angle. It is also available as a combination auto-collimation projection and right angle eyepiece.

5.7.2.5 *Levels.* Levels are used to establish horizontal planes or lines of sight in conjunction with telescopes and other instruments. There are three basic types.

5.7.2.5.1 *Bull's eye or circular level.* Used to rough level an instrument base or fixture in two planes at one time.

5.7.2.5.2 *Tubular level.* Used to semi-precision level an instrument base, an instrument, or a fixture in one plane at a time.

5.7.2.5.3 *Coincidence level.* The halves of each end of a split bubble, figure 60, are attached (as viewed through a prismatic system).

(a) Used to precision level an instrument or a fixture in one plane at a time.

(b) Accurate to within 1 or 2 seconds of arc.

(c) Level setting is indicated when ends of bubble are in coincidence as in 3 of figure 60. A striding level, as pictured in Figure 61, is a coincidence level that clips on the barrel of an alignment collimator or alignment telescope for precision leveling. It also contains a bull's eye level for rough leveling and a rotating viewing mirror.

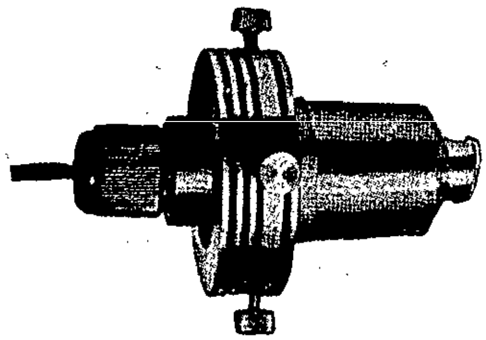


FIGURE 59. *Projection eyepiece*

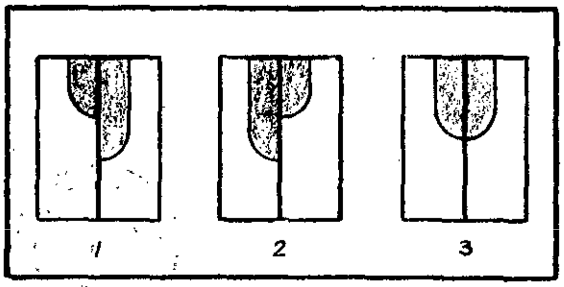


FIGURE 60. *Coincidence level.*

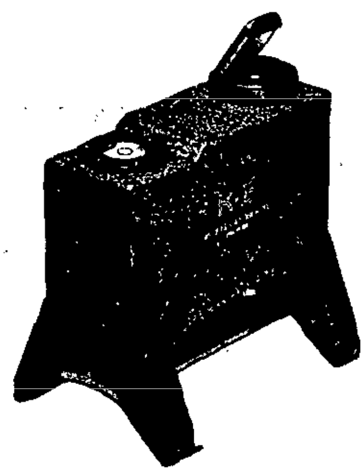


FIGURE 61. *Striding level.*

5.7.2.6 *Optical Square.* The optical square is an instrument which, when used in conjunction with an alignment telescope, will establish a plane perpendicular to the telescope's line of sight without the need for auto-collimation or auto-reflection. It consists of a penta prism (a penta prism has the ability to turn a line of sight exactly 90° even though it is not accurately aligned itself) mounted in a spherical housing. The square has a unique feature in that it has both a front and a side aperture, permitting the observer's line of sight (by manipulation of aperture covers) to be turned through the 90° angle or to pass undeviated through the instrument. This feature allows the basic line of sight to be checked while the optical square is in place. The spherical housing, when seated in a special cup mount, permits the line of sight to be fully rotatable in the vertical plane for 360°. See figure 62.

5.7.2.7 *Mirrors.* Mirrors play an important part in optical tooling. Their main use is in auto-collimation and auto-reflection to establish a plane perpendicular to a line of sight. They may also be used to check the perpendicularity of a surface to a line of sight or to establish the axis of rotation of shafts, spindles, etc., so that other parts may be aligned with them.

5.7.2.7.1 *Axle Mirror.* An axle mirror is a front surface mirror that is optically flat within ¼ wavelength of light (.0000058 in.) and can be screwd on either end of the telescope axle of a jig transit. It is adjustable to make it parallel to the telescope's line of sight.

5.7.2.7.2 *Magnet Black Mirror.* A circular front surface mirror from 2 to 4 inches in diameter whose reflecting surface is optically flat within ¼ wavelength of light. One to three magnetic feet are cemented to the back of the mirror. Their contact surfaces are ground parallel to the mirror surface.

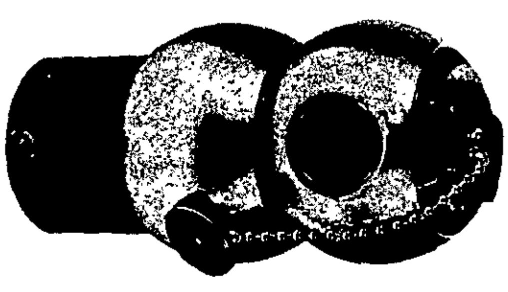


FIGURE 62. *Optical square*

When the mirror is not in actual use, an iron or steel keeper should be placed over the magnets to retain their magnetism.

5.7.2.8 *Tooling Tapes.* An important problem in optical tooling is the difficulty of making precision measurements over considerable distances (20 ft. to several hundred ft.). Optical Tooling Tapes fulfill this requirement. They are made of steel, ⅜ inch wide and about .008 inch thick. The graduations are .006 inch wide, spaced at 10 inch intervals and are clearly visible under the magnification of a jig transit. Inch numbers are printed beside each graduation. Tooling tapes are available in 20 ft, 50 ft, and 100 ft. lengths and can be made in any desired length up to 300 feet.

5.7.2.8.1 A certificate is furnished giving the tension at which the overall length will be correct at 68°F. Tapes 100 ft. long or less require about 10 lbs. tension and those over 100 ft. long require about 20 lbs. When the correct tension is applied, no graduation will vary more than .005 from its true position and no 10 inch length will vary more than .003.

5.7.2.8.2 A temperature correction need not be applied when the tape is used on a machine tool, steel jig or other structure, since the tape will assume the same temperature as the structure. But if the tape is used to determine an exact distance, the following corrections must be applied:

$$\text{Change in length} = (L_o)\ (C_e)\ (T_c)$$

Where L_o is the original length in inches, C_e is the coefficient of linear expansion (.00000645 in. per degree F.) for steel and T_c is the temperature change in degrees from 68°F.

5.7.2.8.3 The temperature correction noted above is applicable to all dimensional inspection equipment any time there is a temperature differential between the object being gaged and the inspection equipment. The only variable possibly being the coefficient of linear expansion which varies slightly with the different types of steel. The difference is usually negligible however and may be safely taken as the figure used above.

5.8 OPTICAL PROJECTION

5.8.1 *PRINCIPLES OF OPTICAL PROJECTION.* Optical projection consists of the projection of a sharply outlined and magnified shadow silhouette of the part being inspected upon a translucent screen. This is accomplished by placing the part within an optical system consisting of a light

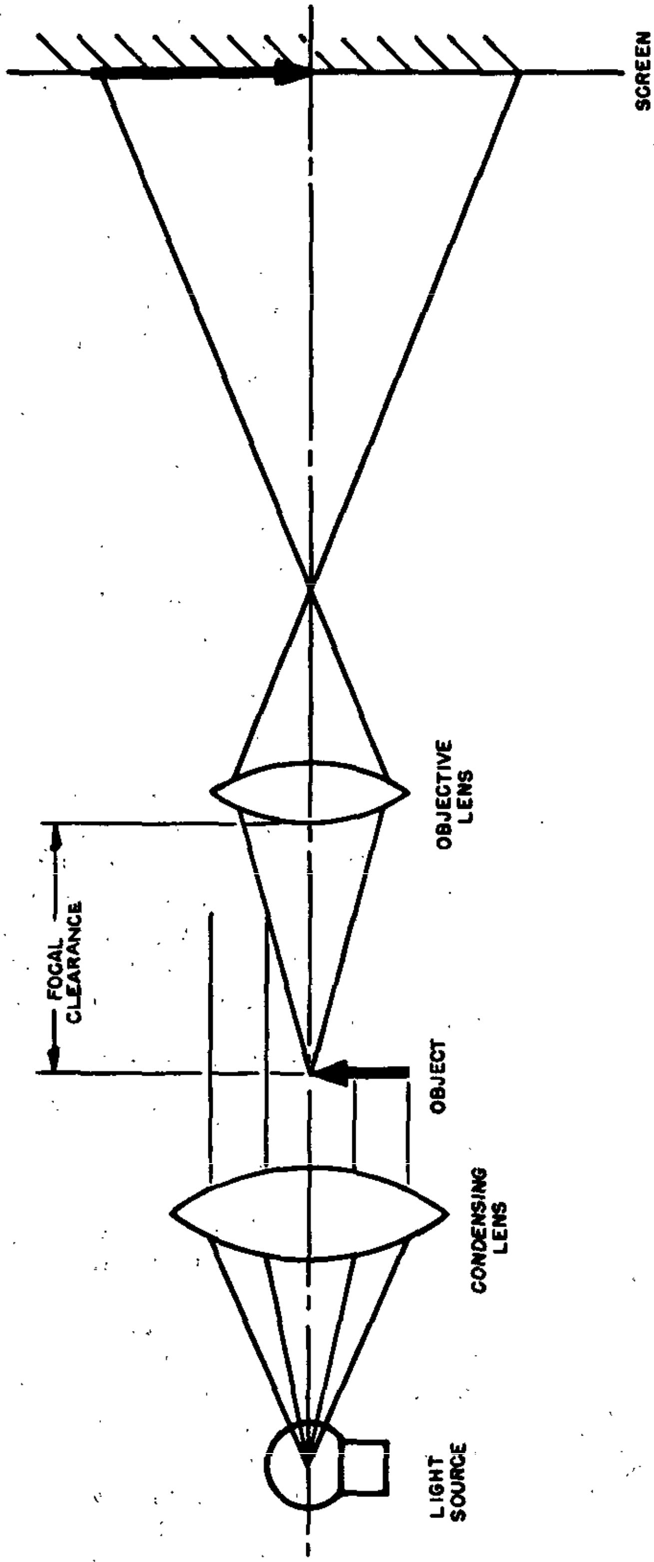


FIGURE 63. *Projector.*

source, condensing lens, objective lens and screen, as in figure 63.

5.8.2 *GENERAL REQUIREMENTS FOR OPTICAL PROJECTION.* The optical system of a projector requires careful design and construction. The more important requirements are:

- (a) The image must be sharp on the screen and there must be no focusing errors.
- (b) There must be no distortion of straight lines into curves.
- (c) There must be no astigmatism, that is, no unequal definition of the image caused by horizontal lines being out of focus with the vertical lines.
- (d) There must be no color fringes.
- (e) The magnification should be capable of variation.
- (f) The image on the screen should not be reversed or upside down.
- (g) The light source should give sufficient illumination to establish a high degree of contrast between the field and the part silhouette.

5.8.3 *REQUIREMENTS FOR OBTAINING MAXIMUM IMAGE SHARPNESS.*

5.8.3.1 *Positioning of the part.* A sharply defined image can be obtained if the distance from the part to the objective lens is equal to the focal length of the lens. A small increment of adjustment, say 1/32 inch added to the focal length, shall be allowed to overcome any minute variations thus producing maximum sharpness of the projected image. In obtaining maximum sharpness of the projected image of a comparatively thick object, the point of focus should be a point at the edge of the part nearest to the objective lens. Gaging of thick parts by direct projection should be avoided wherever possible.

5.8.3.2 *Necessity for Parallel Light.* The projection of a parallel beam of light emanating from the condenser is of major importance in obtaining a sharply defined image. If non-parallel light rays are emitted from the condensing lens, the sharpness of the image on the screen will decrease as the thickness of the part increases. The majority of commercially manufactured projectors or comparators have condensing systems that emit light rays which for all practical purposes approach true parallelism.

5.8.3.3 *Selection of Proper Magnification.* The magnification of the projector is the ratio of the linear size of the image to the linear size of the object. The common commercial magnifications are 10X, 20X, 31¼X, 50X, 62½X, and 100X. It is not always possible or desirable to completely fill the screen for a given magnification. The line of demarcation of the image should be sharply differentiated from the surrounding field. If the sharpness is not of the desired intensity, the magnification may be high. Therefore, the lowest magnification consistent with the size of the component and the magnitude of the tolerance should be used.

5.8.4 *OPTICAL PROJECTORS.*

5.8.4.1 *General Features.* An optical projector may be used for comparison or for measurement. If used for a comparison, the image is compared with an outline drawn on the screen. When used for measurement, the projector incorporates the use of a lateral table travel or a cross-slide table which can be moved in a horizontal or vertical direction or both and at right angles to the beam of light. For linear distances up to one inch, micrometer heads are provided. For measurements over one inch, provisions are made in the table for the use of gage blocks.

5.8.4.2 *Types.* Projectors can be classified into two types by usage; gaging and measuring projectors. A gaging projector is used to project an image for comparison purposes against an outline laid out on a screen chart and is intended for production gaging. No actual measurements are performed, but a determination is made as to whether the part lies within specified limits. The measuring projector finds its use mainly in the metrology laboratory, the tool room, and in production control, and is not generally adapted to the final inspection of parts in quantity. See figure 64 and 65.

5.8.5 *STAGING FIXTURES.*

5.8.5.1 *General Design Features.* The holding or staging of a component determines the degree of accuracy obtained from optical projection. The function of the staging fixture is to hold the component at a fixed distance from the objective lens with the focal plane of the component perpendicular to the center line of the lens system. The component must be positioned in the horizontal and vertical directions in order that the desired outline will always fall in the same position with relation to the screen. The design principles of gaging and staging fixtures are similar. However, it is not necessary to maintain the high dimensional accuracy common to gages in designing staging fixtures. The accuracy required is achieved by the accuracy of the screen

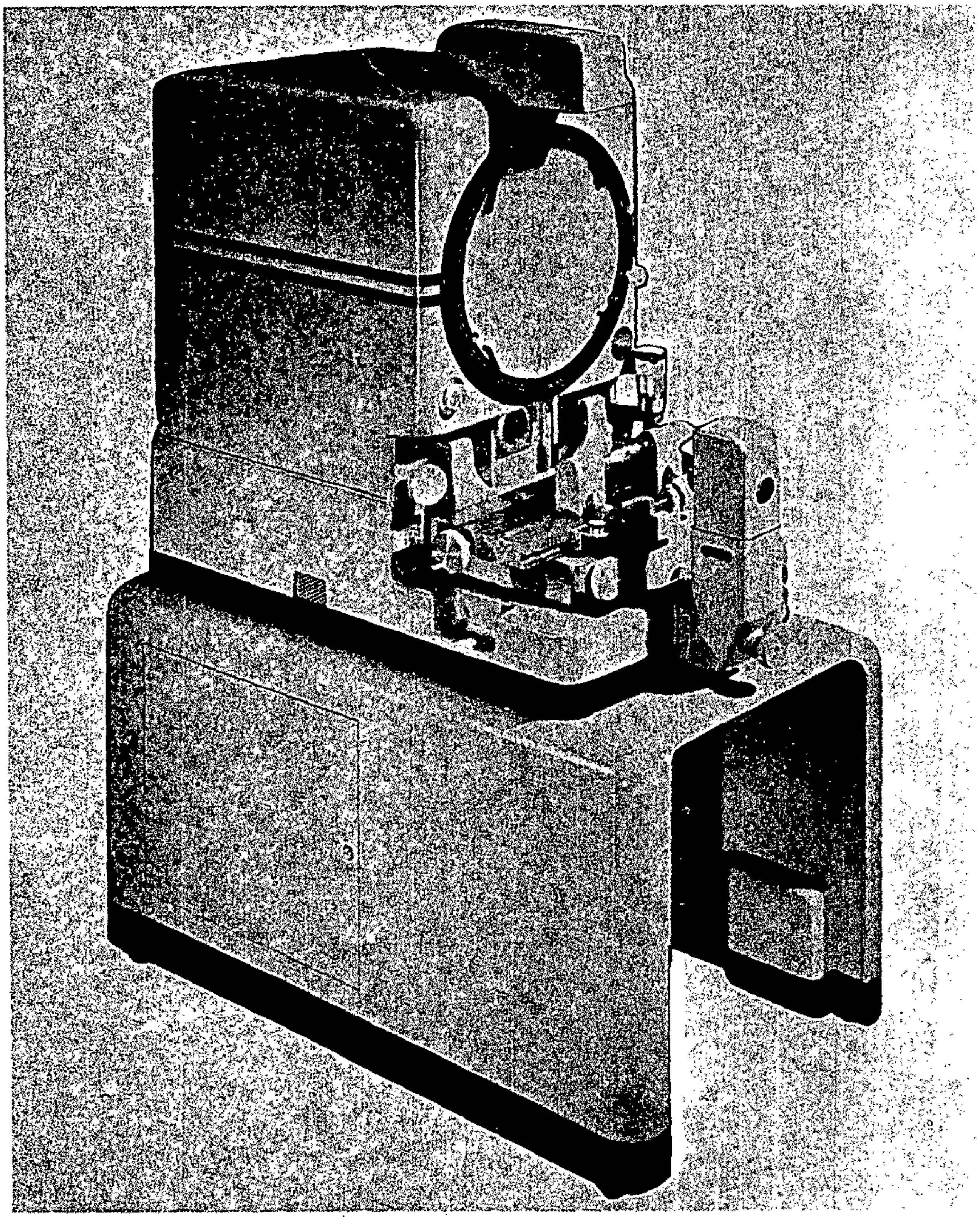


FIGURE 64. *Measuring projector.*

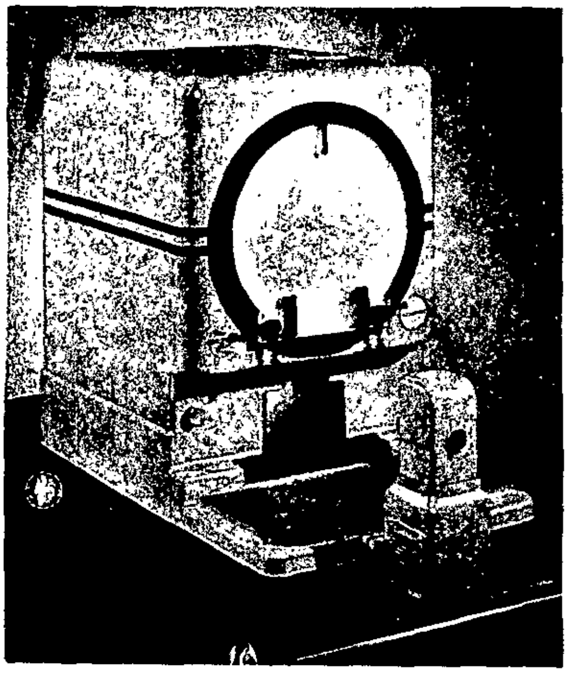
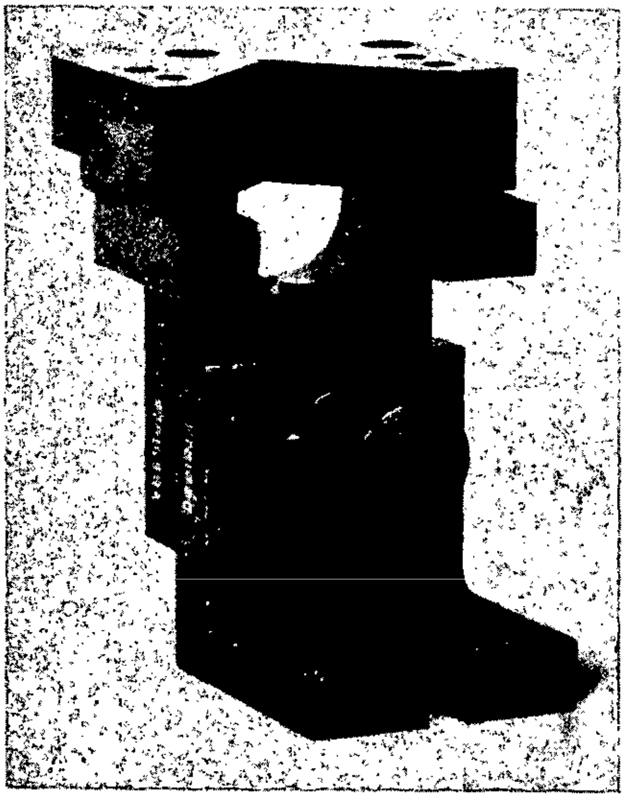
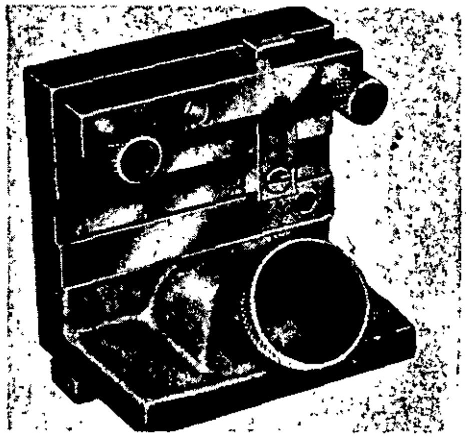


FIGURE 65. *Gaging projector.*

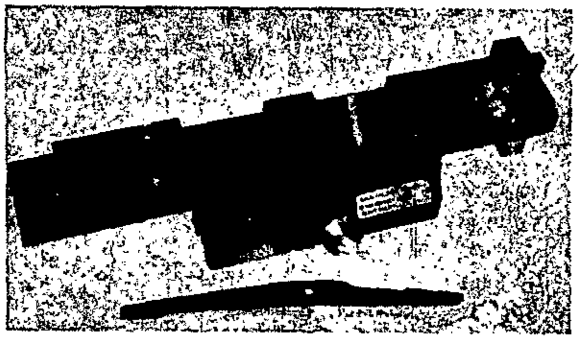


a. Compensating type.

FIGURE 66. *Staging fixtures.*



b. Permanent aligned type.



c. Position locking type.

FIGURE 66—Continued.

layout and the method of setting the staging fixture with reference to the screen. A simple setting check may be provided to aid in setting up the staging fixture.

5.8.5.2 Types of Staging Fixtures. Staging fixtures may be classified into three distinct categories:

Compensating Type
Permanent Aligned Type
Position Locking Type

5.8.5.2.1 *Compensating Type.* The compensating type of fixture is used with optical comparators which have no adjustments for either focus or positioning of the component on the screen. In this type of fixture, all the necessary adjustments are incorporated into the fixture. See figure 66(a).

5.8.5.2.2 *Permanent Aligned Type.* The permanent aligned type of fixture is clamped to the table of the comparator and is positioned with reference to the low lens system by means of slots or other locating points. See figure 66(b).

5.8.5.2.3 *Position Locking Type.* The position locking type of fixture is used with optical comparators having adjustments for focus and positioning of the part silhouette on the screen. Usually a series of part dimensional features are checked with this type of staging fixture. The part is first positioned in a movable element of the fixture and then, in order to view another portion of the part on the screen, repositioned by moving the element with respect to the base of the fixture. In another type of multiple positioning fixture, the part is actually moved with respective to the fixture. See figure 66(c).

5.8.5.3 *Indirect Observation.* In a fixture having provisions for indirect observation, an element of the holding fixture which is either fixed or movable is stopped against the surface of the part that is to be gaged which will be out of focus with the screen. An extension of this element which is located in such a manner that it is in focus, then shows the relative position of the gaging surface on the screen.

5.8.5.4 *Auxiliary Gaging.* Auxiliary gaging may be incorporated into the staging fixture by use of flush pins or dial indicators to take care of additional dimensions which cannot be gaged by optical projection.

5.8.6 *SPECIFIC DESIGN INSTRUCTIONS.* The following procedure should be followed in the design of a staging fixture.

1. Determine the part dimensional features to be gaged by optical projection methods.
2. Determine whether optical projection is practical and will obtain the desired results.
3. Determine how part is to be held in the staging fixture.
4. Determine focal point or plane.
5. Select the proper magnification keeping in mind the part tolerance and size of image relative to screen.
6. Plan the actual design.
7. If a compensating type of fixture is being designed, check that sufficient adjustments are provided in the fixture. In the position locking type of fixture, check to insure that the optical comparator has sufficient adjustment to line up the fixture with the screen.
8. Check focal clearance.
9. Check complete design for proper functioning.
10. Design a setting check.

5.8.7 *SCREEN CHARTS.*

5.8.7.1 *General Features.* The screen chart shows the magnified image of the part and the tolerance lines in which the image shall fall. The screen chart may be prepared on translucent Engineer's glass, plastic, or paper. Permanent master layouts are prepared on Engineer's ground glass. On screen charts requiring greater accuracy, the layout is scribed on scribing glass.

5.8.7.2 *Different Types of Screens.* In ordreing screens, it should be noted that there are two types of screens:

Overscreen (or Screen Chart)
Replacement Screen

5.8.7.2.1 *Overscreen.* The Overscreen type of screen has the layout on the side of the glass away from the inspector. This type is made of either plain or ground glass, and is placed over the regular ground glass screen furnished with the comparator.

5.8.7.2.2 *Replacement Screen.* The replacement type of screen has the layout on the side of the glass facing the inspector. This type of screen is furnished in ground glass and is used in place of the original which must be removed from the comparator.

5.8.7.3 *Accuracy.* Actual tests have shown that with reasonable care charts can be laid out by drafting room methods with an average error of .005. The actual error is computed thus:

Actual Error = Deviation from basic size on Chart divided by magnification.

5.8.7.4 Methods of Screen Layout and Checking. Layouts should first be pencilled and then traced using full strength ink. Care should be taken in maintaining uniform thickness of line and in blending of radii and corners. The following suggestions may aid in producing satisfactory layouts:

(a) When broken lines are required, it is suggested that the line be ruled in completely and then parts of the line erased. This will insure a straight and uniform line.

(b) In drawing circles and radii, a good non-slipping center for divider or compass points is made by attaching two or more small pieces of scotch cellulose or draftsman's tape, one upon the other to the surface of the layout.

(c) For greater accuracy, fit a set of points to the jaws of a vernier caliper or special gage block accessory for the purpose of measurement.

(d) In the lower magnifications, many of the commercially manufactured optical comparators project reversed and inverted images on the screen. This should be taken into consideration before preparing the screen layout.

5.9 INTERFEROMETRY. As mentioned in paragraph 5.1.1, light appears to travel in waves and therefore produces certain effects that are quite predictable. Referring to figure 67, the top figure represents an idealized light wave. One wavelength is measured from where it begins to where it starts to repeat itself. In the middle figure, if two waves of the same wavelength coincide, they produce a new wave which is equal to their sum. In the bottom figure, if two lightwaves of the same wavelength are out of phase by ½ of a wavelength, they will cancel themselves out and darkness results. The problem here is to accurately displace the two waves one half wavelength, when this is a distance of .0000108 on the average. In interferometry, the very accuracy of the pieces being measured sets up this phenomenon.

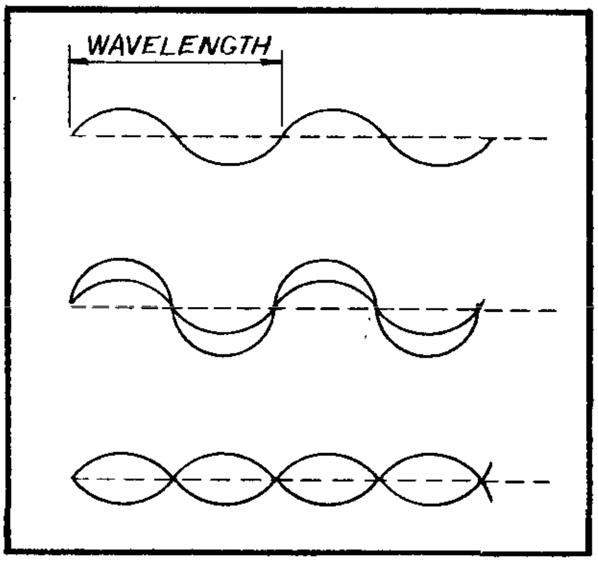


FIGURE 67. *Properties of light waves.*

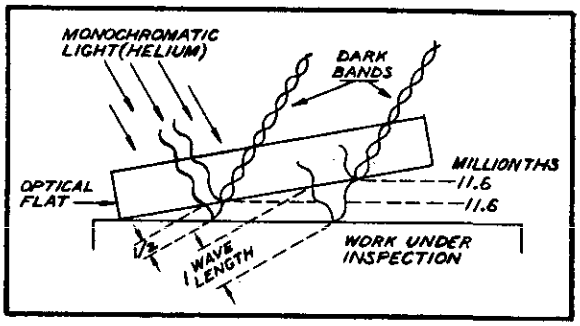


FIGURE 68. *Production of interference bands.*

5.9.1 *PRODUCTION OF INTERFERENCE BANDS.* When an optical flat is placed upon a precision finished reflecting surface, it is almost impossible to place it in absolute contact since a thin wedge-shaped air film will always be present. The spacing between the two is in millionths (assuming that the precision surface is not perfectly flat) so this spacing lies in or near the range of the wavelengths of light. Therefore, if light is passed through the flat and reflected partially from the lower surface of the flat and partially from the precision surface, the tilt or displacement between the two can produce the phase shift necessary to cause interference. Referring to figure 68, the dark bands are produced whereever the flat-reflected portions of waves are correctly out of phase with the inspected surface-waves. This occurs whenever the distance between the reflecting surfaces is one-half a wavelength or its multiples. Using sunlight or an ordinary incandescent bulb, the fringes will be colored like small spectra and be rather wide. Therefore, a monochromatic light is generally used. It is a source that produces light of nearly one particular wavelength that is obtained by exciting the gas of a particular element with an electric current (somewhat similarly to an ordinary neon sign light). Helium is used most generally for its combination of low price, purity, and availability. It produces a wavelength of 23.1323 microinches and has a greenish yellow color with good sharpness of the bands. Krypton, Sodium, Cadmium and Mercury are also used as monochromatic sources.

5.9.2 *INTERPRETATION OF INTERFERENCE BANDS.* When the flat is placed in contact with the work, bands immediately appear. They may assume many varied patterns, depending upon the surface properties of the work. If the work is nearly flat, the bands will be straight and parallel. If the work surface is uneven, the bands will show it by assuming the role of contour lines just like those on maps. First, the reference point or point of contact between flat and work must be established. This is done by pressing down on the flat at a point directly above an edge that runs parallel to the general direction of the bands. If they remain the same distance apart, this edge contacts the flat. If they tend to spread apart, the opposite edge is in contact. If they appear to be spaced irregularly, then the point of contact lies within the surface somewhere. Since each band represents ½ wavelength of light, and if helium light is used, each band then represents 11.6 millionths of an inch distance of the flat from the work, so that 3 bands equal 35 millionths and so on.

5.9.3 *DETERMINATION OF FLATNESS.* The bands and their relative arrangement can be used to assess the flatness of a surface. Since each band is representative of a fixed distance from the optical flat to the test surface, if the surface is not flat the lines will tend to outline its irregularities in the manner of contour lines on a map. For example, if a surface is faintly spherical, the bands would be a series of concentric circles around the point of contact with each successive circle a little closer to the one inside it. If the surface was faintly cylindrical, a series of arcs would appear. If a true cylinder, the arcs would be equally spaced, but if it were uneven, the arcs would be spaced unevenly. Finally, a warped surface would give an effect such as figure 69. To utilize this effect, the point of contact is first located as mentioned in 5.9.2. Now, remembering that the optical flat is flat within one or two millionths across its diameter and the foregoing discussion of contours, the accuracy of the test surface may be assessed. It is most easily done by visualizing an imaginary scale on the image of the bands with the zero point at the point of contact between flat and work. The scale should consist of equally spaced divisions which in nearly all cases should be equal to the distance from the point of contact to the first band. If it is difficult to visualize, a small layout can be made to place on the flat as an aid in estimating spacing. If the scale divisions are fairly wide, they should be mentally sub-divided into tenths for convenience. If the surface was flat, the bands and scale divisions would coincide and also there would be relatively few bands. If the surface is irregular, there will be many more bands irregularly spaced. The bands will be close together on slopes and further apart on level or nearly level spots or at points of contact. See figure 70. If it is difficult to pick out the actual deviation (too many lines), transferring the point of contact to the adjacent side of the piece will give a different pattern to be evaluated. It may have fewer lines and thus be more easily interpreted.

5.9.4 *MEASUREMENT OF HEIGHT.* Height may be measured by interferometry in two ways, either by comparison with a known height, or by direct measurement.

5.9.4.1 *Measurement Height by Comparison.* In this method, a precision height standard of known size such as a gage block, which is very close to the size of the height to be determined, is compared with the piece to be measured by placing an optical flat on both surfaces. The tilt or angle assumed by the flat due to the height difference can be measured by counting the bands on the lower block.

5.9.4.2 *Absolute Interferometry.* Absolute interferometry is a method of measuring the length of gage blocks directly using wavelengths of monochromatic light as natural and invariable units of length. This is accomplished in two ways. The first and original method is to produce bands on the inspected surface, then raise the platen until it is at the same level, and count the bands in between.

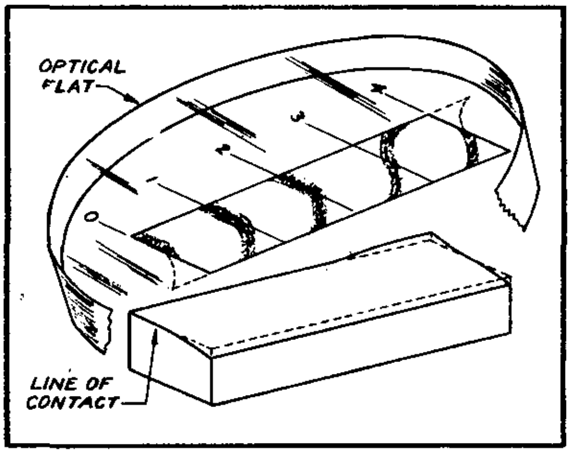


FIGURE 69. *Determination of flatness.*

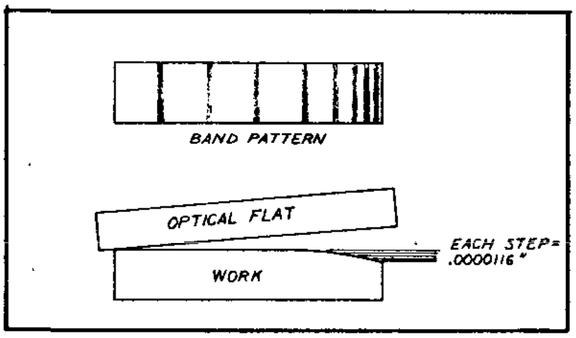


FIGURE 70. *Band spacing.*

This can be accomplished visually or automatically by an electric eye scanning device in the so-called fringe-count interferometer. The second method utilizes a dispersion prism to resolve the light from a cadmium discharge tube into monochromatic radiations of several different colors (usually red, green, and blue), the wavelength of each being precisely known. Two groups of fringes from each color in turn are seen when the rays are directed at the gage block and the base plate to which the gage block is wrung. The length of the gage block is equal to a specific number of half wavelengths plus the fractional displacement between the two groups of fringes. The amount of displacement is read from internally located optical micrometers. This is repeated for each color, and from the measurement of these fractional displacements it is possible, by a method known as coincidence, to determine the error of the gage block from its nominal length. A special slide rule is used to assist in this computation. Finally, corrections must be made for temperature, humidity, and barometric pressure.

CHAPTER 6. NON-DESTRUCTIVE TESTING

6.1 INTRODUCTION. Non-destructive testing is an important part of the Acceptance Inspection Equipment Program. Even though a part may be dimensionally acceptable, it may have surface cracks that are invisible to the naked eye or sub-surface defects such as blow-holes or segregations. These flaws, whether surface or sub-surface, may cause the part to fail in service when placed under a normal operating load. It is the object of non-destructive testing to discover these flaws in the most economical manner without damage to the part in any way. Non-destructive tests are specific. Generally, they reveal only the specific kinds of defects and conditions for whose detection they were designed. Consequently, they must be selected in accordance with the specific material conditions and the job to be done.

6.1.1 *PROBING MEDIUMS.* Most non-destructive tests depend upon a probing medium for the detection and transmission of information about the object under test. This medium is supplied by an external source such as x-ray tube, magnetizing coil, or ultrasonic transducer. The probing medium may be distributed throughout the test object (broad x-ray beam), or it may be concentrated into a narrow beam (ultrasonic testing). The depth of penetration of probes varies greatly. X-rays may pass through several inches of steel, while ultrasonic waves have detected discontinuities through as much as 50 feet of steel or 300 feet of concrete.

6.2 LIQUID PENETRANTS. Liquid penetrants is one of the oldest methods of non-destructive testing. Because the method relies on a penetrant seeping into a discontinuity, it is obvious that it is applicable only to surface defects or subsurface defects with surface openings. It is applicable to all materials, magnetic and non-magnetic, ferrous and non-ferrous, except those materials that are of a porous nature.

6.2.1 *BASIC PROCESS.* Basically, it is a very simple process. First, a liquid dye penetrant is applied to the surface of a part. It is then permitted to remain on the surface for a period of time, during which it penetrates into any defects open to the surface. After the penetrating period, the excess penetrant is removed. Then a developer is applied to the surface, which acts as a blotter and draws out a portion of the penetrant from the defects, causing indications to be formed which are much wider than the defects with which they are associated. The inspector then views the part and looks for these colored indications against the background of the developer. See figure 71.

6.2.2 *VARIATIONS.* There are several variations to this basic process:

(a) The dye penetrant may be applied to the part by dipping, spraying or brushing.

(b) The penetrant may be a brilliant, fluorescent dye. If this type of dye is used, the part is inspected in a darkened area under "black" or ultraviolet light. Any cracks or defects show up as a brilliant yellow-green fluorescence.

(c) The penetrant may be water-washable, excess penetrant being removed by a coarse water spray, or the penetrant may be post-emulsifiable, in which case an emulsifier is applied to the part after the penetrating period. After a short time, the penetrant may be removed by a water spray. The post-emulsification process is more sensitive in detecting very fine cracks.

(d) The developer, which is a light-colored, powdered material, may be applied dry by dusting or blowing it on the part, or it may be applied as a solution by dipping, brushing or spraying.

(e) Inspection of the part is accomplished by viewing the part for color-contrasting indications against the background surface if a visible dye penetrant is used, or by viewing the part under "black" or ultraviolet light in a darkened area, if a fluorescent dye penetrant is used. When using "black" light, the inspector should become accustomed to the darkened area before looking for indications and should avoid going from dark to light and back without allowing time for his eyes to become dark-adapted. Sometimes an inspector experiences a cloudiness of vision; this is caused by the liquid in the eyeball fluorescing under the "black" light. It is annoying, but harmless.

6.2.3 *PORTABILITY.* Dye penetrant inspection facilities are available in portable kit form for on-the-spot or field inspection in both visible and fluorescent dye types.

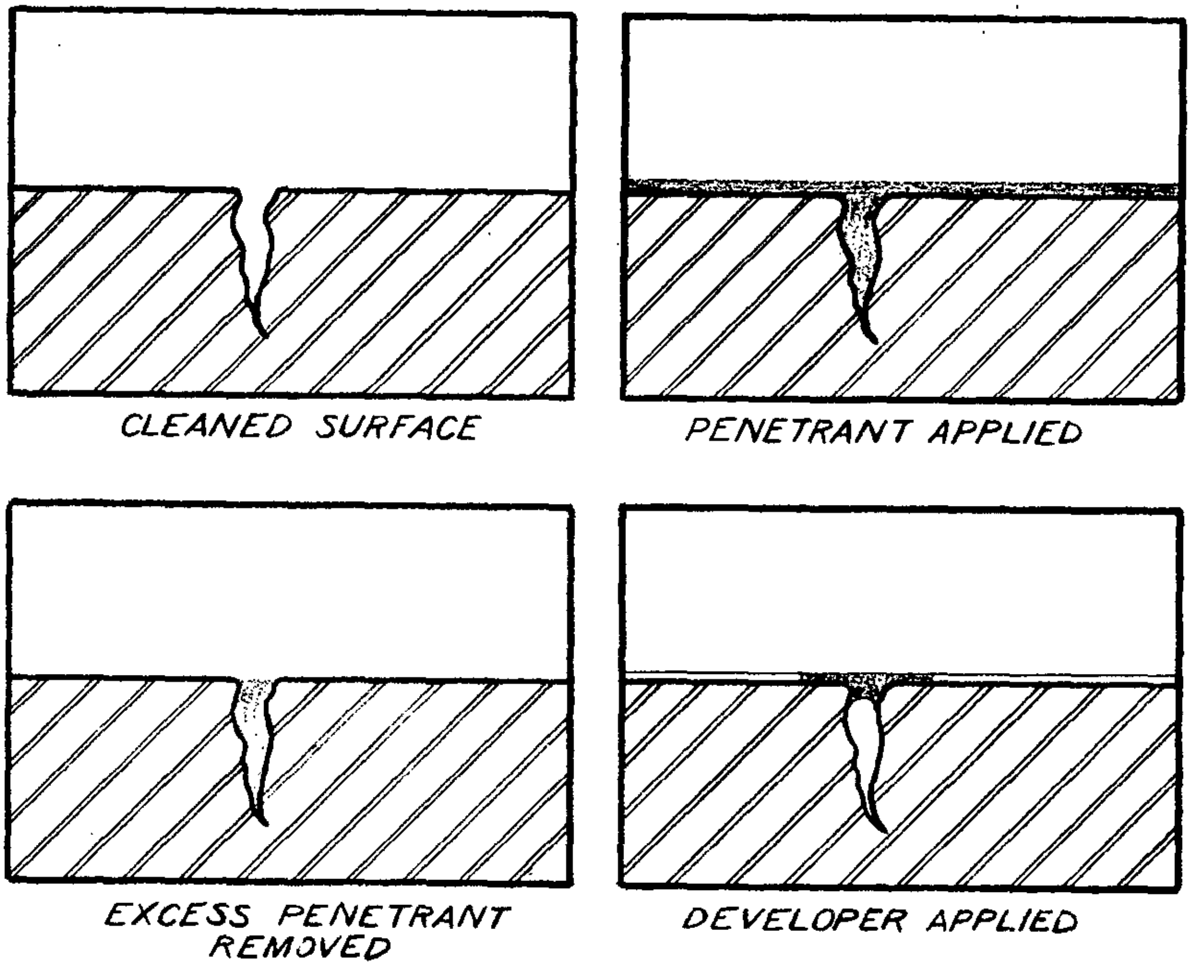
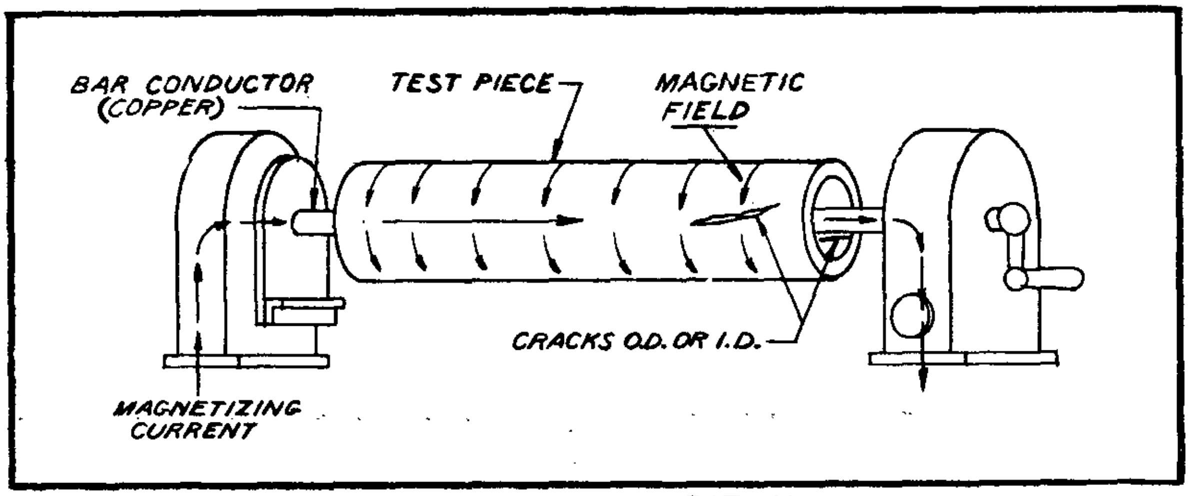
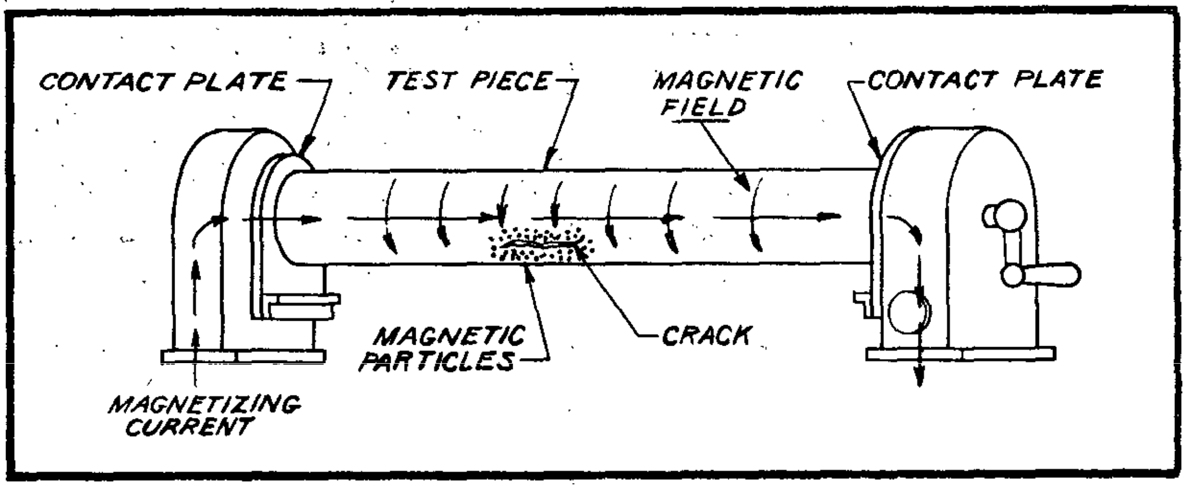


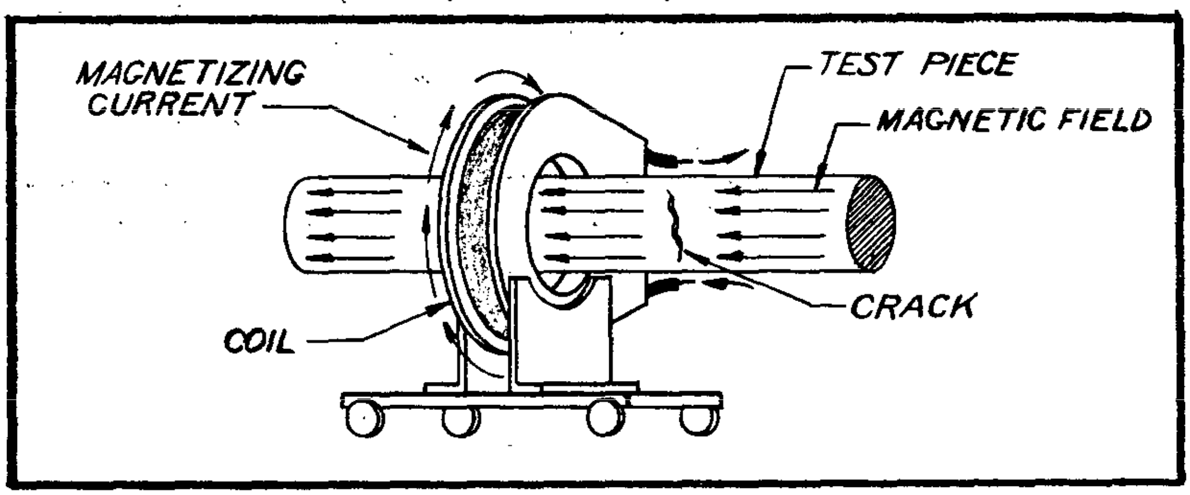
FIGURE 71. *Liquid penetrant flaw detection.*



CIRCULAR MAGNETIZATION.
(HOLLOW PARTS)



CIRCULAR MAGNETIZATION.
(SOLID PARTS)



LONGITUDINAL MAGNETIZATION

FIGURE 72. *Magnetization with electric current.*

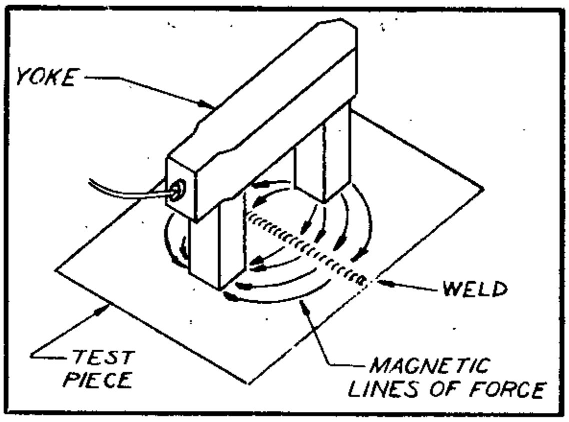


FIGURE 73. *Yoke magnetization.*

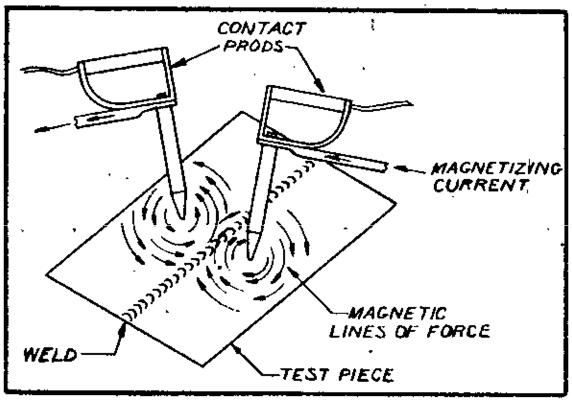


FIGURE 74. *Prod magnetization.*

6.3 MAGNETIC PARTICLE TESTING. Magnetic Particle Testing is used extensively for the detection of surface discontinuities of ferro-magnetic materials and, under certain conditions, those which lie under but close to the surface.

6.3.1 *BASIC PRINCIPLE.* The process is based upon the difference in the ability to conduct magnetic lines of force (magnetic permeability), between a sound piece of steel and one with a discontinuity. When magnetic lines of force are present in a ferro-magnetic material, any cracks, flaws, or other areas of low permeability set up a resistance to their passage. The force lines spread out in order to detour this area. Immediately after passing this area, the distorted lines of force tend to resume their normal flow. When this low permeability area is on or near the surface and the flux density is sufficient, many of the distorted lines of force will leave the material and enter the surrounding atmosphere in order to "bridge" the area. Where these force lines leave and re-enter the material, external magnetic poles are produced on the surface which will attract and hold finely powdered magnetic particles. The particles will generally conform to the shape of the discontinuity, thereby creating a visible indication. A crack at right angles to the lines of force, interrupts the most force lines, giving an indication of maximum size.

6.3.2 *MAGNETIZATION.* Electric currents are used to induce magnetic fields in the material. The method of application of these currents will determine the direction of the lines of force so that they are at right angles to the anticipated discontinuities. Current passing through an object longitudinally will create *circular* lines of force, revealing any *longitudinal* cracks. When an object is placed in a current-carrying coil, longitudinal lines of force are created, revealing any transverse cracks. Alternating or direct current may be used in these tests. See figure 72.

6.3.3 *METHOD OF APPLICATION.* There are two methods of applying the magnetic particles to a properly magnetized part, a "wet" and a "dry" method. In the wet method, the particles are suspended in a liquid such as kerosene or a light clear oil, and flowed or sprayed on the surface to be inspected. In this method, the particles are in contact with the entire surface of the part and it is recommended only for machined surfaces. In the "dry" method, the particles are applied by spray bulb or shaker into the still air adjacent to the part and allowing them to settle evenly on the surface. This method may be used on machined and unmachined surfaces. Particles for both the "wet" and "dry" method are available in black or red for good color contrast with the part being inspected. They are also available as fluorescent particles for viewing under a "Black" or ultraviolet light for maximum visibility. The "wet" fluorescent particle method is generally the faster and more sensitive method.

6.3.4 *CONTINUOUS AND RESIDUAL METHOD.* When the particles are applied to the part while the magnetizing current is flowing, the technique is known as the "continuous" method. When the residual field left in the part is high, such as in hardened steel parts, the particles may be applied after the current has stopped. This is known as the "residual" method and is not as sensitive as the "continuous" method.

6.3.5 *PORTABILITY.* Magnetic particle testing units are available in portable kit form for in-service or field testing in both visible and fluorescent types with a variety of magnetizing sources such as prods, cables, yokes, etc. See figures 73 and 74.

6.4 PENETRATING RADIATION TESTS. The ability of x-rays and gamma rays to penetrate solid substances and convey information concerning their internal structure is utilized in non-destructive testing of materials.

6.4.1 *FILM RADIOGRAPHY.* Film radiography is a process in which the passage of x-rays or gamma rays through a test object produces a photographic record on film.

6.4.1.1 *Basic Principle.* The rays emanate in straight lines from the source, which may be an x-ray tube or a radioactive isotope, to the test object. The test object will absorb some of these rays and transmit some. The amount of absorption for a given material is dependent upon the type of material and its thickness in the direction of travel of the rays, and can be precisely calculated.

6.4.1.2 *Film Interpretation.* For example, if the object is a steel casting having a void formed by a gas bubble, a higher percentage of rays will pass through the section containing the void. The void represents a reduction in the total thickness of the steel to be penetrated; therefore, a *dark* spot corresponding to the projected area of the void will appear on the developed film, resulting in a kind of shadow picture. The darker regions on the film represent the more penetrable parts of the casting and the lighter regions the more opaque. See figure 75.

6.4.1.3 *Advantages.* Film radiography provides a permanent visible record of a metal product, thus permitting its soundness to be further evaluated.

6.4.1.4 *Portability.* Radiographic units are available as permanent installations in a shop or as portable tank units for field work.

6.4.1.5 *Penetrameters.* As an aid in evaluating the sensitivity of the radiographic picture, it is customary to place a standard test piece, called a penetrameter, on the source side of the test object. The usual penetrameter consists of a plaque of metal, radiographically similar to the test object, having holes and a thickness some percentage of the test object (usually 2%). Sensitivity is determined by the visibility of the penetrameter on the finished radiograph.

6.4.2 *FLUOROSCOPY.* Fluoroscopy is the process of examining an object by direct observation of the fluorescence of a screen caused by radiation transmitted through the object.

6.4.2.1 *Comparison with Film Radiography.* The basic difference between fluoroscopy and radiography is that a fluoroscopic image is a positive picture on a screen and the radiograph is a negative transparency. The voids in the material under observation appear as lighter areas on the fluoroscopic screen. The additional quantities of x-rays passing through a void will activate the fluorescent crystals of the screen to a higher degree of brightness.

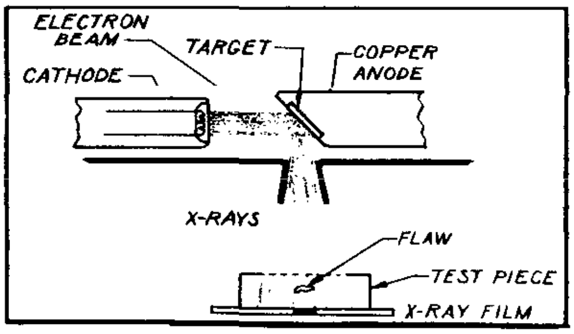


FIGURE 75. *Film radiography—principle of operation.*

6.4.2.2 *Position of Test Object.* The most direct image is obtained when the test object is placed in the x-ray beam between the source and the back side of the fluorescent screen. The image appears on the front side of the screen.

6.4.2.3 *Barriers.* A transparent barrier, opaque to x-rays, is placed in front of the screen to protect the observer. The image is viewed through this transparent barrier, thus permitting observations at close range. This is only one of several arrangements available.

6.4.2.4 *Motion Observation.* One of the greatest advantages of fluoroscopy is the fact that it permits viewing of objects in motion. This allows the observation of the action of switches, the arming of fuzes, etc.

6.4.2.5 *Installation.* Fluoroscopic installations are generally fixed-type installations because of the need for a darkened area to view the screen.

6.4.3 *RADIOISOTOPES.* Gamma rays, emitted from a radioactive source such as radium, can be utilized as a means of measuring the wall thickness of piping, vessels, etc. For the purposes of this discussion on non-destructive testing, wall thickness measurements shall be restrained to those measurements which are taken in an effort to discover unsafe conditions in equipment where the interior is inaccessible.

6.4.3.1 *Basic Principle.* A radioactive source is placed in the vicinity of the part whose wall thickness is to be measured. Penetrating gamma rays, emerging from this source, impinge on the wall and penetrate into it. A portion of the rays pass through the wall; these are disregarded. Another portion is scattered in all directions by the electrons of the atoms which make up the wall. Some of these scattered rays emerge on the same side from which they entered. It is this portion of the radiation, called "back-scattering", which is utilized for measuring wall thickness.

6.4.3.2 *Detection.* The "back-scattered" radiation is picked up by means of a detector and sets off current discharges or pulses which are amplified and registered on a microammeter. The rate at which these pulses are generated is proportional to the intensity of the radiation entering the detector, which in turn is a function of the wall thickness. For a wall of any given composition, the intensity of the back-scattered radiation increases as a direct function of the wall thickness; therefore, the readings obtained on the microammeter are directly indicative of the wall thickness and may be graduated in inches after calibrating on specimens of tubing and plates having known wall thicknesses.

6.5 ULTRASONICS

6.5.1 *GENERAL.* Sound waves, above and beyond those which we hear, are utilized for the detection of internal flaws in a large variety of metals. With ultrasonic inspection it is possible to find flaws in metal parts which cannot be detected by other non-destructive means and to determine the actual flaw geometry, size, and position.

6.5.1.1 *Reflection.* A characteristic of ultrasonic sound vibrations is their ability to be directed in a beam through an object and upon striking the opposing outer wall, are bounced or reflected back as a light beam is reflected from a mirror. This characteristic is known as reflection.

6.5.1.2 *Attenuation.* A second characteristic of sound is its decrease of vibrational intensity as it passes through a conducting medium. The difference in the amount of energy conveyed into the body at one surface and the amount received from it at the opposing surface is the quantity of sound energy absorbed by the body. This decreasing or falling away of energy is known as attenuation.

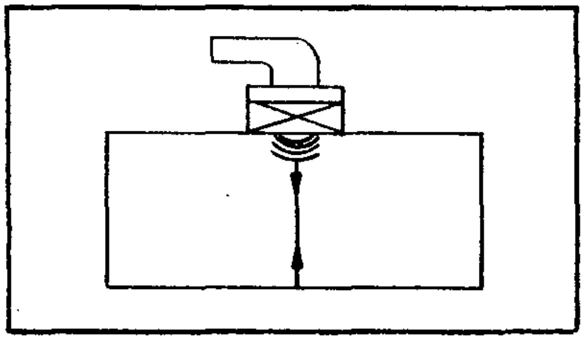


FIGURE 76. *Straight beam search unit.*

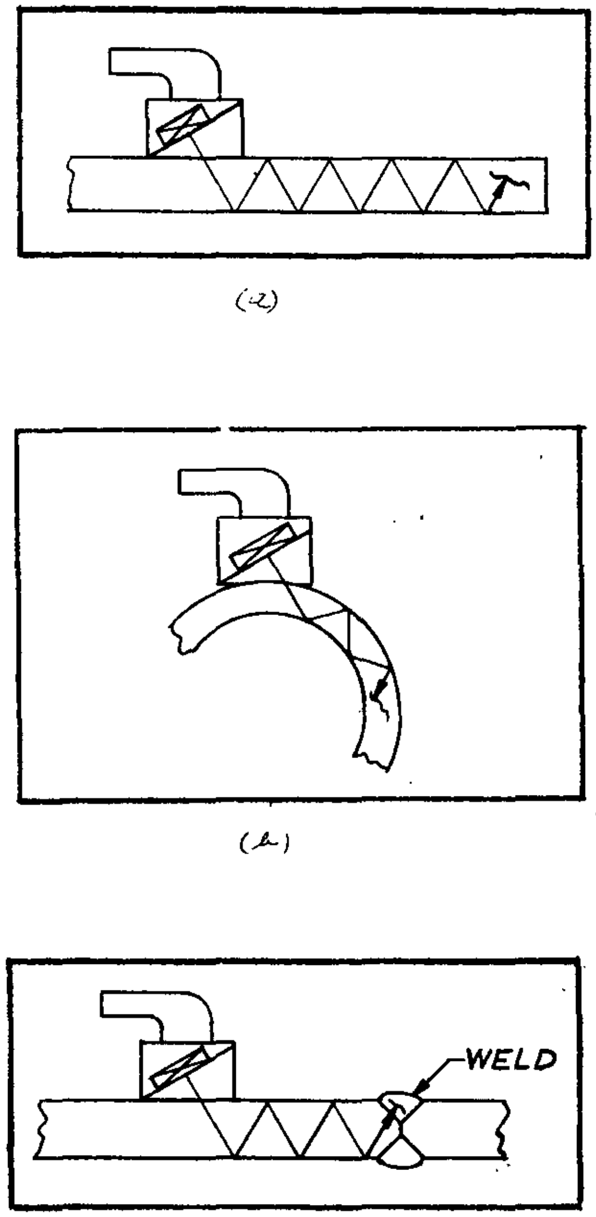


FIGURE 77. *Angle beam search units.*

6.5.1.3 *Harmonics.* A third characteristic of sound, in addition to the "Basic Period", (and under certain conditions) is the occurrence of harmonics, existing as multiples or sub-multiples of the original period which causes the part to vibrate.

6.5.2 *SEARCH UNITS.* Sound vibrations are transmitted into a body by a transducer housed in a suitable holder (search unit). A transducer is a quartz crystal that has the unique faculty of transforming high-frequency, alternating current into high-frequency, mechanical vibrations. This phenomenon is reversible since a varying mechanical pressure will generate a pulsating current whose frequency is directly related to the rate of vibration of the transducer. There are three general types of search units that are employed in the majority of flaw detection.

6.5.2.1 *Straight Beam Search Units.* This type of search unit projects a beam of ultrasonic vibrations perpendicular to the test surface. It can be used for either the reflection (par. 6.5.1.1) or the through transmission (par. 6.5.5) technique. See figure 76.

6.5.2.2 *Angle Beam Search Unit.* This unit is used for testing plate and sheet material, pipe, and for locating flaws which, due to their orientation, cannot be located by the straight beam method. The crystal is mounted on a plastic wedge so that the ultrasonic beam will enter the test material at a specific angle. See figure 77(a), (b), and (c).

6.5.2.2 *Surface Wave Search Unit.* Surface waves are used to scan the surface and a thin layer immediately below the surface. The crystal is mounted similar to the angle beam unit in that it uses a plastic wedge but the wedge angle is such that the ultrasonic beam is refracted at a 90° angle. Figure 78 shows the wave traveling on the surface to a defect, where it is then reflected back to the search unit.

6.5.3 *CONTACT PULSE REFLECTION.* Contact Pulse Reflection utilizes the first characteristic of sound; reflection. The transducer, in direct contact with the test object through a coupling medium (thin coat of light oil), directs a pulsing ultrasonic beam from 25 kilocycles to 10 megacycles per second into the object. These transmitted pulses are timed so that the crystal is energized for an extremely short period, the resulting small groups of waves being sent out at regular intervals. The crystal is at rest for a comparatively long time between pulses, during which time the crystal acts as a receiver for the reflected wave trains from the opposite face or a defect or flaw in between. These reflected waves are then converted into an electrical impulse by the reverse effect of the crystal. The electrical impulse is fed into an amplifier and thence to the plates of a cathode-ray oscilloscope. A line representing the travel of the waves is transposed on the screen of the oscilloscope. When a defect or flaw is present, the wave is reflected from the flaw and consequently returns in a shorter time causing a hump or variation in the tube trace. A distance marker in the form of square waves can be imposed on the screen, permitting the inspector to note the depth of the defect. The inspector merely moves the crystal over the surface of the test object and watches the oscilloscope for any indications. See figure 79.

6.5.4 *IMMERSION PULSE REFLECTION.* This process differs from the contact method in that the test object and the search unit are immersed in a tank containing water or other suitable liquid couplant. The crystal is affixed to the end of a scanning tube that is attached to a movable carriage. The carriage has a longitudinal and transverse movement to permit complete scanning of the test object and may be motorized or manual. This method enjoys certain advantages over the contact method in that objects of irregular shape may be thoroughly tested. See figure 80.

6.5.4.1 *Coupling.* The surfaces do not require any preparation as is sometimes necessary in contact testing to insure good coupling. Another advantage is, that due to the lack of intimate contact between the test object and crystal, the problem of crystal wear is removed. A thinner crystal may be employed, permitting higher frequencies (up to 25 megacycles per second) which will pick up flaws much closer to the surface than the lower frequencies.

6.5.5 *THROUGH TRANSMISSION.* In the Through Transmission method of ultrasonic testing, as shown in figure 81, two transducers are employed, one to transmit and the other to act as a receiver. The process utilizes the second characteristic of sound, that of attenuation. The immersion technique may also be employed in the Through Transmission method.

6.5.5.1 *Flaw Detection.* A continuous, rather than pulsed, ultrasonic beam is sent through the test object by one transducer and is picked up by the receiving transducer as a constant signal registration, except when a flaw is encountered. The energy picked up by the receiving transducer is amplified

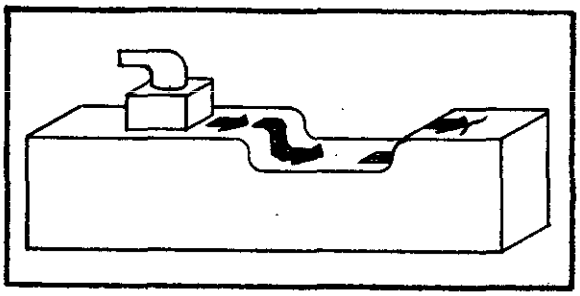


FIGURE 78. *Surface wave search unit.*

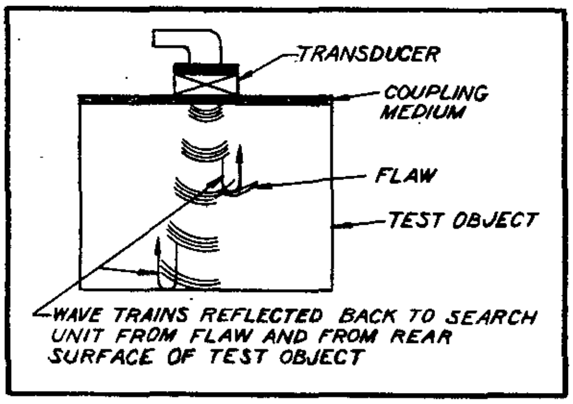


FIGURE 79. *Contact pulse reflection.*

sufficiently to operate a trigger relay tied into any of several indicating, recording, or rejecting devices.

6.5.5.2 *Disadvantages.* The Through Transmission process is not in widespread use, the big disadvantage being that access to both sides of the test object is required.

6.5.6 *RESONANCE.* Ultrasonic Resonance testing utilizes the third characteristic of sound, resonant frequency and harmonics. Continuous, compressional, ultrasonic waves are transmitted by a transducer in direct contact (through a coupling medium) with one face of a test object. The frequency (and therefore the wavelength) of these waves are varied manually or automatically by an oscillator to bring the output to the correct frequency to cause the part to vibrate in resonance. At this frequency, the particles of the material vibrate at their natural period or a harmonic of it and considerably more energy is required than normal to maintain this resonant state of vibration. Because of this characteristic when the resonant period is reached, the output meter shows a marked change in the power required. This point is very sharp and if the oscillator is detuned as little as 1% the indicated amplitude is greatly reduced. See figure 82 for idealized example of resonance.

6.5.6.1 *Flaw Detection with Oscilloscope.* In some systems, a cathode-ray oscilloscope has been incorporated. The oscillating circuit contains a motor driven capacitor which is synchronized with the horizontal sweep of the trace across the cathode-ray tube. Each rotation of the capacitor produces a varing frequency range which is represented on the cathode-ray tube as the horizontal axis. If this frequency range contains resonant frequencies, the trace line will be deflected vertically, producing an indication to the inspector.

6.5.6.2 *Coupling.* While the transducer and part can be immersed, the transducer must always be relatively close to the surface of the test object. It is not practical to couple the energy through a long liquid column, since the instruments would detect and indicate resonant frequencies for the liquid column.

6.5.6.3 *Portability.* Ultrasonic resonance equipment is widely used for non-destructive thickness gaging of in-service equipment subject to corrosion and for the detection of laminar discontinuities. Inherent accuracy, small size, and battery operation have made this equipment particularly suitable for field inspection.

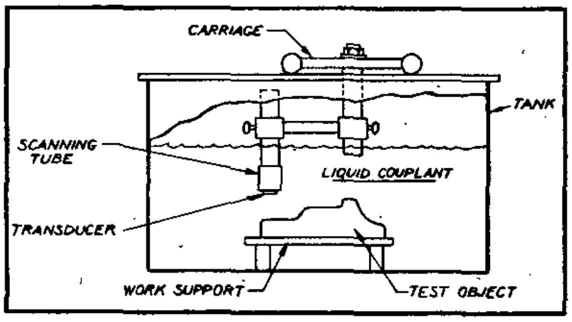


FIGURE 80. *Immersion pulse reflection.*

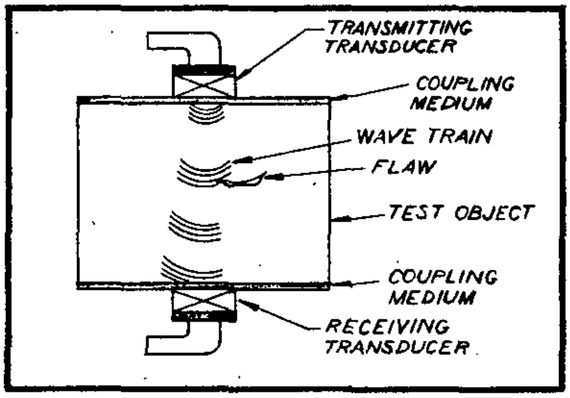


FIGURE 81. *Through transmission.*

6.6 ELECTRO-MAGNETIC TESTS.

6.6.1 *DIRECT CURRENT CONDUCTION.* There are two techniques that employ the passage of a direct current through the test object:

a. The direct current test method can be used for wall thickness measurements from one side only, but its greatest field of application is for depth measurement of cracks that are previously delineated by visual observation, magnetic particle, or dye penetrant techniques. In this process, four pointed, spring-loaded, hardened steel electrodes mounted in an insulating head, are placed in contact with a metal object to be tested. If an electric current, up to 10 amperes, is caused to flow between two of the electrodes, a potential (volts) will be produced in the other two electrodes. In a fixed electrode arrangement and with like materials, a change in the resistivity of the material (such as that caused by a crack or variation in wall thickness) will cause a change in the proportions of current and potential and will be registered on a moving coil galvanometer, these proportions having previously been set up by a calibration specimen. The surface of the test object needs only adequate preparation to insure good electrical contact.

b. In the other method, a heavy current of low voltage is passed through an object to be tested. This sets up magnetic lines of force that are perpendicular to and concentric with the test object. Any defect or flaw in the test object will reduce the cross-sectional area by an amount that is equal to the transverse area of that defect. The current flow will be deflected by the flaw, thereby causing a proportionate deflection of the magnetic lines of force; see figures 83 and 84. If a coil is moved through this magnetic field at a constant speed, parallel to the axis of the test object, a voltage will be induced in the coil where it cuts a decreasing number of lines of force. This will occur at the depressed magnetic field surrounding the defect. This voltage may be noted on a meter or it may be amplified to actuate a marking mechanism.

6.6.2 *EDDY CURRENTS.* In an eddy current (or electro-magnetic induction) test, the metal test object is inserted in the varying magnetic field of a coil, carrying an alternating current. The test object constitutes the core of this coil and is the recipient of eddy currents induced by the AC magnetic field of the coil. These eddy currents, in turn, produce an additional AC magnetic field in the vicinity of the test object, which is superimposed on the original magnetic field of the coil, causing a variation or modification of the original magnetic field of the coil.

6.6.2.1 *Flaw Indications.* The coil is part of a tuned circuit and these variations produce power losses in the circuit which are measurable and are used in various ways to give indications on a cathode-ray tube. Indications are obtained without electrical contact in as short a time as 1/1000 second, thereby permitting the establishment of high speed, automatic inspection procedures. Eddy current methods of non-destructive testing are among the fastest tests available.

6.6.2.2 *Coil Shapes.* Coil shapes include: Solenoid or feed-through coils, inside coils, hand-probe coils, fork-shaped coils, and specially shaped coils for specific test objects.

6.6.2.3 *Applications.* Eddy current tests may be used on a variety of ferrous and non-ferrous parts of many forms. It is one of the most versatile of the non-destructive tests. Some of the physical properties tested by this method include: Electrical conductivity, Cracks, Hardness, Depth of case, Plating thickness, Diameter, etc.

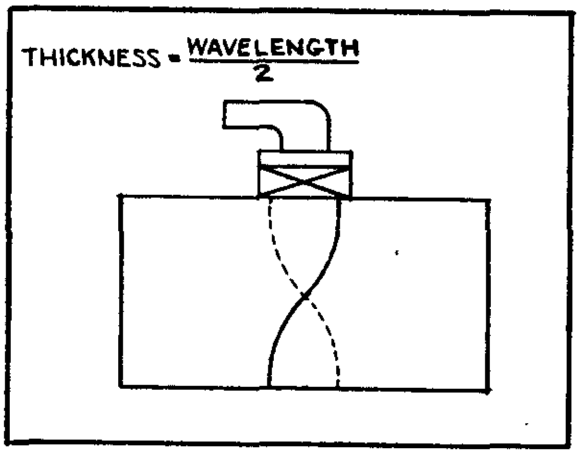


FIGURE 82. *Resonance.*

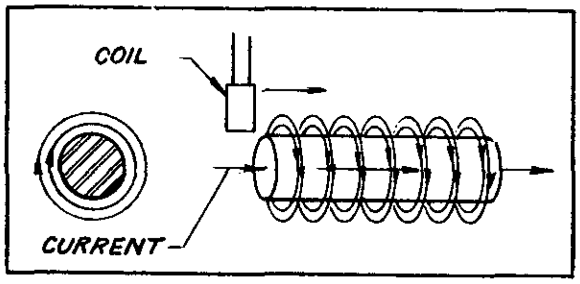


FIGURE 83. *Magnetic lines of force around a sound test piece.*

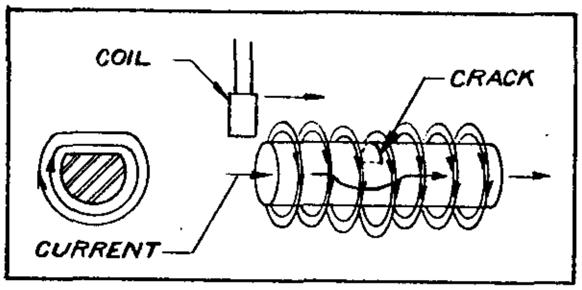


FIGURE 84. *Depressed lines of force due to a flaw.*

6.6.2.4 The coil method is only one of several variations of eddy current, testing, many different type instruments being available for whatever type of test desired.

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☐ VENDOR

☐ USER

☐ MANUFACTURER

☐ OTHER *(Specify)*: ______

b. ADDRESS *(Street, City, State, ZIP Code)*

5. PROBLEM AREAS

a. Paragraph Number and Wording:

b. Recommended Wording:

c. Reason/Rationale for Recommendation:

6. REMARKS

7a. NAME OF SUBMITTER *(Last, First, MI)* – Optional

b. WORK TELEPHONE NUMBER *(Include Area Code)* – Optional

c. MAILING ADDRESS *(Street, City, State, ZIP Code)* – Optional

8. DATE OF SUBMISSION *(YYMMDD)*

DD FORM 1426, 82 MAR

PREVIOUS EDITION IS OBSOLETE.