NOT MEASUREMENT SENSITIVE

MIL-HDBK-728/4A
28 December 1993
SUPERSEDING
MIL-HDBK-728/4
16 December 1985

MILITARY HANDBOOK

MIL-HDBK-728/4A

MAGNETIC PARTICLE TESTING

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

NO DELIVERABLE DATA REQUIRED BY THIS DOCUMENT

AMSC N/A
AREA NDTI

DISTRIBUTION STATEMENT A Approved for public release; distribution unlimited.

CONTENTS

CONTENTS

CONTENTS

CONTENTS

1. SCOPE

* 1.1 General. This document is intended to provide information on the use of magnetic particle testing and inspection both broad and specific applications. The use of this handbook requires MIL-HDBK-728/1, on Nondestructive Testing, to provide introductory material for the general subject, and to indicate how magnetic particle testing and inspection are an integral part of NDT.

It has been updated and is consistent with MIL-STD-1949, on Magnetic Particle Inspection, and agrees on basic principles with ASTM E709 and ASTM E1444, which are Standard Guide and Standard Practice for Magnetic Particle Examination respectively.

2. REFERENCED DOCUMENTS

* 2.1 Government documents.

* 2.1.1 Specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the issue of the Department of Defense Index of Specifications and Standards (DODISS) and supplement thereto, cited in the solicitation.

STANDARDS

MILITARY

MIL-STD-1907	Inspection, Liquid Penetrant and Magnetic Particle Soundness Requirements for Materials, Parts, and Weldments
MIL-STD-1949	Magnetic Particle Inspection

HANDBOOKS

MIL-HDBK-728/1	Nondestructive Testing
MIL-HDBK-728/3	Liquid Penetrant Testing

(Unless otherwise indicated, copies of federal and military specifications, standards, and handbooks are available from the Standardization Documents Order Desk, Bldg. 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.)

* 2.2 Other publications.

* 2.2.1 Non-Government publications. The following documents form a part of this specification to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted are those listed in the issue of the DODISS cited in the solicitation. Unless otherwise specified, the issues of documents not listed in the DODISS are the issues of the documents cited in the solicitation.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM E125	Standard Reference Photographs for Magnetic Particle Indications on Ferrous Castings
ASTM E1316 (Section G)	Standard Terminology for Nondestructive Examinations - Magnetic Particle Examination
ASTM E709	Standard Guide for Magnetic Particle Examination
ASTM E1444	Standard Practice for Magnetic Particle Examination

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.)

* 2.2.2 Technical references and articles. General technical references for information purposes and for elaboration of background material in theory and usage practice for this handbook are listed at the end of this handbook, as REFERENCES.

3. DEFINITIONS

* 3.1 Definitions. Definitions given herein shall be as specified in ASTM E1316 (Section G), "Standard Terminology for Nondestructive Examinations - Magnetic Particle Examination" (1991b)

4. SAFETY NOTICE

* 4.1 General. Magnetic particle testing involves the use of magnetic fields usually produced by electrical currents. The use of electrical currents requires that standard safety practices associated with electrical equipment be observed. The magnetic forces established can impart motion to loose parts which can result in pinched fingers or other harm to personnel or damage to the parts.

* 4.2 Chemical The particles and liquids used in magnetic particle inspection are relatively low hazard chemical materials. However, some safe practices associated with the handling of chemical materials must be considered. Detailed information is provided in Paragraph 12.

* 4.3 Black Lights. The black lishts used with fluorescent magnetic particles are long wavelength ultraviolet (UV-A). Exposure to properly filtered black light (UV-A) does not cause an epidermal (erythemal) action or reddening of the skin. There are some safety precautions that should be observed when using high intensity (1,000μW/Sq cm or greater) black lights. These precautions are detailed in Paragraph 12.

5. INTRODUCTION

5.1 General. Magnetic particle testing is used to detect surface and near surface flaws in ferromagnetic (magnetizable) materials. The indications provided by this type of test occur at the surface of the part, directly above the location of the flaws, and the general size, shape, and orientation of the flaws can usually be directly inferred. Magnetic particle testing is used in receiving inspections, in in-process or final inspections, and in in-service inspections. Magnetic particle testing can be used for forgings and castings, for crankshafts and simple plates, for large and small parts and for welding inspections. It is one of the best established nondestructive testing methods used on ferromagnetic materials. MIL-HDBK-728/4 presents the fundamental principles and guidelines associated with magnetic particle testing. This handbook includes descriptions of the basic theory of operation, the equipment and materials used, the advantages and disadvantages of the method, various applications and standards, and guides for specific disciplines. MIL-HDBK-728/1 contains general NDT information that should be studied along with MIL-HDBK-728/4A for a more complete understanding of magnetic particle testing and its comparison with other methods.

6. BASIC PRINCIPLES

6.1 General. Magnetic particle testing requires the induction of a magnetic field into the part to be tested. If the part has discontinuities in its magnetic permeability, singularities in the magnetic field can exist. These field singularities - or leakage fields - can attract and hold small ferromagnetic particles. Therefore, when a magnetic field is established in a part, and small ferromagnetic particles are applied over the surface, some of these particles will collect at leakage field locations thereby forming indications that can be associated with underlying discontinuities. The basic principles associated with magnetic particle testing involve magnetic properties of materials, magnetic fields, and the visual detection of small particles.

6.2 Magnetic fields. There are difficulties in studying magnetic fields because historically there have been a large number of magnetic units and concepts utilized. There are some systems that establish relationships with the strength of the magnetic sources in terms of magnetic moments, ampere-turns per meter, or in fictitious magnetic monopoles - all of which are usually constants for any one problem. Then there is the magnetic field intensity due to these magnetic sources in terms of the "H" field - which is also a constant for most problems. Then there is the induced magnetic field, B, inside the part, which often is the magnetic field intensity changed into different units, but can also be modified or affected by the presence of "permeable" matter. This type of magnetic field is seldom linear or constant, but varies with several characteristics of these materials.

6.2.1 Relationships among magnetic fields. In most cases in this handbook, equations are given where the B field is directly calculated from various sources. Usually this "bypassing" of H is accomplished by assuming the absence of, or ignoring the effects of, magnetically permeable materials which might be present. Although it is not possible to point out all of the relationships between these magnetic variables in this handbook, some of the more important relationships that are generally applicable to magnetic particle testing are presented.

6.2.2 Sources of magnetic fields. The magnetic fields used in magnetic particle testing are usually created by the flow of current, but permanent magnets can also be used. Figure 1 shows a simple bar magnet with its magnetic field indicated by magnetic flux lines, or lines of force, with direction arrows. All magnets have a north (N) and a south (S) pole, all magnetic flux lines are continuous and form closed loops. The strength of the magnetic field, at any point, can be measured in terms of the number of lines of force per unit area, the area being at right angles to the lines of force at the point being measured. The direction of the flux lines, shown by the arrows, indicates the direction that an infinitely small north (N) monopole (which exists only theoretically) would move if it were placed at that point in the field. (Inside the magnet, these arrows go from S to N; outside the magnet they follow a path which goes from N to S.)

(B)

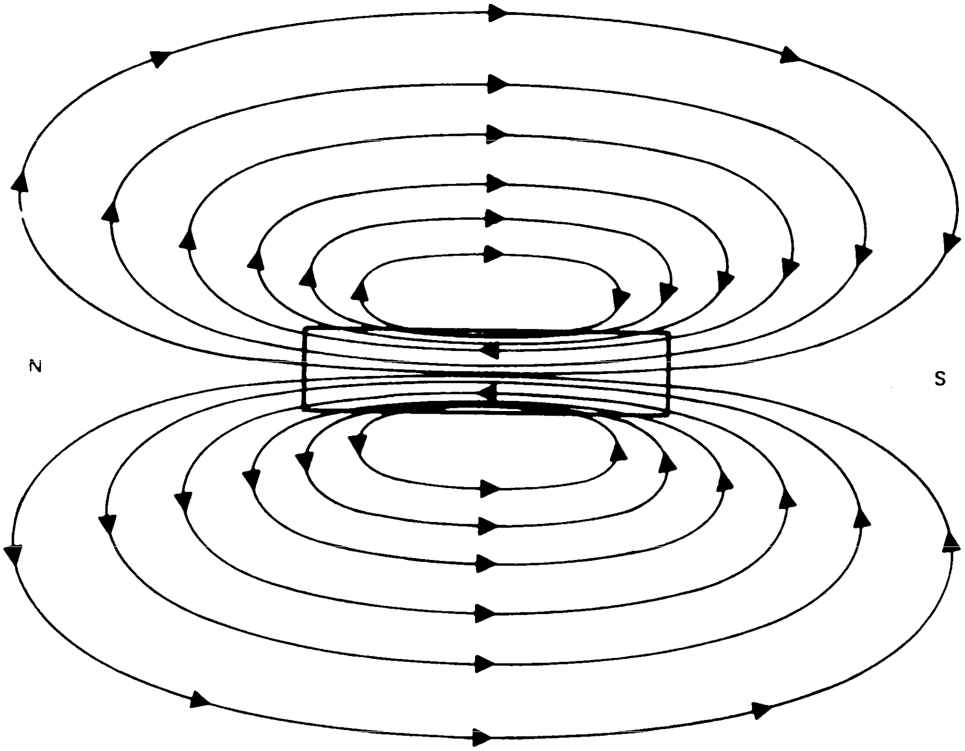
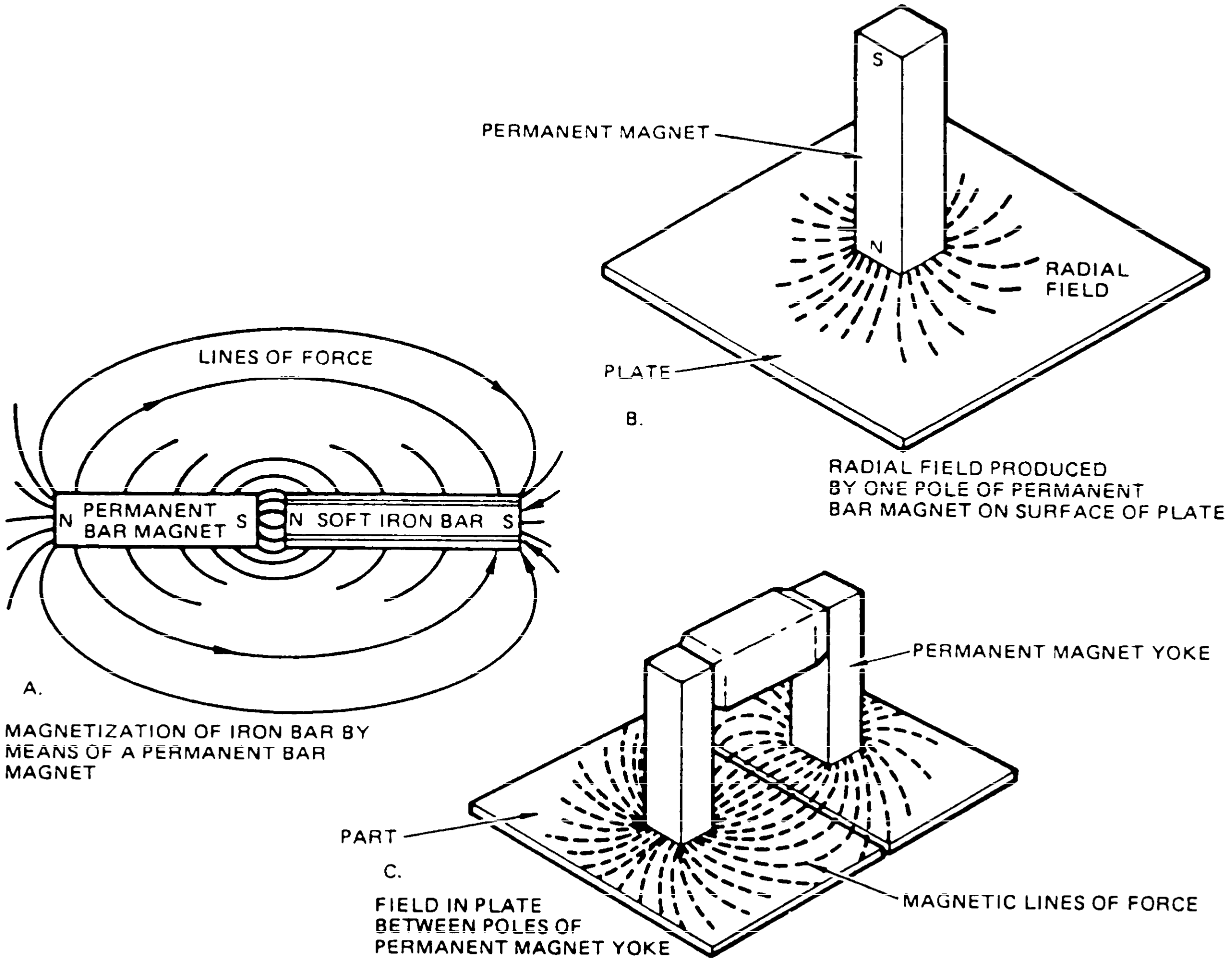


FIGURE 1. Magnetic-induction field around a simple bar magnet.

* 6.2.3 Relationships between sources and fields. Relationships exist between the strength of the magnet (the source), the strength of the field, and the reluctance of the path of the lines of force, that are similar to the relationships between electromotive force (voltage), current, and resistance in electrical circuits. The magnetic relationships, however, are much more difficult to apply because their effects are not confined to discrete paths - they readily extend through empty space - and the total effects are therefore based upon the combined results of an infinite number of parallel paths. Magnetic fields are linearly dependent on currents, but have a tensor dependence on magnetic materials. Also, results are often affected by previous conditions such that all of the conditions are not always directly repeatable; i.e., hysteresis effects are normally involved. Therefore, exact relationships are not easily established by equations, and a nonlinear relationship between sources and the magnetic induction fields invariably exist.

As far as working relationships and effective use for testing are concerned, the most important thing to understand is that the magnetic field is the strongest at the poles (at corners or edges near the poles), and testing is usually enhanced when the magnetic reluctance of the flux paths is reduced by having the magnet in direct contact with the part.



A. MAGNETIZATION OF IRON BAR BY MEANS OF A PERMANENT BAR MAGNET

B. RADIAL FIELD PRODUCED BY ONE POLE OF PERMANENT BAR MAGNET ON SURFACE OF PLATE

C. FIELD IN PLATE BETWEEN POLES OF PERMANENT MAGNET YOKE

FIGURE 2. Permanent magnet magnetization.

* 6.2.4 Consideration of permanent magnets. To facilitate this reduction of the reluctance, permanent magnets used for inspecting are sometimes arranged in a "U" shape so that both poles can touch a flat surface close together at the same time. Figure 2 shows some examples of permanent magnets and their uses. Permanent magnets should not be exposed to mechanical shocks or to high temperatures. They should, when not in use, have a "keeper bar" (usually a soft iron bar) placed between the poles so that the magnetic flux is maintained at a high level.

Permanent magnets are not to be used for magnetic particle inspection unless specifically authorized by the contracting agency. When permanent magnets are used, adequate magnetic field strength shall be established according to guidelines in MIL-STD-1949.

Note that when a magnetic field is being generated or naturally exists, it is "H". When something solid is placed in the magnetic field, then the induction field inside the solid is "B". The magnetic induction field inside the solid is a combination of the original field plus magnetization within the solid.

For iron, the B field inside is much larger than outside this ferromagnetic material. If the bar consists of nonmagnetic material, the magnetic induction field is the same as outside. Reference back to figure 1 clarifies this. Concentration of field lines always indicates field strength.

* 6.2.5 Relationships between electrical currents and magnetic fields. When electrical currents are used to establish magnetic fields, the following relationships are useful: The strength of the induced magnetic field, B, in Wb/m^2 (webers per square meter), around a long, straight conductor carrying a current, I, in amperes, is given by the equation:

*

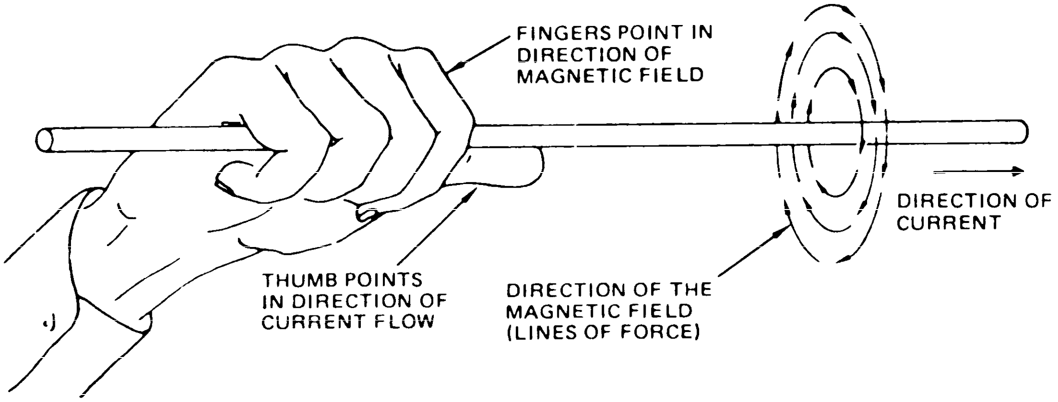
$$B = \frac{\mu_0}{2\pi}\frac{I}{x} = 1/2\pi(4\pi \times 10^{-7})\ \frac{I}{x}\frac{Wb}{m^2} \qquad (1)$$

where

* x = distance from the center of the conductor, in meters

μ_o = magnetic permeability of free space (essentially the same as in air), defined to be $4\pi \times 10^{-7}$ Wb/A·m.

Figure 3 shows that the direction of this field depends upon the direction of current flow, and can be determined by use of the right-hand rule.



* FIGURE 3. Right-hand rule demonstrated on a straight conductor.

The strength of the induced magnetic field, B, at the center of a flat coil of N turns, each carrying I amperes, is:

*

$$B = \frac{1}{2}\mu_o \frac{NI}{r} = 1/2\ (4\pi \times 10^{-7})\ \frac{NI}{r}\frac{Wb}{m^2} \qquad (2)$$

where

r = radius of the coil in meters

Figure 4 shows the field distribution of a flat circular coil. The right-hand rule also applies to this type of coil.

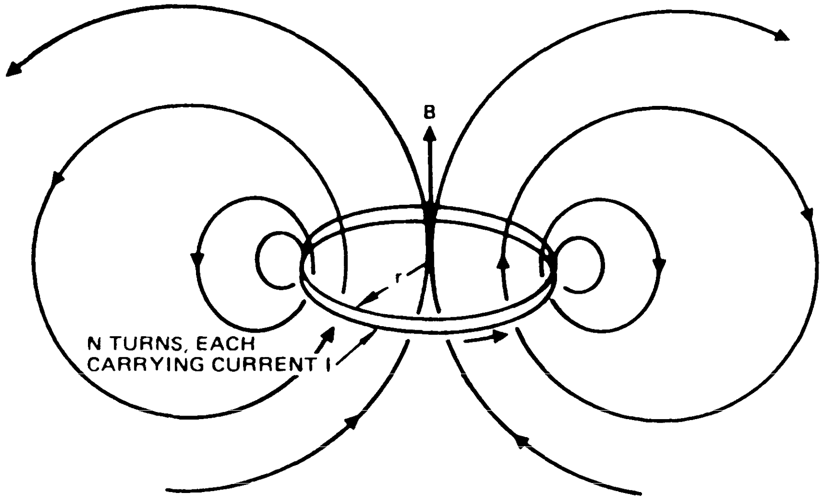


FIGURE 4. Magnetic-induction field at the center of a flat circular coil.

The magnetic-induction field in the central region of a long, straight solenoid is essentially uniform and its strength, B, is equal approximately to:

* $$B = \mu_0 nI = (4\pi \times 10^{-7})\ nI\ \frac{Wb}{m^2} \qquad (3)$$

where

n = number of turns per meter length of coil
I = current, in amperes, flowing in coil

Figure 5 shows the right-hand rule for finding the direction of the field.

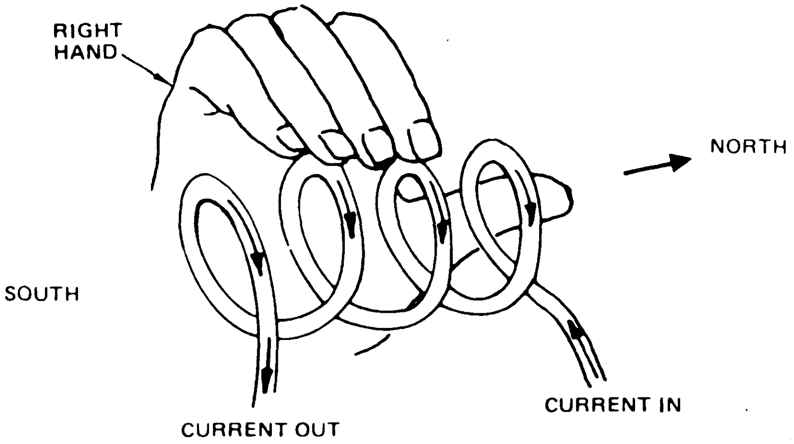


FIGURE 5. Direction of a magnetic field in a coil.

6.2.6 Relationship of field strengths to currents in test specimens. In many practical applications current is sometimes carried directly in the test specimen, which may be either a solid bar, a tube, or a flat plate.

Figures 6 through 9 indicate the magnetic field distribution produced by these common configurations.

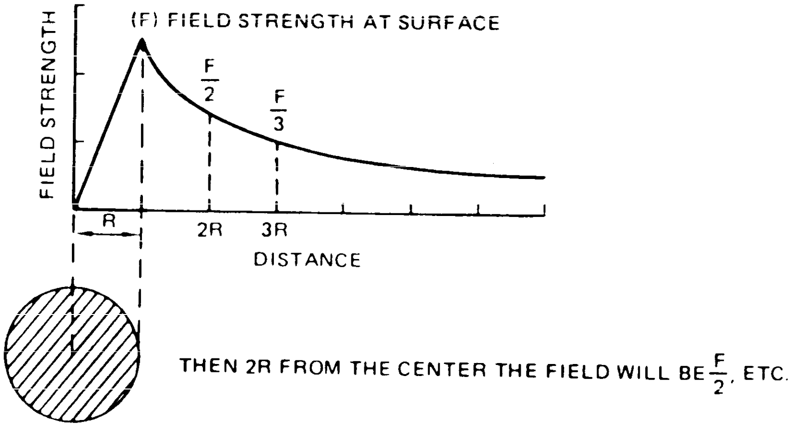


FIGURE 6(a). Field distribution in and around a solid nonmagnetic conductor carrying direct current.

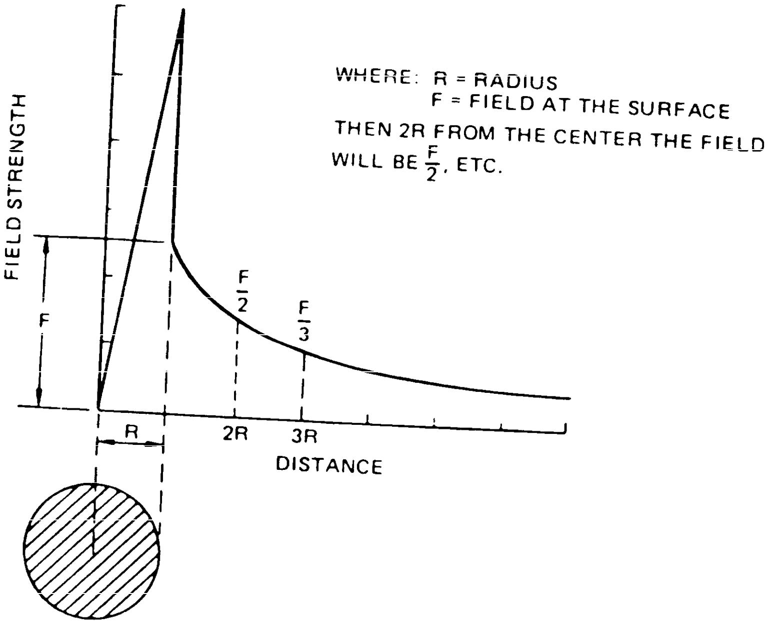


FIGURE 6(b). Field distribution in and around a solid magnetic conductor carrying direct current.

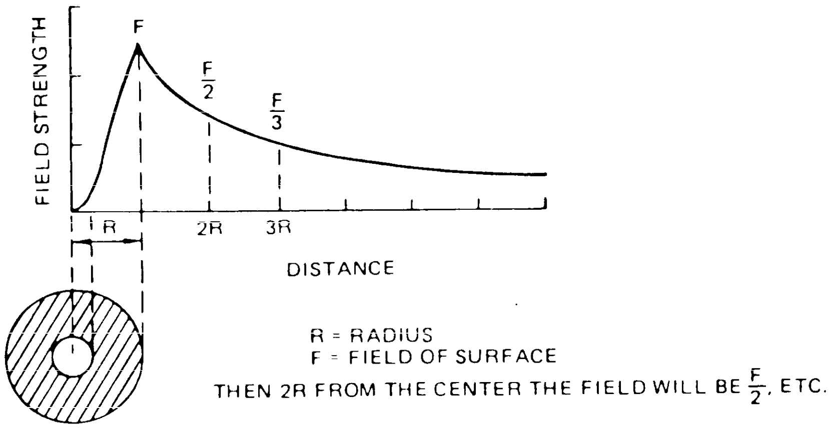


FIGURE 7(a). Field distribution in and around a hollow nonmagnetic conductor carrying direct current.

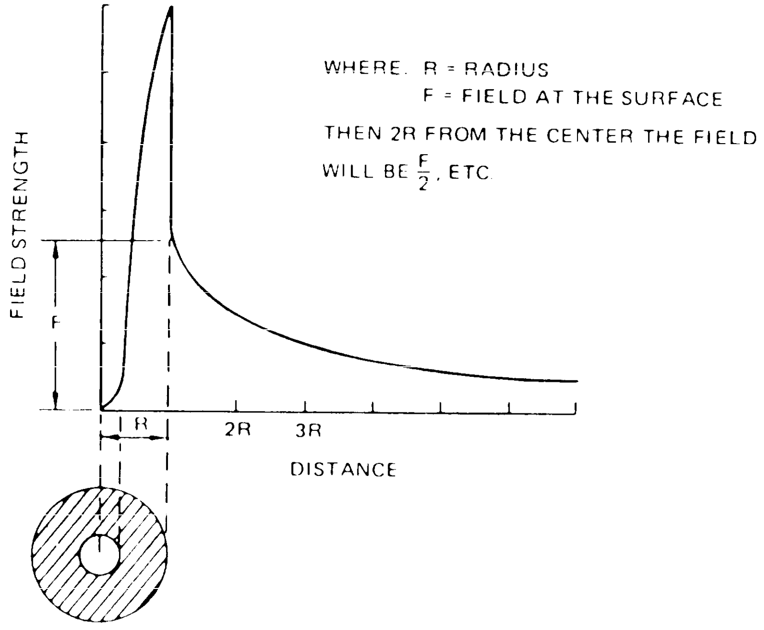


FIGURE 7(b). Field distribution in and around a hollow magnetic conductor carrying direct current.

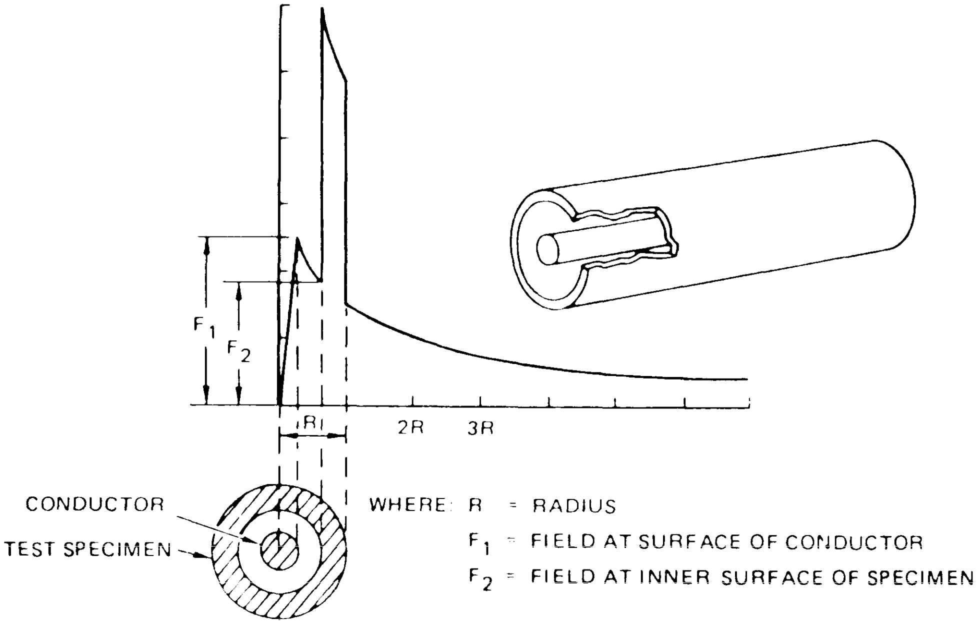
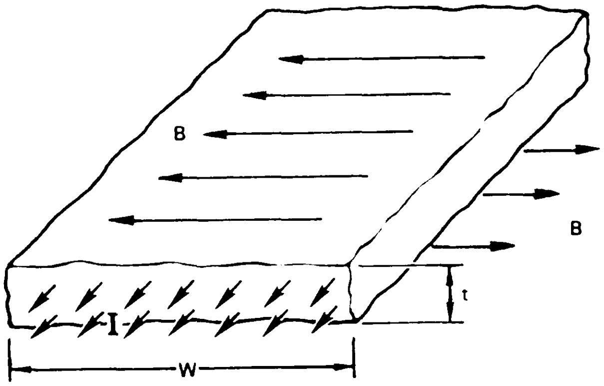


FIGURE 8. Field distribution in and around a hollow magnetic cylinder with central conductor carrying direct current.



A LARGE FLAT SLAB BEARING A UNIFORM DISTRIBUTION OF THE CURRENT ESTABLISHES A UNIFORM MAGNETIC-INDUCTION FIELD OUTSIDE THE MATERIAL. THE MAGNITUDE OF THE FIELD AT THE SURFACE IS: $B = \frac{1}{2}\mu_0 I/W$.

FIGURE 9. Field distribution in and around a large, flat slab.

6.2.7 Relationship of magnetic permeability to magnetic susceptibility. Equation 4 shows the relationship between the magnetically-induced field, B, and the "magnetizing" force field, H.

$$B = \mu H, \tag{4}$$

where

μ = the magnetic permeability

When there are no magnetizing materials present (when we are in free space),

$$\mu = \mu_o. \tag{5}$$

When simple magnetizing materials (that form isotropic fields) are present

$$\mu = \mu_o (1 + X_m), \tag{6}$$

where X_m is the magnetic susceptibility of the material. Its value can range from 0, for completely nonmagnetic materials, to very large values, in the thousands, for highly magnetic materials. Although X_m is not a fixed constant even for any one material, it often has common or limited ranges for most materials that allow it to have some utility.

6.3 Magnetic properties of materials. The main magnetic property of a material is its susceptibility, normally described in terms of its magnetic permeability. Magnetic permeability is qualitatively the "ease of magnetization of the material." In equation form, it is the ratio of the induced magnetic flux density, B, to the magnetizing force field, H, that is present. It is the "μ" in Equation 4 of paragraph 6.2.7. The "relative" magnetic permeability and the "effective" magnetic permeability terms are also used. The relative permeability is the permeability divided by the magnetic permeability of free space, μ_o, as defined previously. Thus, it is dimensionless, and has the same value in all unit systems. It is equal to one plus the susceptibility (see Equation 6 in paragraph 6.2.7). The "effective" permeability is the ratio of the existing B field in a material divided by the B field that is present without the material. These two permeabilities, the "effective" and the "relative," are essentially identical when long, bar materials are placed in the direction of the magnetic field. The effective and relative permeabilities are not the same when short length-to-width material shapes are used. The effective permeability includes the geometric factor that recognizes the effects of the poles established at the end boundaries of the material which can reduce the effects of the original external magnetic force field within the material.

* 6.3.1 Effective permeability of magnetic materials. For a sphere, the reduced field results in an effective permeability around 3, even if the true relative permeability is 1000. This field reduction is referred to as a demagnetization effect and, as can be seen with the sphere, it can be a very sizable effect. It is, therefore, the effective permeability that must be considered for magnetic particle testing. Thus geometry of the part being tested is important along with the actual permeability of the material.

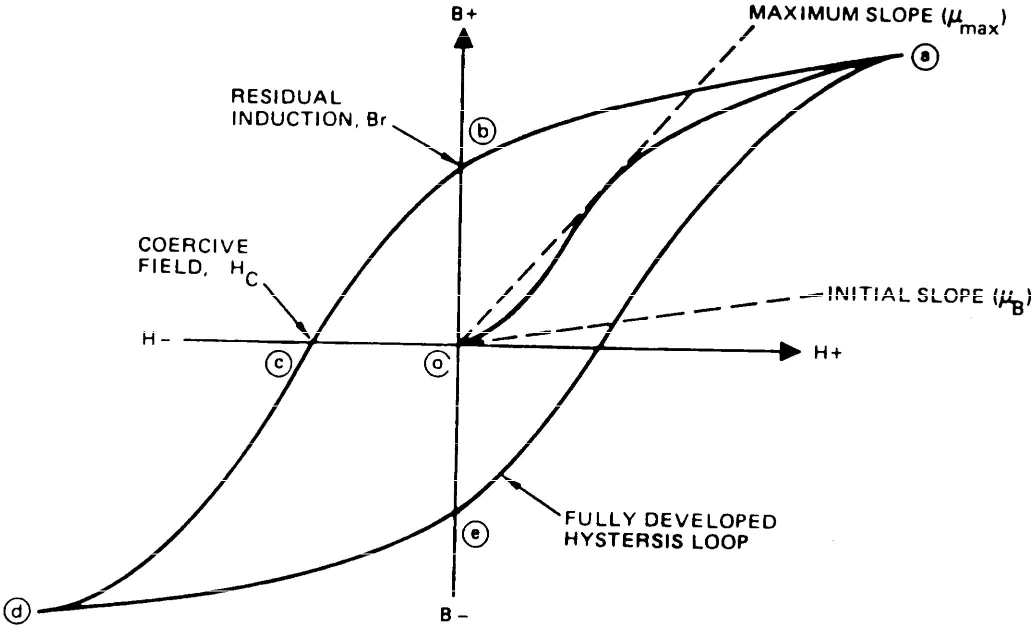


FIGURE 10. A generic hysteresis curve for ferromagnetic materials.

Each material has its own permeability characteristics. These characteristics can be shown on a B versus H curve. Figure 10 shows an example of one of these curves from which various definitions can be obtained. The specimen is completely demagnetized at the starting point (0) of the fig- ure. As the magnetic force, H, is increased, the total flux in the specimen increases until it reaches a point beyond which any additional increase in the magnetizing force does not cause significantly further increases in B. This curve, from 0 to a, is defined as the virgin curve. The virgin curve provides the "maximum permeability" of the material, which is the slope of the line from the zero point to the tangent point on the curve. The point at which significant increases in B cease is known as the "saturation" point. If the magnetizing force is then reduced back to zero, the curve a to b is obtained. The amount of magnetism that the material retains at point b is called residual magnetism. If the magnetizing force is reversed (the current is caused to flow in the opposite direction), the residual magnetism will eventually disappear at point c. The value of "H" at this point represents the "coercive force" for the material, or the magnetizing force required to remove the residual magnetism. As the reversed magnetic force is increased beyond c, the specimen is again saturated as indicated at point d. Returning the magnetizing force back to zero takes the curve to point e. Repeating the start of the cycle for H then takes the curve back up to a where the full hysteresis curve has now been completed. Each material, with its own characteristic curve, exhibits a different amount of saturation, residual magnetism, and coercive force. These variables are all important in magnetic particle testing. The material being tested should be slightly below saturation. If it is too close to saturation, too many field lines will be leaving the surface of the material at arbitrary points, producing false indications. If the material is not near enough to saturation, flux lines, when they meet a discontinuity, can move into the non-saturated middle of the material and not produce visible indications.

If a material shows high residual magnetism, the material can be tested even after it is removed from a magnetic field. Also, demagnetization might be required, and the coercive force will indicate the degree of difficulty in obtaining the demagnetization.

6.4 Small magnetic particles and their visual detection. When a small magnetizable particle (usually with high permeability but low retentivity or low residual magnetism) is placed in a magnetic field, a dipole is formed. That is, opposite magnetic poles, separated by the effective size or length of the particle, are induced on opposite sides of the particle. The strength of these poles multiplied by the effective distance between them (the "size" of the particle) is the magnitude of the dipole moment. Within a magnetic field, dipoles will tend to move in the direction of the field gradient. The force acting on the particle will be proportional to the strength of the gradient and the strength of the dipole moment. Therefore, the strength of the magnetic field (which determines the strength of the induced poles), and the strength of the gradient of the magnetic field are all important. Magnetic gradients, under normal conditions, increase as the poles of a magnet are approached. The shape of the field gradient is determined by the B field, but the direction of the gradient is not necessarily the direction of the lines of force that make up the B field. The lines of force show the direction of orientation that a dipole particle would tend to assume, but the net force acting upon a dipole particle will include components of forces perpendicular to B in most regions of the field. Because gradients are large at the poles, or at points where the magnetic lines of force leave the surface of a magnetic material, small magnetic particles, acting as dipoles, will tend to move and attach themselves to these locations. Because these particles form their own poles, they can hang together end-to-end, and not all collect side-by-side at the same concentrated point. This formation effectively extends the size of the gradient, and can actually amplify the indication to a size several hundred times larger than the actual discontinuity. This allows easy observation of flaws or other anomalies.

6.4.1 Methods for increasing the detectability of indications. Additional enhancement of the observations can be accomplished by several means: a contrasting background can be applied over the inspected part before the test begins, and/or the magnetic particles can be dyed a bright color, or the particles can even be made to be fluorescent. The strengths of these magnetic gradients are not always great; therefore the "mobility" of these small magnetic particles is important. Particle size and shape, the medium in which they are carried, if any, and any mechanical vibration or other inducement to move become important considerations. The material the particles are made of, and their size and shape, also affect the magnetic moment that can be induced. Thus, a wide variety of characteristics can be associated with the magnetic particles used, and the expected visual detection capabilities that can be obtained will depend upon several characteristics of the particles used.

7. EQUIPMENT AND MATERIALS

7.1 General. The equipment and materials required to perform a magnetic particle test can be as simple as a strong permanent magnet and a supply of magnetic particle powders. However, sources of electrical currents, with control over the current magnitudes and directions, magnetic coils and yokes, and tanks for holding magnetic powders, either in dry or wet form, can all be considered as necessary facilities for most magnetic particle testing.

7.2 Commercial equipment for magnetic particle testing. Today there is commercial equipment available for portable, mobile, or stationary systems.

7.2.1 Portable testing units. The portable magnetic-particle testing units are available as hand-portable current sources or as hand-held magnetic yokes. A typical portable magnetic-particle unit (current source) is shown in figure 11. These portable units are generally designed for operating on 110 or 220 Vac and supplying 500 and 1000 amperes. The output voltage will range from 5 to 25V depending upon the current level being supplied. Portable units are especially desirable for inspecting small items and for inspecting in remote areas.

7.2.2 Mobile equipment. Except for added features of demagnetizing circuits, the mobile equipment may be best described as heavy-duty portable equipment on wheels. The electrical circuitry is generally designed to provide heavy currents ranging up to 3000 amperes. Since heavier transformer wires and connectors are required to carry these currents, and cooling fans are

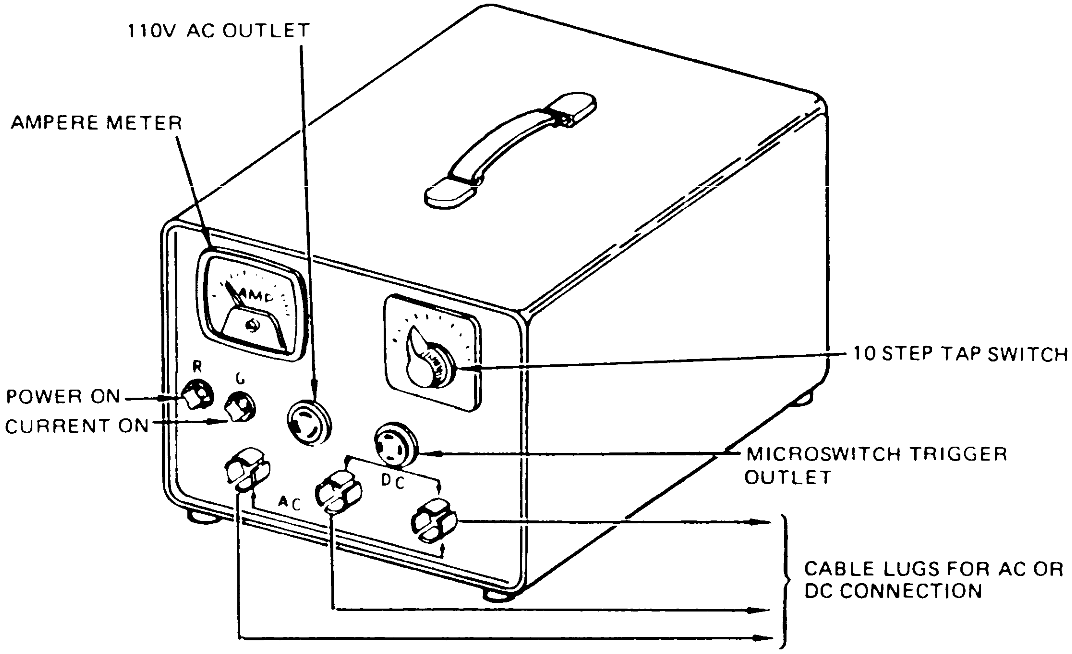
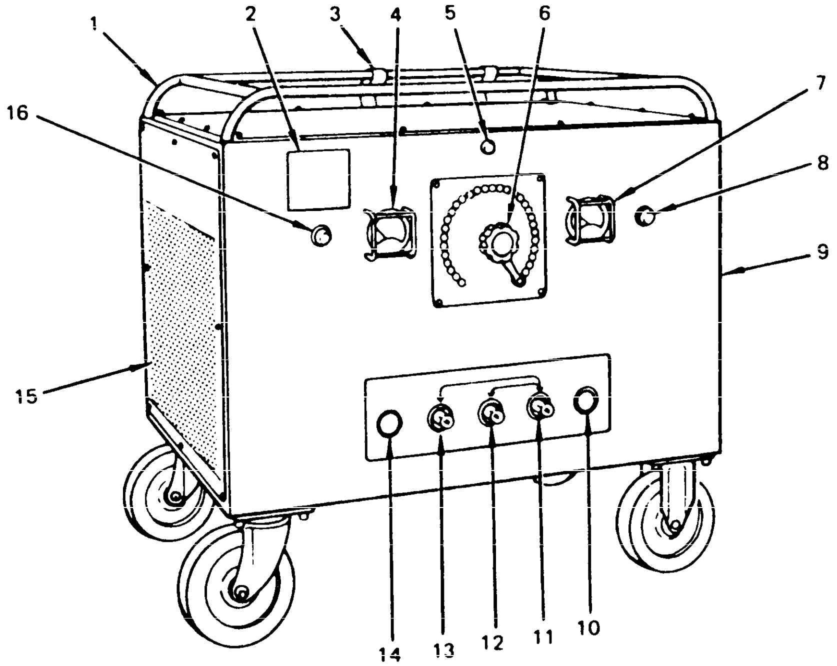


FIGURE 11. Portable magnetic particle current source.

added to aid in cooling, the equipment weight becomes excessive. However, such equipment may still be used effectively in many different locations by rolling on wheels. A typical mobile magnetic particle test unit is shown in figure 12. Selection of ac or half-wave dc is easily changed by switching cables on cable lugs located in front of the unit. Cables ranging from 15 to 30 feet may be further extended by additional lengths to as much as 90 to 100 feet. When extension cables are used, a decrease in current output can be expected. Although prods are usually used with mobile equipment, solenoid or cable wrapping techniques can be used. Also, use of a central conductor hooked up between the two cables facilitates variation in test techniques. Dry magnetic particle powder is most often used with this type of equipment but the wet technique (with an external tank) or materials in kit form can also be used.

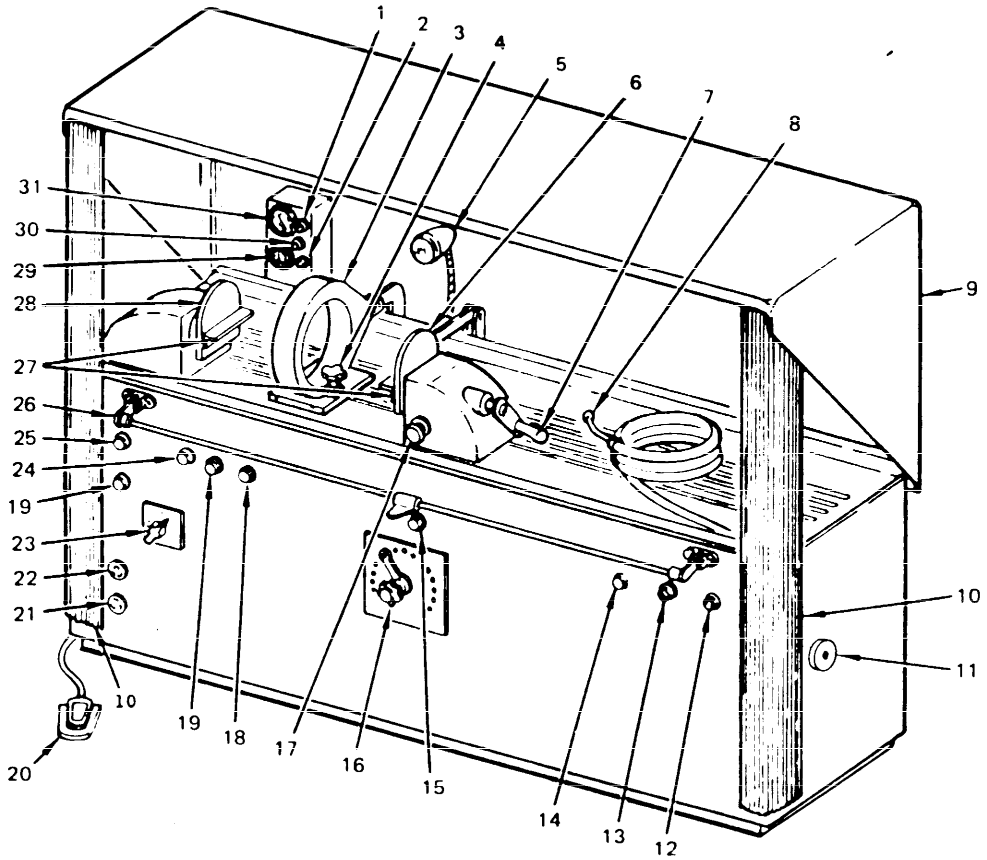


1. CARRYING RACK
2. IDENTIFICATION PLATE
3. CABLE HOOK
4. DC AMMETER (OUTPUT)
5. DEMAGNETIZATION PUSHBUTTON
6. CURRENT VALUE IS SELECTED BY TURNING OF KNOB
7. AC AMMETER (OUTPUT)
8. POWER ON LIGHT (RED)
9. POWER HOOK-UP TO THE TERMINALS IS FACILITATED AND EASILY ACCESSIBLE THROUGH A SMALL DOOR HERE
10. CABLE LEADING TO MICROSWITCH ON THE PROD HANDLE
11. CABLE LUGS (GROUND CABLE)
12. CABLE LUGS
13. CABLE LUGS
14. 110 VOLT AC EXTENSION CABLE
15. COOLING INTAKE
16. CURRENT ON LIGHT (GREEN)

FIGURE 12. Mobile magnetic particle test unit.

REFERENCES

7.2.3 Stationary test equipment. Stationary magnetic particle test equipment may be obtained as either general-purpose or special-purpose inspection units. The general-purpose unit is primarily for use in the wet method, and has a built-in tank that contains the wet-particle bath pump which continually agitates the bath and forces the fluid through hoses onto the test article. In addition, curtains and an ultraviolet light are provided for inspection whenever fluorescent particles are used. A general-purpose stationary unit is shown in figure 13.



1	DC PILOT LIGHT
2	AC PILOT LIGHT
3	COIL
4	COIL LOCKING HANDLE
5	BLACK LIGHT
6	TAILSTOCK CONTACT PLATE
7	TAILSTOCK CRANK HANDLE
8	NOZZLE
9	HOOD
10	CURTAIN
11	FLOW CONTROL VALVE
12	DEMAG CURRENT PILOT LIGHT
13	AC TRANSFER SWITCH
14	MAGNETIZING CURRENT CONTROL
15	30 POINT SWITCH START BUTTON
16	CURRENT REGULATING SWITCH
17	TAILSTOCK LOCKING HANDLE
18	DC TRANSFER SWITCH
19	DC AC SELECTOR SWITCH
20	FOOT SWITCH
21	CONTROL CABLE RECEPTACLE
22	110V AC OUTLET
23	CURRENT CONTROL
24	LINE PILOT LIGHT
25	PUMP SWITCH
26	ACTUATOR
27	HEADSTOCK AND TAILSTOCK LEDGES
28	HEADSTOCK CONTACT PLATE
29	AC AMMETER
30	MAGNETIZING CURRENT PILOT LIGHT
31	DC AMMETER

FIGURE 13. General-purpose stationary magnetic particle test bench.

Special-purpose stationary units are designed for handling and inspecting large quantities of similar items. Generally, conveyors, automatic markers, and alarm systems are included in such units to expedite the handling and disposition of parts.

7.3 Demagnetization equipment. Most common types of demagnetization equipment consist of an open tunnel-like coil through which alternating current at the incoming frequency (usually 60 cycles) is passed (see figure 14). The larger type of equipment is frequently placed on its own stand and incorporates a track or carriage to facilitate moving large and heavy articles. Smaller demagnetization equipment such as table-top units, yokes, or plug-in cable coils, may be feasible for demagnetization of small test items. The large, stationary equipment is preferable when multidimensional test items are involved.

7.4 Accessories. The number of accessories used in magnetic particle testing are extensive. Some are available from the manufacturers of magnetic particle equipment; others are made up for specific purposes. Accessories usually depend on the type and method or application of the test selected. Such accessories are chosen primarily to facilitate and enhance the quality and performance of a given test or test technique. The following list contains frequently used accessories and their applications.

1. Cables - used to carry the current to prod or solenoid.
2. Prods - used for magnetizing of welds, sheet, or plate.

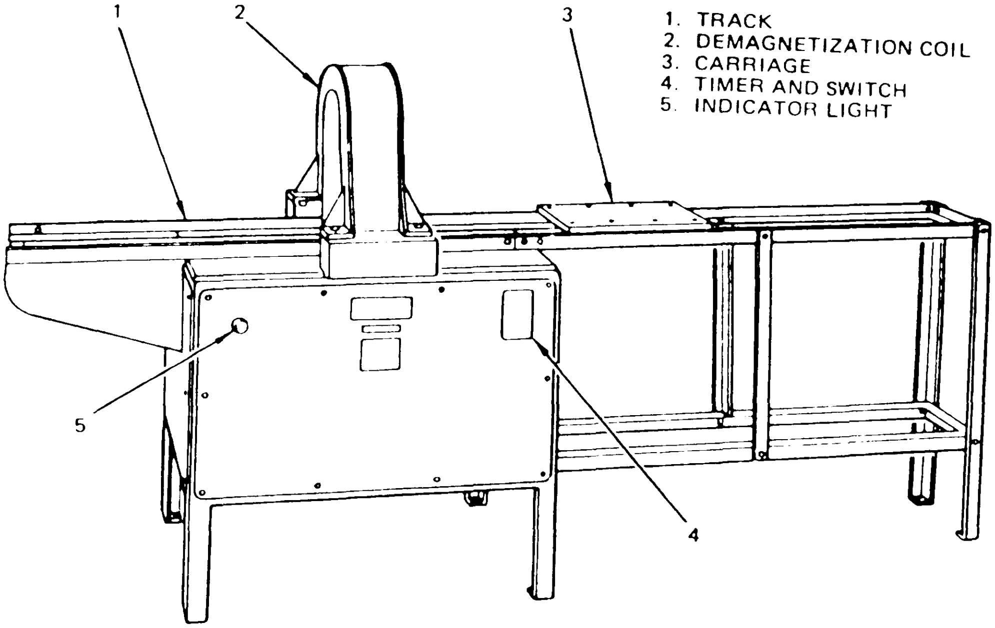


FIGURE 14. Demagnetization equipment.

3. Clamps - used instead of prods to facilitate good contact with article or when one-man operation is required.
4. Contact Blocks - used to facilitate cable connection from stationary equipment for external use of prods or coils.
5. Field Indicators - used in measuring residual magnetism in an article.
6. Metal Mesh - used between contact points and article tested to avoid sparking and burns.
7. Liquid Applicators - used in applying fluorescent or nonfluorescent test medium: can be manual, electric, or air operated.
8. Powder Applicators - used to apply magnetic particle powder to the test area: can be a powder-puff or powder blower.
9. Black Light - The use of black light is standard in fluorescent type inspection. In some instances, more than one black light may be desirable. A portable black light may be used with mobile equipment when wet method testing is performed.

7.5 Magnetic particle powders. Four properties enter into the selection of satisfactory magnetic particles: magnetic, geometric, mobility, and visibility.

7.5.1 Magnetic properties. It is desirable that the particles of the testing medium possess two important magnetic properties: high permeability and low retentivity. Permeability may be defined as the degree of ease with which a particle is magnetized. Retentivity is that property which enables particles to hold (to a greater or lesser degree) a certain amount of residual magnetism. Particles incorporating high permeability and low retentivity give maximum response in a leakage field, and at the same time do not remain magnetized when they pass out of the influence of the magnetic field.

7.5.2 Geometric properties. The spherical shaped particle offers a high degree of mobility but has low attractive power. The long, slender, jagged particle has a high degree of attractive power and low mobility. A multi-faceted nugget type particle is a good compromise in that it reasonably combines the optimum qualities of the other two types. Particle size is also an important consideration, and it is desirable to have particles of various sizes. Small particles are required to bridge a tight-lipped crack. Larger sizes are necessary for wider cracks. A weak leakage field is unable to hold a large particle but is able to fix and retain one of smaller size. Thus, dry powder, magnetic particles are usually available in a wide range of sizes - but all are small enough to pass through a 100-mesh screen. In the wet technique of magnetic particle testing, magnetic oxides of iron are generally used. Although they are extremely fine in size, they are of lower permeability than the metallic, dry particles and have neither the most desirable shape nor variety of sizes available in metallic particles. Fine magnetic oxides are generally used in the technique because they can be suspended in a liquid when a dispersing agent is employed.

7.5.3 Mobility. When the particles are brought into the influence of the leakage field of a flaw, they must be free to form a pattern or indication. This freedom is influenced by several conditions, including the shape of the particles and how they are applied to the surface.

In the dry particle technique of magnetic particle testing, particle mobility is obtained by dusting or blowing the particles over the surface of the article. This permits the magnetic field at the flaw to catch and hold some particles as they move by. Mobility is also obtained by vibrating the article after the particles have been applied. Alternating current may be used advantageously because the alternating field causes the particles to "dance" and thus enhances mobility. However, pulsating direct current is sometimes considered superior in other test characteristics.

The principal advantage of the wet technique of magnetic particle testing is the excellent mobility (freedom to move in the three dimensions) of the suspended particles. It is important to use a low viscosity liquid so that the suspended particles are retarded as little as possible by the liquid in which they are suspended.

7.5.4 Visibility. So that an indication can be made readily visible, a good light source is essential. Particle color also affects visibility. With various types of part surface finishes (from highly polished to rough castings), no one color of particle is always satisfactory. The choice of particle color is entirely dependent on the test item. The most widely used particles are gray, red, and black. The gray powder has excellent contrast against practically all surfaces (with the exception of certain silver-gray sand-blasted surfaces). Particles coated with fluorescent dye often are used to enhance visibility.

8. BASIC PROCEDURES AND TECHNIQUES

* 8.1 General. Magnetic particle testing can be broken down into five basic steps:

1. Preparation of the test surface
2. Magnetization
3. Application of magnetic particles
4. Inspection
5. Demagnetization and cleaning

Each of these steps is presented with the appropriate test techniques where applicable. ASTM E709, "Standard Practice for Magnetic Particle Examination," is useful in describing material in a more quantitative fashion on some techniques and applications discussed below, as well as in other paragraphs in this handbook.

8.2 Preparation of the test surface. The test surface should be cleaned of grease, heavy coatings of paint, rust, slag, or other materials that would interfere with the mobility of the magnetic particles and the forming of indications. A smooth surface and a uniform color are desired for optimum formation and examination of the magnetic particle pattern. When it is necessary to perform magnetic particle testing on items that have been covered with anti-corrosive protective coatings (such as primers, paints, or cadmium-, chromium-, nickel-, or zinc-plating), the coatings do not necessarily have to be removed, since flaw indications are not usually affected. The acceptable thickness limits for such coatings on test items should be checked before conducting a test. In certain cases, coatings are purposely applied to the test item to provide a contrasting background for the medium. The acceptable thickness limit of such coatings is often up to 0.125-mm (0.005 inch). All holes and openings leading to internal areas where complete removal of magnetic substances or other matter cannot be readily accomplished are plugged. Any material which can be completely removed and is not detrimental to the part may be used for plugging. When necessary, all faying surfaces or component parts that can be damaged by the bath are masked. It should be noted that the cleaning of the surface is not necessarily the same thing as cleaning materials out of cracks or flaws that might be on the surface. For liquid penetrant testing (see MIL-HDBK-728/3), the contaminants in the flaws must be removed to allow the entry of the penetrant; but for magnetic particle testing, non-magnetic contaminants do not usually have to be removed from the flaws. This can be an extensive savings in both time and expense. In magnetic particle testing, if current is to be injected into the part, the injection area should also be cleaned to allow good electrical contact.

8.3 Magnetization. To magnetize a specimen, the permeability of the material, the shape and size of the specimen, and the type, size, orientation, and location of the expected discontinuities will all need to be considered. The accessibility of the part, the facilities available, and the required sensitivity of the testing are also parameters that affect the test decisions.

8.3.1 Permanent magnet or electrical source. Basically, one has to first decide if the magnetic field source will be established by a permanent magnet or by an electric current. If a permanent magnet is used, then the distance from the poles or distances between inspection points that can be allowed to detect particular discontinuities must be determined for that particular magnet and material. This is usually determined by trial and error. When accessibility, power source, and facilities allow it, fields from current sources will normally be chosen because they provide greater flexibility in terms of the strengths of magnetic fields obtainable and in the shape and direction of those fields. Ability to demagnetize is also increased when electrical currents are available.

8.3.2 Alternating, direct, or half-wave currents. If electric currents are to be used, decisions to use alternating current, or half-wave or pulsed direct current must be made. It is generally accepted that the best types of magnetizing currents for magnetic particle testing are alternating and half-wave, rectified currents. Alternating current is best suited for locating surface discontinuities (because of skin effect). Half-wave, direct current is best suited for locating below-the-surface discontinuities.

Figure 15 compares the abilities of various methods to detect subsurface discontinuities. The graph plots amperage against depth of discontinuity. This experiment was performed using the test specimen shown at the lower right in figure 15. The lowest amperage that gave a minimum threshold indication at various discontinuity depths was recorded.

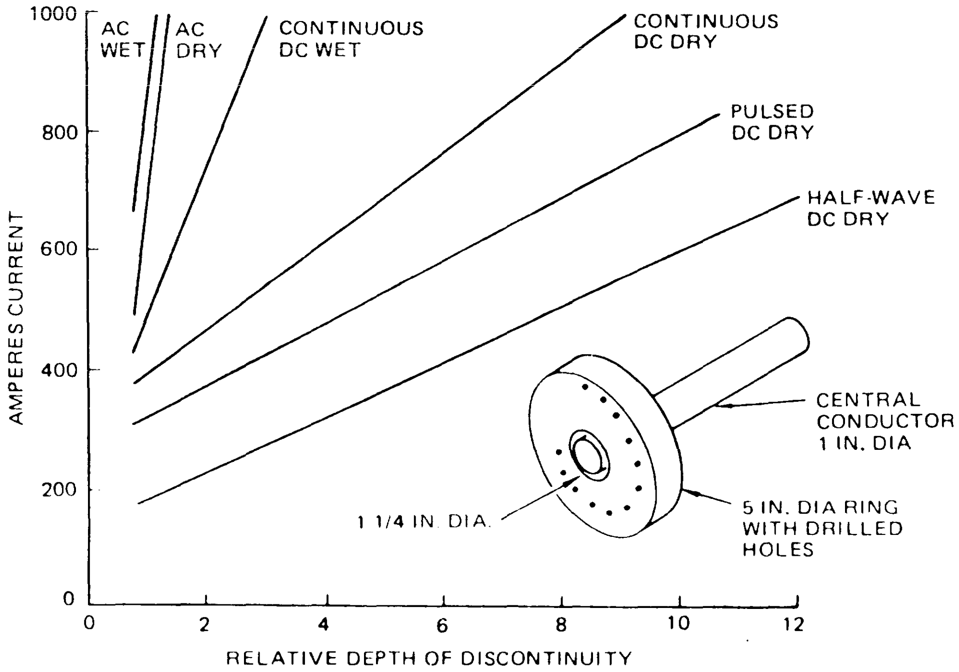


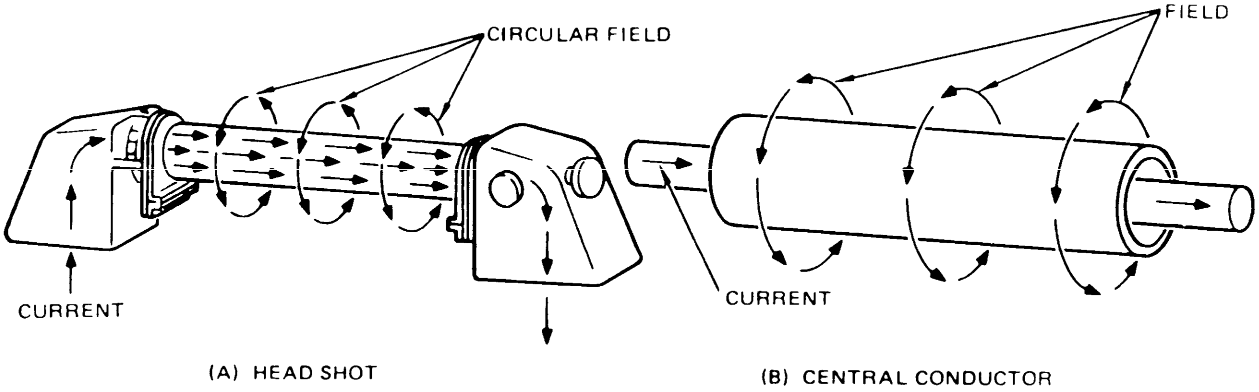
FIGURE 15. Threshold sensitivities of various test methods.

The advantage of using alternating current is that the voltage can be stepped up or down by the use of a transformer. Also, the reversal of magnetic fields, due to the alternating current, makes the magnetic particles more mobile, thus facilitating their collection at leakage fields.

The advantage of half-wave direct current is that, by the use of a rectifier, it can be generated from any commercial alternating current source. Penetration is comparable to that of straight direct current with the pulsating effects of the rectified wave being helpful in adding mobility to the magnetic particles.

8.3.3 Direction of current. After the type of current is chosen, the direction of current application must be determined. Basically, there are two directions usually considered: 1) a "head shot" that establishes a flow of current along the length of the part, resulting in circular magnetization around the part which will locate cracks orientated in the direction of the length of the part, and 2) a "coil shot" that establishes longitudinal magnetization along the length of the part, which will locate cracks oriented perpendicular to the length of the part.

Figure 16 illustrates a head shot and an alternate version where a central conductor is used. Figure 17 indicates a coil shot. Figure 18 indicates other possible current setups. Usually setups for more than one direction must be made to ensure that all discontinuities will be seen. It should be noted that in some cases the current may flow through the part, and in other cases through separate conductors or coils.



(A) HEAD SHOT

(B) CENTRAL CONDUCTOR

FIGURE 16. Circular magnetization by direct and indirect current induction.

* 8.3.4 Multidirectional magnetization. Multidirectional magnetization is defined in the glossary E1316 of the ASTM Book of Standards 03.03 as the alternative application of magnetic fields in different directions during the same time frame. Suitable circuity can be utilized to establish magnetic fields sequentially in more than one direction. The simplest techniques utilize perpendicular fields, switched back and forth. Cracks that are

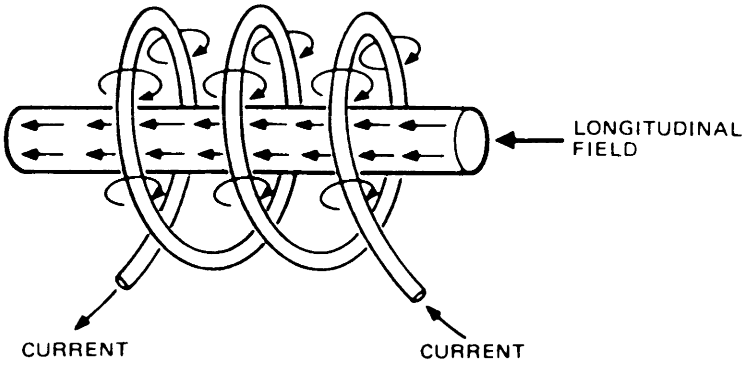


FIGURE 17. Longitudinal magnetic fields.

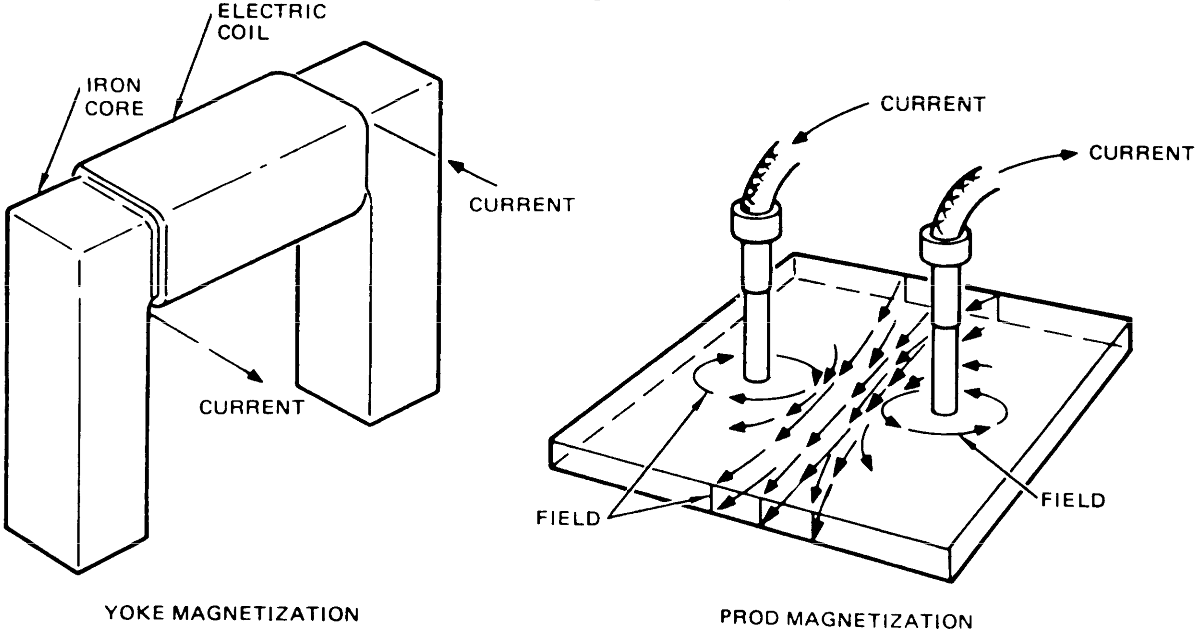


FIGURE 18. Magnetization with prods and yokes.

perpendicular to the magnetic flux lines are observed. Thus, by having flux produced both in circular and longitudinal directions, cracks that are oriented predominantly longitudinally and circulary respectively will be detected clearly.

* 8.3.4.1 Balanced magnetic fields. For general purposes, only two directions of magnetization are usually required: circular and longitudinal. When setting up for the multidirectional methods, the fields are usually balanced so that equivalent magnetization capability exists in the two directions during the operation. This can be attained successfully by using artificial-flaw standards at various locations on the test objects. There may be situations in which the magnetizing fields can be somewhat different. In these cases, it is important that a predetermination (or calibration) be performed to assure usefulness. In most applications, balanced fields are

desirable. Even then, there may be a lack of confidence that they have been achieved <u>inside</u> complex parts. However, the usefulness for inspection still exists, and even small discontinuities can be detected successfully with multidirectional fields.

* 8.3.4.2 <u>Multi-directional magnetization</u>. Three-dimensional magnetic particle inspection units have been set up that have potential for developing two field directions or more for magnetic particle inspection. These can be tailored for specific applications, according to Hagemeier in a review article. (7) It is critical that the magnetic fields are demonstrably balanced so that equivalent magnetizing force exists in all directions during the operation for inspection. Two perpendicular directions are usually selected. It has been found that multidirectional magnetization improves detectability of indication significantly because blind spots are less probable if the technique is properly applied.

8.3.5 <u>Direct and indirect application of current</u>. Magnetization by injecting current into the test item is usually preferred whenever maximum sensitivity to tiny flaws is desired or whenever a magnetic field cannot be conveniently induced in the test item by other methods. However, if the part under inspection is magnetized by injecting current into its surface, care must be taken to avoid arcing as this may severely damage the surface, particularly whenever hand-held prods are used to inject current. Arcing tends to occur whenever the current contacts are dirty or are moved during excitation. A simple way around the arcing problem is to securely clamp the contacts to a clean area. When magnetization is induced by placing the part in an external magnetic field, the arcing problem does not occur.

* 8.3.6 <u>The current and magnetic field strength</u>. The required amount of magnetizing current is affected by the permeability of the material, the shape and thickness of the test specimen, and the type of discontinuity sought. When an article is not uniform in section, it is necessary to use one value of current for the thinner sections and a second, third, or more values of current for heavier sections. In circular magnetization the length of the test specimen does not affect the current requirement. The electrical resistance will, however, increase with length and so will require more electrical energy to develop the required amperage. In longitudinal magnetization, specimen length is a factor to be considered. It is always proper to use the smaller current value first to test the thinner section and then proceed with successively higher currents to test the increasingly larger sections. This procedure avoids overmagnetization of the thinner sections. Whenever a stronger field has been imposed than is required for a subsequent test, it is necessary to demagnetize the specimen before applying the lower amperage. As summarized in ASTM E1444 and here, adequate magnetic field strength can be calculated from various formulas relating it to applied current, with certain approximations being used. Formulas are included for historical continuity. If used, they should be limited to parts that have a simple shape. Appropriate field strength can also be determined by testing parts having known or artificial defects of the type, size, and location specified in acceptance requirements. Various magnetic field indicators, such as a Hall effect gauge, can also be used to measure the peak value of the field tangential to the surface. Judicious use of formulas together with choice of standards and appropriate measurement can yield sufficient but not excessive magnetic field strength for consistent results for indications.

* 8.3.6.1 Circular magnetization. For direct circular magnetization or indirect circular magnetization using a centrally localized conductor, only enough current to show the indication is normally used. The test gauge of magnetizing current strength is a test specimen with a typical indication. The test specimen is kept and used as a reference and the current required to reproduce the indication is checked from time to time. The recommended values for circular magnetization vary because of the different factors involved for different setups and different spatial factors. An acceptable rule is to use from 300 to 800 amperes per inch (120 to 320 amperes per centimeter) diameter or greatest diagonal width of cross section of the part. The amperages shown in table I, therefore, are only suggested averages for various diameters and widths, and may be incorrect for certain alloys and shapes. For indirect circular magnetization using an offset central conductor, the specimen diameter is replaced with the sum of the diameter of the central conductor plus twice the specimen wall thickness. Figure 19 shows test specimens of several sizes and shapes, both in English and metric units.

* 1. View A of figure 19 shows a multiple diameter, solid specimen, the smaller diameter being 2 inches, and the larger 3 inches. Following table I, and recalling the foregoing discussion, the thinner section is magnetic-particle-tested first, requiring 600 to 1600 amperes. The second "shot," for the 3-inch diameter section, requires 900 to 2400 amperes.

* 2. View B of figure 19 illustrates a tubular section to be tested by a head shot. It can be seen from table I, that the current required is 1200 to 3200 amperes. If a centrally located conductor is used to inspect this article, the current requirement remains the same.

* 3. View C of figure 19 illustrate the use of an offset central conductors. It can be seen that calculating the amperage based upon the diameter of the central conductor plus twice the wall thickness yields a current range of 450 to 1200 amperes.

* 4. View D of figure 19 illustrates a number of smaller articles (nuts) requiring testing on an offset central conductor. The maximum outer diameter is 4 centimeters. From table I, we obtain a current requirement of 300 to 800 amperes.

8.3.6.2 Longitudinal magnetization using coils. When a coil is used for longitudinal magnetization, the strength of the field is determined by the product of the number of amperes and the number of turns in the coil. For example, a current of 800 amperes through a five-turn coil creates a magnetizing force of 4,000 ampere turns; it is necessary to know how many turns there are in a coil to calculate the magnetizing force. On most stationary equipment, this information is usually shown on the coil; if not, it may be obtained from the equipment manufacturer. Another type of coil used is the wrapped cable. This is frequently used when an article is either odd-shaped or too big to handle on the equipment. For reliable coil magnetization (longitudinal), the article to be magnetized must be at least twice as long as its diameter, or width. This relationship is known as the length-diameter (L/D) ratio. The L/D ratio and the number of turns in a coil determine the required amperage for coil shots, providing the following conditions are met.

1. The article has an L/D ratio of between 2 and 15.
2. The article or section thereof to be magnetized is not greater than 18 inches (46 cm) long.
3. The cross-sectional area of the article is not greater than 1/10 the area of the coil opening.
4. The article is held against the inside wall of the coil and not positioned in the center of the coil.

If the foregoing conditions are met, then the formula for determining a correct amperage is:

$$A = \frac{45{,}000}{L/D} \times \frac{1}{N} \text{ or } \frac{45{,}000\ D}{LN}$$

where:

* 45,000 = constant
L = length
D = diameter
N = number of turns in coil
A = amperes

Assuming a solid article, 12 inches long (L) by 3 inches in diameter (D), and a coil consisting of 5 turns (N) was available, then the required amperage is determined as follows:

$$\frac{45{,}000\ D}{LN} = \frac{45{,}000 \times 3}{12 \times 5} = 2250 \text{ Amperes}$$

The formula may be used for any number of coil turns. Theoretically, the more turns of cable, the stronger the field though there is a limit to the number of turns (5 when using alternating current) that will increase the flux density. Also, an excessive number of turns will have a heating effect. Since the effective field is limited by the size of the coil, several shots may be required when testing a long article.

8.3.6.3 Use of prods for dual circular fields. The correct flux density is somewhat easier to determine when using prods because it is possible to vary either the current setting on the equipment or the spacing between the prods. If the accumulation of particles between the points of the prods is too heavy, the particles tend to form bands. Banding indicates that the field strength is too great and should be reduced by either lowering the amperage or increasing the space between the prods. Spacing between the prods varies, depending on the size and thickness of the article to be tested; 6- to 8-inch (15 to 20 cm) spacing is found to be most effective on larger articles. American Society for Testing and Materials Standard E709 and MIL-STD-1949 provide additional guides on magnetization requirements.

8.4 Application of magnetic particles. Once the proper level of magnetic flux has been established in a part, magnetic particles are applied. Normally this application is made while the magnetic field source is "on." It is possible, however, where materials exhibit high retentivity, for the residual magnetic field to be adequate for testing, and the magnetizing source can be removed. When the magnetizing source can be removed, the test specimen can be placed in an immersion bath where the magnetic particles are suspended in a liquid. A bath allows maximum particle mobility and usually uniform coverage of the part by the magnetic particles with improved sensitivity and consistency in the test results.

8.4.1 Dry method for testing. Often the application of particles is by a dry method or by a wet flow. The dry magnetic particles are commonly applied from shaker cans or bulbs. The dry method is probably the simplest application method, but certainly not always the best. Automatic particle-blowing equipment can be used. Methods utilizing such equipment are economical in their use of particles and, on most tests, are an acceptable way of "flowing" dry particles over the test surface. A minimum flow velocity is desired in this process.

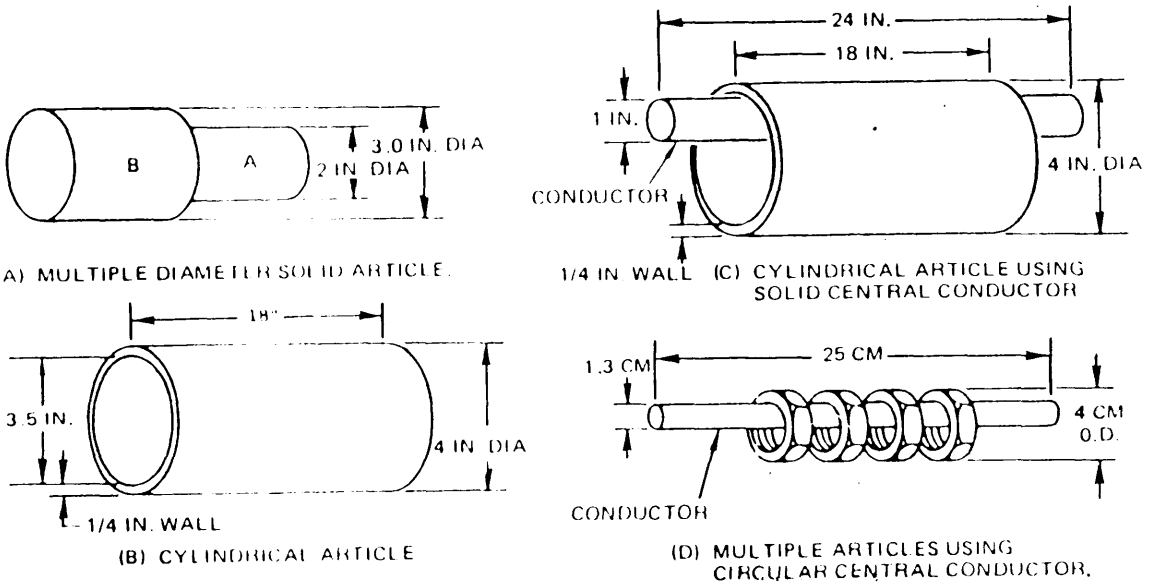
* TABLE I. Magnetizing current for circular magnetization of solid and tubular articles.

Tubular and Solid Articles Greatest Diameter* or diagonal In Inches	 in Centimeters	 Magnetizing Current (Approx) in Amperes
0.4	1.0	100 - 320
0.5	1.3	150 - 400
0.75	1.9	225 - 600
0.8	2.0	240 - 640
1.0	2.5	300 - 800
1.2	3.0	360 - 960
1.5	3.8	450 - 1200
1.6	4.0	480 - 1280
2.0	5.0	600 - 1600
2.4	6.0	720 - 1920
2.5	6.3	750 - 2000
2.8	7.0	840 - 2240
3.0	7.6	900 - 2400
3.2	8.0	960 - 2560
3.5	8.9	1050 - 2800
3.6	9.0	1080 - 2880
4.0	10.0	1200 - 3200

* For an offset Central Conductor, use the Conductor Diameter plus Twice the Wall Thickness.

8.4.2 Wet method for testing. Wet suspensions can be sprayed or otherwise caused to flow over the surface. Again, velocity of flow is important. The flow should not be so strong that the indications are destroyed. For the wet flow or bath method the liquid used is usually a light oil. Water, suitably treated with anti-corrosion, anti-foam, and wetting agents may also be used. Ideally, this liquid should not be fluorescent and, for safety purposes, the liquid should be non-toxic and non-volatile and should have a high flashpoint.

8.4.2..1 Wet bath considerations. The particles are usually obtainable in a dry form, a paste form, or in a highly concentrated liquid form and may be either fluorescent or nonfluorescent. To achieve the required test sensitivity, the degree of particle concentration in the bath must be correct - too light a concentration leads to very light indications of discontinuities; too heavy a concentration results in too much overall surface coverage, which may mask or cause incorrect interpretation of discontinuity indications.



(A) MULTIPLE DIAMETER SOLID ARTICLE.

(C) CYLINDRICAL ARTICLE USING SOLID CENTRAL CONDUCTOR

(B) CYLINDRICAL ARTICLE

(D) MULTIPLE ARTICLES USING CIRCULAR CENTRAL CONDUCTOR.

FIGURE 19. Circular magnetization of typical specimens using head-shot or central conductor. (1)

Table II lists the preferred particle concentration for wet suspensions. Check applicable specifications for exact allowable concentrations. While the bath is in use, it must be constantly agitated to maintain the particles in suspension. A short period of agitation prior to use is desirable. Agitation is usually accomplished by electrically driven pumps or by compressed air. Compressed air agitation, while effective, is the less desirable since moisture and foreign matter carried by the air may contaminate the bath and shorten its useful life. The particle concentration should be checked periodically since the liquid can evaporate and particles are lost as they are removed from the bath on the test specimens.

TABLE II. Concentration for wet suspensions.

Type Particles	Oz. Particles/Gal Suspension	ML or CC Particles/ 100 ML or 100 CC Liquid
Nonfluorescent	See Manufacturer's Instructions	1.2 - 2.4
Fluorescent		0.1 - 0.5

8.4.2.2 Wet bath settling test to determine usefulness. A simple test for particle concentration is the "settling test" shown in figure 20. The suspension is agitated for 30 minutes to assure an even distribution of the particles in the liquid. Then, 100 cc (ml) of the bath is pumped through the hose nozzle into the pear-shaped centrifuge tube and allowed to settle for a minimum of 30 minutes. The amount of particles (measured in cc or ml) settling in the bottom of the centrifuge indicates the concentration of solid matter (particles) in the bath. In measuring the solid matter in the centrifuge, foreign material such as lint and dirt, which settles on top of the particles, is not considered. If the particle reading is high, liquid (vehicle) is added; if low, paste or liquid concentrate containing particles is added. Paste is never directly added to the bath because it might not disperse properly. The paste should be premixed with sufficient bath solution that it can be poured into the holding tank.

When in use, the bath eventually becomes contaminated by dirt, lint, and chips to a degree that efficient formation of discontinuity indications is hindered. Degree of contamination is determined by the amount of foreign matter settling with the paste in the bottom of the centrifuge tube during the settling test. The bath should be checked on a regular schedule depending on the inspection volume: weekly if the volume is high; monthly if the volume is low. When the bath is contaminated beyond usefulness it is discarded, the bath tank and the liquid system are thoroughly cleaned, and a new bath is mixed. Contamination can be minimized by keeping the bath covered when not in use.

8.4.2.3 Control of bath for production procedures. For water-based vehicles, a clean part is flooded with conditioned water to obtain a continuous even film over the entire part, provided sufficient wetting agent is present. If the suspension film breaks, exposing bare surface, insufficient wetting agent is present, or the part has not been cleaned adequately, or the water vehicle is no longer usuable. When wet particle concentration/lack of contamination are not within limits determined by MIL-STD-1949/ASTM E1444, then it is time to dump the bath, clean the tank, and charge a new bath. If settled particles appear as loose agglomerates rather than as a solid layer over two sequential samples, then the bath also needs to be replaced; this is required by MIL-STD-1949/ASTM E1444.

8.5 Inspection Indications of discontinuities located on the surface usually appear in sharp distinct lines, whereas discontinuities located below the surface appear as irregular, rough, hazy indications. The width of a subsurface discontinuity indication varies with the depth of its location below the surface. Correct interpretation of indications caused by subsurface discontinuities requires a certain amount of skill and experience on the part of the operator.

8.6 Demagnetization and cleaning. Ferrous materials usually retain some residual magnetism after the magnetizing current is shut off. The strength of the residual field depends upon the retentivity of the material, and the strength and direction of the magnetizing force. Complete demagnetization is difficult if not impossible to obtain; thus, the demagnetization process is limited to reducing the residual field to an acceptable level. The basis for all demagnetization methods is the subjecting of the magnetized article to the influence of a continuously reversing magnetic field that gradually reduces in strength causing a corresponding reversal and reduction of the field in the article. Although some residual magnetization will remain, the method quickly reduces the field to insignificant proportions. Figure 21 shows graphically how the method works. On the right the graph represents the reversing and reducing magnetic field in the article. On the left are the hysteresis curves corresponding to this action.

8.6.1 Demagnetization (general). The most convenient method of demagnetization uses a specially built demagnetization coil (see figures 14 and 22). When such a coil is energized by passing the current through its windings, it induces a magnetic field in the article placed in the coil. Since current direction reverses itself, the polarity of the induced magnetic field also reverses with each reversal of the current. As the article is withdrawn from the coil, the magnetic field becomes weaker the further the article is withdrawn from the coil. Demagnetization is accomplished only if the article is removed from the influence of the demagnetizing coil while the current is flowing; if the current is stopped while the article is still in the influence of the magnetic field the article may still retain some magnetism.

8.6.2 Demagnetization - effecting. Since the magnetic field produced by alternating current does not penetrate very deeply below the surface of the material, some articles may be difficult to demagnetize completely. This is particularly true with large, heavy, or unusually shaped articles. Direct current can be used to demagnetize if provisions for controlling the amount of current and for reversing the direction of the current are made. Direct current demagnetization is usually more complete and effective than alternating current demagnetization. Some magnetic particle testing equipment is provided with facilities for dc demagnetization. Without such equipment, dc demagnetization is a slow operation. Demagnetization is preferably done on individual articles rather than on groups of articles. To demagnetize with direct current, the article is placed in a coil connected to a source of direct current. The current is adjusted to a value at least as great (but usually greater) than that initially used to magnetize the article. A magnetizing shot is given at this initial value. The direction of the current is then reversed, the current value reduced, and a magnetizing shot is given at the new value. This process of reversing and reducing the current is continued until the lowest value is reached.

8.6.3 Demagnetization-geometrical considerations. For best results in demagnetization, the diameter of the demagnetization coil is just large enough to accommodate the article. If demagnetization of a small article is performed in a large coil, the article is placed close to the inside wall or corner of the coil, since the demagnetization force is strongest in that area.

8.6.4 Demagnetization-practical considerations. For practical purposes, it is always correct to utilize a field indicator after performing demagnetization to determine that residual field strength has been reduced to a desired level. The field indicator is a small, pocket-sized device that measures the strength of a field against a set of small, enclosed, permanent magnets which restricts the needle movement on a relative scale. Whether to demagnetize an article or not depends on a number of factors.

8.6.5 Demagnetization - criteria for use. Demagnetization is usually required if:

1. A strong residual field interferes with subsequent operations, such as welding or machining. Strong fields can "flow" the weld metal as it is deposited, or magnetic chips may cling to the cutting tool and interfere with machining.

2. The article is a moving part of an assembly and a deposit of accumulated magnetized particles might cause wear.
3. Leakage fields interfere with nearby instruments that work on magnetic principles; for example, compasses or indicators of various types.

4. Residual fields interfere with proper cleaning of the article.

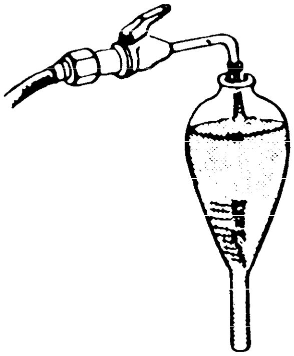
5. The article is to be magnetized at a lower magnetizing force in a different direction than the original or previous test.

6. Specified by procedural standards.

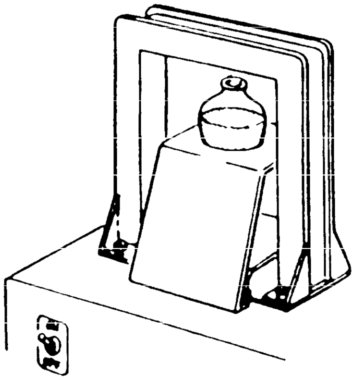
1 AGITATE THE SUSPENSION THOROUGHLY TO ASSURE PARTICLE DISTRIBUTION

2 FILL 100cc (100 ML) SAMPLE FROM THE DELIVERY HOSE INTO A 100cc (100 ML) GRADUATED CENTRIFUGE TUBE OR GRADUATE.

3. PLACE CENTRIFUGE IN STAND



4 DEMAGNETIZE, IF NECESSARY (IF CLUMPING OCCURS).



5 ALLOW TO SETTLE FOR 30 MINUTES.

6 TAKE READING AND RECORD IN THE LOG.

7 ADJUST BATH EITHER BY ADDING PARTICLES OR LIQUID AS NECESSARY.

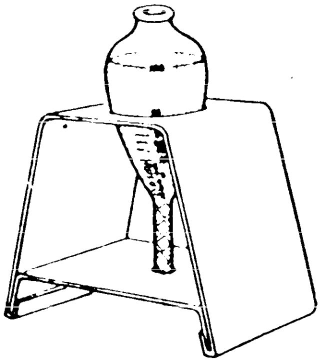


FIGURE 20. Settling test procedure.

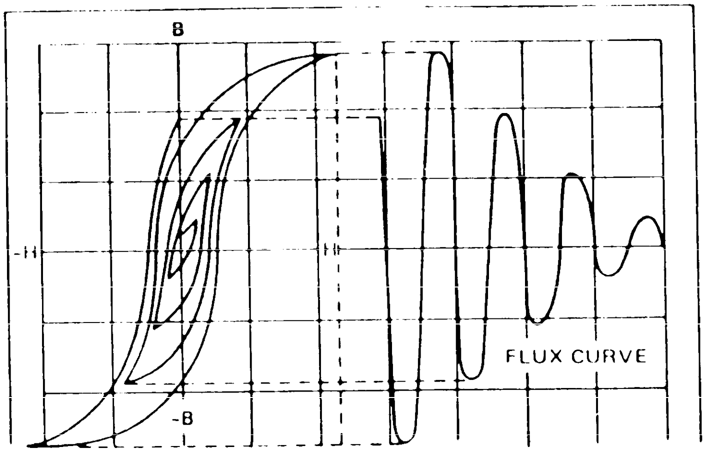


FIGURE 21. Demagnetization flux-curve projected from hysteresis curve.

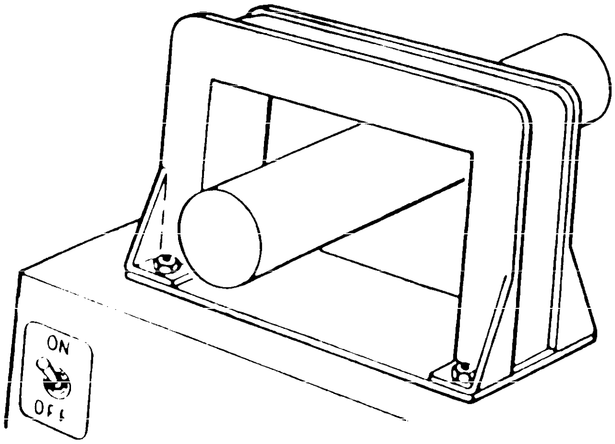


FIGURE 22. Demagnetization coil.

Demagnetization is usually not required or necessary:

1. On articles of soft steel or iron where retentivity is low.
2. If, after the magnetic particle test, the article is to be heat-treated.
3. On large castings, weldments, or vessels where residual fields will have no material effect.
4. If the article is to be magnetized again in another direction with the same or a greater magnetic force.
5. If the article is likely to become remagnetized during handling by being placed on a magnetic chuck, or lifted with an electromagnetic lifting fixture.

8.6.6 Cleaning after demagnetization. Magnetic particles should be completely removed from the specimen after test and demagnetization. Cleaning is accomplished by use of air, solvents, washes, and wiping equipment suitable to the size and complexity of the task. After cleaning, the article is returned to its original state by the removal of all plugs used to seal holes and cavities during the testing process.

*9. MAGNETIC FIELD INDICATION AND SYSTEM VERIFICATION

* 9.1 General. Use of discontinuity standards can be established for magnetic particle inspection as well as for the other nondestructive inspection methods. Quantitative generic standards (such as the IQI's used in radiology) are presently unavailable, although numerous efforts are being made to develop them. An advantage of magnetic particle method is the appearance of the indications over the discontinuities, and the interpretation of their significance by experienced inspectors. For simple test pieces, the adequacy of the magnetic field can be judged by experienced operators, who can determine when a weak field misses indications and when too strong a field masks a significant small discontinuity. As test objects have become more complex and as the types of defects have become more critical, true generic standards will be required to supplement the replicative discontinuity standards and the magnetic field indicators. Magnetic field strength determination (outside the test piece) as well as system verification are presently achievable as described below.

* 9.2 Discontinuity standards and magnetic field indicators. Standards are used to verify that the system is operating satisfactorily and that the applied magnetic field is appropriate for giving indications of discontinuities/defects that the test was designed for. Two types of these "standards" are described below: (1) Discontinuity standards made from test parts identical to or close to those being inspected and (2) System verification test parts for magnetic field indication or external magnetic field measuring instruments.

* 9.2.1 Discontinuity "standards". Discontinuity standards are used to demonstrate that the performance of a magnetic particle testing system is appropriate and sufficient for intended use. Among other purposes, these standards can be used to ensure that the system achieves appropriate field strength and direction to obtain accurate indications. As described in MIL-STD-1949 (or ASTM E1444), the ideal test parts for these goals are production parts that contain defects of the type, location, and size specified in the acceptance requirements.

If actual production parts with these defects are not available or are impractical for use, fabricated test parts with appropriate artificial defects should be used. Artificial defects on the parts may be put in to simulate anticipated discontinuities in similar actual parts or they may be used as magnetic field indicators with a magnetic particle inspection system in which repetitive testing occurs.

* 9.2.2 System verification standards/magnetic field indicators. Two types of indicators are useful for system verification. The first type includes magnetic specimens or pieces with artifically removed material that simulate possible defects in various types of test parts. Thus, during magnetic particle inspection, magnetic flux is shared (as completely as possible) between the object being inspected and this artifical discontinuity specimen. Two common examples of this are the pie gauge and shims. The second type of magnetic field indicators useful for system verification are those that read the magnetic field directly and electronically. These include Hall effect meters and eddy current devices (5). Eddy current instruments have greater

flexibility, but also much poorer repeatability, and thus are generally not useful.

* 9.2.3 Magnetic field determination from formulas. An alternative method for determining the applied current needed to obtain the magnetic field required for producing satisfactory indications is by the use of formulas such as those given in the paragraphs following 6.3.7 of ASTM E1444. Better values for the required fields in specific instances can be achieved from variations of the formulas that can be gotten through the use of known artificial standards and the correlation of the observed indications with the applied current values. Whenever formulas are used, current levels may be adjusted to values verified to be in conformance with the magnetic field strength that has been determined as needed (30 to 60 gauss is often indicated).

10. APPLICATIONS

10.1 General. Magnetic particle testing can be applied to finished articles, billets, hot-rolled bars, castings, and forgings of all ferromagnetic or magnetizable materials. It can also be used to check that processing operations such as heat treat, machining, and grinding did not uncover or cause discontinuities in these materials. Since a large amount of structural parts today are made of magnetizable materials, magnetic particle testing is one of the most widely applied nondestructive test methods.

10.2 Comparison of magnetic particle testing with other NDT methods. For ferromagnetic materials, magnetic particle testing is normally better than liquid penetrant testing for two important reasons: the magnetic particle testing can find subsurface flaws that liquid penetrant testing cannot find and, for most cases, the contamination in surface flaws does not have to be removed. Also, the magnetic particle testing can be quicker, since the dwell times required for liquid penetrant are not needed.

10.3 Non-applicability of magnetic particle method. There are conditions when the application of magnetic particle testing is inappropriate. There are situations where special demagnetization problems may prevent the use of this method. The presence of residual magnetic forces may interfere with subsequent operations or use of the part. Normally, however, magnetic particle testing can be applied throughout all phases of the manufacturing cycle and service life of production parts that are made from ferromagnetic materials. The fluorescent dyes used on the magnetic particles are much less brilliant than the fluorescent pigments used in liquid penetrants.

10.4 Problems in application of magnetic particle method. The biggest problem with magnetic particle testing is human error. Visual inspection is the means for segregating cracks from scratches. Magnetic particle testing can become impractical when the signatures of cracks are identical to the signatures of scratches.

10.5 Use of residual magnetism. In the residual magnetization method, the particles are applied to the test object just as or immediately after the magnetic field has been turned off. Recalling the hysteresis loop, a small to moderate field remains. Specific requirements call for this practice. It is also sometimes useful to help in interpretation when used in conjunction with the usual continuous method. As mentioned in MIL-STD-1949/ASTM E1444, it is especially useful to detect certain fatigue cracks. The usefulness is also degree directly related to the degree of retentivity of inspected parts. It is sometimes necessary to use the residual method for surfaces of some parts with complex shapes or the inner part of long tubes, where it is difficult to use the continuous method. When a central conductor is used, inspection can take place after the removal of the central conductor for discontinuities in cavities inside the test piece. Some ingenuity in particle application may be required in these instances. The only useful general approach to assure detection of discontinuities/defects is to use test parts that have the same material, processing steps, and similar geometry to the actual parts being inspected. As indicated in the ASNT Nondestructive Testing Handbook on Magnetic Particle Testing (5) and in T.O. 33B-1-1(10), the residual method is reliable for the detection of some surface discontinuities only.

10.6 Coatings. Magnetic particle inspection can be performed with some thin conductive coatings on the ferromagnetic substrate of the piece being inspected. Limits on thickness of various permissible coatings are given in MIL-STD-1949 (ASTM E1444) and the ASNT Handbook on Magnetic Particle Testing. Also, limits are given in T.O. 33B-1-1. The least stringent requirements, under special conditions,allow coating thickness of 0.125 mm (0.005 in).

10.7 Use of reference photographs. Reference photgraphs are sometimes used to show indications for purposes of comparison with magnetic particle indications observed in actual castings. It is critical that comparable ferrous materials are analyzed. Sufficient correlation of test pieces being inspected and the pieces from which the photographs were generated is essential to provide useful results for the indications. The color, size, and orientation must all be considered. Distance scales placed on the top or bottom or both sides of each photographed image should be used to establish the true perspective exhibited by the photograph. Reference photographs should show both acceptable and non-acceptable conditions. In addition, reference photographs showing actual limits - indications this large or smaller are acceptable, or indications this small or larger are rejectable - are of value. ASTM E125, "Reference Photographs for Magnetic Particle Indications on Ferrous Castings," describes old quality reference photographs that are commercially available for ferrous castings. These are of limited value. MIL-STD-1907 and MIL-STD-1035 for acceptance criteria may also be used.

11. SPECIFIC GUIDELINES

* 11.1 General. The guidelines for specific individuals and areas must be combined with the guidelines given in HDBK-728/1 to be complete. HDBK-728/1 includes general guidelines for all NDT methods.

11.2 Guidelines for designers. Designers are not always aware of the magnetic properties of their materials. Errors are often made by requiring magnetic particle testing of nonmagnetic materials (such as austenitic stainless steels) or by overlooking the use of magnetic particle testing on materials that are magnetic. Magnetic materials include most of the iron, nickel, and cobalt alloys. Some materials are magnetic only after aging (17-4 PH, 17-7 PH, and 15-4 PH stainless steels). All magnetic materials lose their magnetic properties when their temperature is at or above the curie point. For many materials, this is approximately 760°C (1400°F). Materials that are not magnetic include aluminum, magnesium, copper, titanium, and most of their alloys.

* 11.3 Guidelines for production engineers. Magnetic particle testing is extensively used by production engineers when components are manufactured from ferromagnetic materials. The fact that magnetic particle testing can also be used to inspect most manufacturing equipment is often overlooked. This inservice testing, checking for developing cracks, etc., can save much time and expense by preventing delays and down-times due to unexpected failures of the manufacturing equipment itself.

* 11.4 Guidelines for quality assurance. Magnetic particle testing, as with most NDT methods, is highly dependent upon the NDT technician for successful operations. Training and proper attitudes are a must, and constant attention should be given to all areas that affect these important parameters. Standards, although not as important in magnetic particle testing as for many of the other NDT methods, are still necessary, and should be a part of any formal program.

* 11.5 Guidelines for the NDT engineer. There is great flexibility in magnetic particle testing. New uses and methods are continuously coming forth. Magnetic paints, magnetic rubber, and magnetic printing methods are examples of specialized approaches. Positive or permanent recordings of indications are possible with lacquer or plastic-film sprays. There is a wide range of magnetic sources that produces a variety of shapes and magnitudes of magnetic fields. Magnetic particles can vary in their shape, size, permeability, color, retentivity, and mobility. There is always room for experimenting and perfecting new methods and procedures. As an engineer in magnetic particle testing, there is no room for complacency. New methods or approaches should be continuously considered. Magnetic particle testing has great merit when used during the start-up of production. Magnetic particle testing rapidly reveals the locations where flaws occur. This information permits quick modifications in production to reduce the occurrence of flaws.

* 11.6 Guidelines for the NDT technician. In magnetic particle testing, attention to details, as in all NDT methods, is vital. Magnetic particle testing equipment is subject to breakdowns, magnetic particles can become

contaminated or "diluted," and "permanent" magnets are not always permanent. Therefore, if differences in the tests are observed or suspected, they should be noted and discussed with the NDT engineer. A magnetic particle inspector should be sensitive to the degree of magnetic saturation that is being applied. An inspector should often check this magnetization. Too much magnetization or full saturation causes false indications to appear. These false indications can usually be identified by their shape and location. They usually shift locations as the probes are moved and do not remain at fixed points on the part. Too little magnetization can result in loss of valid indications. An inspector, that does not have a gauss meter, can change the distances between the probes and/or the amount of current being used to check these saturation limits. The inspector should vary the probe spacing and/or current as often as necessary to remain within an acceptable range. If the material being tested has high retentivity, then the inspector must exercise some care if the same point on the part is to be used to explore for the saturation limits. A complete demagnetization between each check is ideal. If direct current is being used, a change in current direction (or exchanging the positions of the probes) between each test can help reduce the retentivity effect. In no case should a check at a lower current follow a higher current check without appropriate demagnetization.

* 11.7 Written procedure. Magnetic particle inspection should be undertaken with a written procedure that is pertinent to the group of parts or elements of structures that are being tested. A sketch is frequently advisable to clarify the location of potential critical areas and the specific magnetic particle method and field distribution, as well as sensitivity for demonstrating discontinuities. Relationship of test to acceptance criteria and rejectable discontinuities should be included, with limits on parameters to be used and quantitative validity of results. Written procedures should be approved by an individual with knowledge and experience in magnetic particle inspection. Reference to ASTM E709 and MIL-STD-1949 (ASTM E1444) should be made when written procedures are being written and approved.

12. SAFETY

12.1 General. Where electrical currents are used to establish magnetic fields and to demagnetize parts, standard safety practices relating to electrical equipment must be observed. This includes the care and handling of electrical cords, observing proper connections and grounding of equipment, and the use of fuses and/or circuit breakers. The magnetic circuit itself is usually a low voltage, high current circuit. Therefore, the greatest danger is from heat, high temperatures, or arcing generated at the points of contact of the circuit.

* 12.2 Chemical. The particles used in magnetic particle inspection are usually highly magnetic oxides with a bonded dye material coating. They are relatively inert however, when used in the dry powder method some respiratory protection (face mask or filter) is advisable. This is especially important when performing inspection of vetical or overhead surfaces.

The wet method uses either an oil base vehicle or a conditioned water to suspend the particles. The oil base is a petroleum product while the conditioned water contains a wetting agent. Both materials are excellent solvents and if in prolonged contact with skin will remove the natural oils from the skin. Protective clothing such as gloves, aprons and face shields are recommended. If contact does occur, the solutions should be removed as soon as possible by washing with soap and water. The natural skin oils should be replaced using a lanolin or equivalent skin cream.

The manufacturer or supplier is obligated to provide a Materials Safety Data Sheet (MSDS) detailing the hazards of the materials. The recommendations in the MSDS should be followed.

* 12.3 Black light or ultraviolet. While the wavelength of black lights does not cause erythemal action, there is evidence indicating that UV-A radiation in excess of 1,000 $\mu W/cm^2$ can be hazardous if allowed to fall upon the eyes or skin without limit. The use of suitable gloves, protective ultraviolet absorbing eyewear and opaque or closely woven clothing to cover potentially exposed dermal areas are recommended to personnel operating in areas where the black light intensity exceeds 1,000 $\mu W/cm^2$.

The typical 100 watt black light bulb has a high operating temperature. They must not be operated if any flammable vapors are present. They also heat the surfaces of the lamp housing and care must be exercised to prevent any exposed part of the body from contacting the surface of the lamp.

12.4 Magnetic equipment/mechanical effects. Loose magnetic specimens, or even loose magnetic coils, etc., can be a problem when strong magnetic forces exist. Pinched fingers or damage to parts can occur if loose parts are pulled together or moved out of position due to these magnetic forces.

* 12.5 Vehicle/bath use. Dry cleaning solvents may not be used for suspending particles in the wet particle technique because they have an inherently low flash point (below 100°C or 212°F). Proper safety precautions must be adhered to when they are used for cleaning. The use of light oils with higher flash points is recommended as a suspensoid for safety reasons. Precautions should be taken to prevent inhaling of dry particle materials. The use of suitable face masks is recommended.

13. NOTES

* 13.1 Subject term (key word) listing.

Magnetic particle testing
Nondestructive testing

* 13.2 Changes from previous issue. The margins of this handbook are marked with asterisks to indicate where changes (additions, modifications, corrections, deletions) from the previous issue were made. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations.

REFERENCES

1. Classroom Training Handbook, CT-6-3, "Nondestructive Testing, Magnetic Particle," (General Dynamics Convair, San Diego) 1977 (Second Edition).

2. NASA SP-5113, "Nondestructive Testing, A Survey," (U.S. Government Printing Office, Washington D.C.) 1973.

3. Metals Handbook, Vol. 11, "Nondestructive Inspection and Quality Control," (American Society for Metals, Metals Park, OH.) 1976 (8th Edition).

4. W.J. McGonnagle, "Nondestructive Testing," (McGraw-Hill Book Co, N.Y), 1961.

* 5. P. McIntire, "Nondestructive Testing Handbook, Magnetic Particle Testing", Second Edition, Volume 6 (ASNT, Columbus, OH), 1989.

* 6. Annual Book of ASTM Standards, Section 3, Volume 03.03, "Nondestructive Testing," (American Society for Testing and Materials, Philadelphia) 1992.

* 7. Hagemeier, D.J., "Quality Indicators for Magnetic Particle Inspection", Materials Evaluation, pp. 346-350, March 1991.

* 8. Swartzendruber, L., ASTM Proposed Draft for Shim Use in Magnetic Particle Examination, 1991.

* 9. Microswitch Company, "Hall Effect Transducers: How to Apply Them as Sensors," Freeport, IL, 1982.

* 10. Military T.O. 33B-1-1, Magnetic Particle Method, Revised 1993.

Custodians:
  Army - MR
  Navy - AS
  Air Force - 11

Review activities:
  Army - AR
  Navy - OS

Preparing activity:
Army - MR

Project NDTI-0047

(WP# ID-1339A/DISC-0111A. <u>FOR ARL/MD USE ONLY</u>)

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

INSTRUCTIONS

1. The preparing activity must complete blocks 1, 2, 3, and 8. In block 1, both the document number and revision letter should be given.
2. The submitter of this form must complete blocks 4, 5, 6, and 7.
3. The preparing activity must provide a reply within 30 days from receipt of the form.

NOTE: This form may not be used to request copies of documents, nor to request waivers, or clarification of requirements on current contracts. Comments submitted on this form do not constitute or imply authorization to waive any portion of the referenced document(s) or to amend contractual requirements.

I RECOMMEND A CHANGE:	1. DOCUMENT NUMBER MIL-HDBK-728/4A	2. DOCUMENT DATE (YYMMDD)

3. DOCUMENT TITLE
MAGNETIC PARTICLE TESTING

4. NATURE OF CHANGE *(Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)*

5. REASON FOR RECOMMENDATION

6. SUBMITTER

a. NAME *(Last, First, Middle Initial)*	b. ORGANIZATION	
c. ADDRESS *(Include Zip Code)*	d. TELEPHONE *(Include Area Code)* (1) Commercial (2) AUTOVON *(If applicable)*	7. DATE SUBMITTED (YYMMDD)

8. PREPARING ACTIVITY

a. NAME

Department of the Army
US Army Research Laboratory
Materials Directorate
ATTN: AMSRL-MA-S
Watertown, MA 02172-0001

b. TELEPHONE *(Include Area Code)*
(1) Commercial 617-923-5286
(2) AUTOVON DSN955-5286

c. ADDRESS *(Include Zip Code)*

IF YOU DO NOT RECEIVE A REPLY WITHIN 45 DAYS, CONTACT:
Defense Quality and Standardization Office
5203 Leesburg Pike, Suite 1403, Falls Church, VA 22041-3466
Telephone (703) 756-2340 AUTOVON 289-2340

DD Form 1426, OCT 89 *Previous editions are obsolete*