Nondestructive Examination (NDE) and Technology Codes
Student Manual

Volume 2

Chapter 7.0

Introduction to Magnetic Particle Examination

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7.0 INTRODUCTION TO MAGNETIC PARTICLE EXAMINATION

Learning Objectives:

To enable the student to:

1. Understand the common applications of magnetic particle testing (MT).

2. Recognize related personnel qualification and certification requirements for this method.

3. Identify different equipment used for this method.

4. Identify and understand common techniques used in the application of MT.

5. Know the relevant indications, how they are produced, interpreted, and evaluated.

6. Understand common interpretation and code requirements.

7. Recognize the advantages and limitations.

7.1 History

The principle of using magnetic fields and ferromagnetism to locate surface cracks in magnetic materials was first noted by the alert observation of an employee of the Bureau of Standards, Mr. William E. Hoke, shortly after the end of World War I. He noticed that metallic grindings from hard steel parts that were being rough ground while held on a magnetic chuck often formed patterns on the face of parts which corresponded to cracks in that surface. This observation was not fully appreciated or applied until 1928, when Mr. A.V. deForest did his initial work in this area, realizing that if cracks in any direction were to be located reliably, the direction of the magnetic field in the part could not be left to chance. His continued work in this area resulted in the development of workable methods and systems for MT, which permitted the detection of surface cracks regardless of their orientation. At the start of World War II, reliable examination methods were needed to assure the government that it was purchasing quality products for defense. MT was one method which offered this capability. Subsequent developments perfected methods and equipment to the stage where it is used in various industries and is recognized as a valuable tool for assuring the quality of material and products.

7.2 Personnel Qualification and Certification

Even though Magnetic Particle Examinations are not performed as frequently as PT for nuclear power plants, it is still an essential and important NDE method. MT requires a slightly higher degree of expertise, more hours of formalized training and more months of experience than PT for qualification. MT examiners must be qualified if MT is to be effective.

The 2007 Edition with 2008 Addenda of the ASME Code Section V requires that NDE personnel be qualified in accordance with either:

SNT-TC-1A (2006 Edition), or
ANSI/ASNT CP-189 (2006 Edition)
ACCP

Qualification in accordance with a prior edition of either SNT-TC-1A or CP-189 is considered valid until recertification. Recertification must be in accordance with SNT-TC-1A (2006 Edition) or CP-189 (2006 Edition).

Section XI requires that personnel performing NDE be qualified and certified using a written practice prepared in accordance with ANSI/ANST CP-189 as amended by Section XI. IWA 2314 states that the possession of an ASNT Level III Certificate, which is required by CP-189, is not required by Section XI. Section XI also states that certifications to SNT-TC-1A or earlier editions of CP-189 will remain valid until recertification at which time CP-189 (1995 Edition) must be met.

A Level II Magnetic Particle Examiner, who is a high school graduate, must complete one of the following for Section V and only the CP-189 requirements for Section XI.

The SNT-TC-1A requirements are:

	Training	Experience
Level I	12 hours	70* hrs/130**hrs
Level II	8 hours	210* hrs/400**hrs

*Hours in Magnetic Particle
**Total hours in NDE
NOTES:

1. To certify to Level II directly with no time at Level I, the training and experience for Level I and II shall be combined.
2. Training hours may be reduced with additional engineering or science study beyond high school. Refer to Chapter 2.
3. There are no additional training requirements for Level III. Refer to Chapter 2 of this manual for Level III requirements.

The CP-189 requirements are:

	Training	Experience
Level I	12 hours	65*/130**
Level II	8 hours	200*/400**

*Hours in MT/** Total Hours in NDE

NOTES:

1. Experience is based on the actual hours worked in the specific method.
2. A person may be qualified directly to NDT Level II with no time as certified Level I providing the required training and experience consists of the sum of the hours required for NDT Levels I and II.
3. The required minimum experience must be documented by method and by hour with supervisor or NDT Level III approval.
4. While fulfilling total NDT experience requirement, experience may be gained in more than one (1) method. Minimum experience hours must be met for each method.

7.3 Principles

To accomplish the magnetic particle examina-

tions, the test object is magnetized either by passing electric current through the part that creates a magnetic field in the part (direct magnetization), or by placing the part near a strong magnetic field, thereby inducing a magnetic field in the part (indirect magnetization).

A discontinuity present in the part disrupts the flow of magnetic flux through the part, and causes the magnetic flux to travel out of the part creating a flux leakage field in the vicinity of the discontinuity. Fine ferromagnetic particles applied to the surface of the part are attracted to the flux leakage and align themselves with the discontinuity.

The accumulation of particles, referred to as an indication, must be interpreted to determine its cause and its relevancy, and if caused by a discontinuity, evaluated in accordance with the applicable predetermined acceptance criteria.

7.3.1 Key Terms

Before proceeding with the principles of magnetism it is necessary to consider some of the key terms relating to magnetism and magnetic fields. It is important to understand and be able to define the following terms.

Magnet - A magnet is a bar or ring made from a ferromagnetic material. It may occur naturally (e.g., a lodestone) or be created by inducing a magnetic force in ferromagnetic materials.

Ferromagnetic - These are materials with permeability greater than unity. Ferromagnetic materials are strongly attracted by a magnet.

Magnetic Field - Magnetic field is the space around a current-carrying conductor or permanent magnet, which contains magnetic lines of force.

Magnetic Flux Lines - These are imaginary lines used as a means of explaining the behavior of magnetic (lines of force) fields. This is demonstrated by the pattern of lines produced when iron filings are sprinkled over a piece of paper or glass laid over a permanent magnet. The unit of a single flux line is called the Maxwell, usually indicated by the Greek letter Phi "Φ."

Magnetic Force - In MT the magnetizing force is considered to be the total force usually designated by letter "H", and the unit is the Oersted.

Flux Density - Flux density is the number of flux lines per unit of area, taken at right angles to the direction of the flux. It is the measure of magnetic field strength and is expressed in Gauss and is indicated by the letter "B".

Gauss - Gauss is the unit of flux density. The strength of the magnetic field induced in a ferromagnetic body is described as being so many Gauss. Numerically, one Gauss is one line of flux per square centimeter of area.

Saturation - Saturation is the point of the magnetization of a magnetizable part at which an increase in the magnetizing force produces no increase in the magnetic field within that part.

Pole - Pole is the area on a magnetized article from which the magnetic field is leaving or returning.

Flux Leakage - Flux leakage are lines of force that leave and enter a part at poles on the surface.

Leakage Field - This is the field forced out into the air by the distortion of the field within a part caused by the presence of a discontinuity.

Permeability (Magnetic) - Permeability is a measure of the ease with which a magnetic field or flux can be set up in a magnetic circuit. It is not a constant value for a given material but is a ratio. At any given value of magnetizing force, permeability is the ratio of flux density (B/H).

Reluctance - Reluctance refers to the opposition of a magnetic material to the establishment of magnetic flux. The reluctance of the material determines the magnitude of the flux produced by a given magnetic force. Reluctance is analogous to the resistance in an electric circuit.

Retentivity--Retentivity is the ability of a material to retain a portion of the magnetic force induced in it after the magnetizing force has been removed.

Residual Magnetism - This is the term applied to the amount of magnetism remaining in a part after the magnetizing force is removed (remnant magnetism).

Coercive Force - Corrosive force is the reverse magnetizing force to bring the retained flux density to zero.

Demagnetization - Demagnetization is the process of reducing the residual magnetism to an acceptable level.

Hysteresis - This is a graphical plot of magnetizing force (H) against the induced magnetism of flux density (B).

7.3.2 Theory of Magnetism

In order to understand MT it is necessary to understand the theory of magnetism.

7.3.2.1 Horseshoe Magnet

One of the most familiar types of magnet is the horseshoe magnet shown in Figure 7-1a. It attracts magnetic materials to its ends where a leakage field occurs. These ends are commonly called "north"' and "south" poles, indicated by N and S on the diagram. There will be no attraction except at these poles. Magnetic flux lines or lines of force flow from the north to the south pole as long as they are external to the magnet. Since these lines of force always form a complete circuit, they also pass through the iron or steel of which the magnet is made. Note that within the magnet the lines are directed from the south to the north pole.

If the ends of the horseshoe magnet are bent so that they are close together, as shown in Figure 7-1b, the ends will still attract magnetic materials. However, if the ends of the magnet are bent closer together, and the two poles are completely fused or welded into a ring as shown in Figure 7-1c, the magnet will no longer attract or hold magnetic materials because there is no longer a leakage field. The magnetic field remains internally as shown by the magnet, but without poles there is no attraction. Such a part is said to have a circular field, or to be circularly magnetized, because the magnetic lines of force are circular.

Any crack in the fused magnet or circularly magnetized part which crosses the magnetic flux lines immediately creates north and south poles on either side of the crack (Figure 7-2). This forces some of the magnetic flux (lines of force) out of the metal path and is referred to as flux leakage. Magnetic materials or particles are attracted by the poles created by the crack, which forms an indication of the discontinuity on the surface. This is the principle whereby magnetic particle indications are formed by means of circular magnetization.

7.3.2.2 Bar Magnet

If a horseshoe magnet is straightened, a bar magnet is created as shown in Figure 7-3. The bar magnet has poles at either end and magnetic lines of force flowing through the length of it. Magnetic particles are attracted only to the poles. Such a piece is said to have a longitudinal field, or to be longitudinally magnetized.

A slot in the bar magnet that crosses the magnetic flux lines creates north and south poles on either side of the slot (Figure 7-4a). These poles attract magnetic particles. In a similar manner, if the discontinuity is a crack, it will still create magnetic poles as indicated in Figure 7-4b. These poles also attract magnetic particles. The strength of these poles is a function of the number of flux lines, the depth of the crack, and the width of the gap at the surface. The will be an increased particle attraction with an increased flux leakage.

7.3.2.3 Flux Line Characteristics

Magnetic lines of force (flux lines) may be described by several characteristics:

- They are closed loops.
- They can be distorted.
- They return upon themselves.
- They are parallel and never cross.
- They seek the path of least resistance.
- They are most densely concentrated at the poles.
- They flow from north to south outside the magnet, and from south to north in the magnet.

7.3.2.4 Classification of Materials

All materials react to a magnetic field in one of three ways. They are, therefore, classified as diamagnetic, paramagnetic, or ferromagnetic. When made into a rod, a diamagnetic material is repelled by a magnetic field and will align itself at right angles to the field. When a paramagnetic or a ferromagnetic material is made into a rod, it will be attracted by a magnetic field and will align itself parallel to the field.

Diamagnetic materials have a permeability slightly less than unity. Bismuth has the lowest permeability known (.9998). Other diamagnetic materials are phosphorus, antimony, flint glass, and mercury. Such materials are usually considered to be nonmagnetic.

Paramagnetic materials have permeability greater than unity. Those whose permeability is only slightly greater than unity, such as platinum

(1.00002), are called paramagnetic and are usually considered to be nonmagnetic.

Ferromagnetic materials have a permeability greater than unity and are usually considered to be magnetic. Ferromagnetic materials are iron, nickel, cobalt, and many alloys such as Permalloy, alnico, permivar, etc. Usually materials with a permeability of 1.1000 or greater are referred to as ferromagnetic.

7.3.2.5 Molecular Theory

Before a part is magnetized it is said to be in its virgin state. The atoms have a very random arrangement or orientation. When a magnetizing force is applied to low carbon content steel, the atoms align easily in a distinct arrangement or orientation. More magnetizing force is required to align the atoms of high carbon steel into magnetic domains. When the magnetizing force is removed from low carbon content steel, most of the atoms return to their normal orientation leaving little retained magnetism. High carbon content steel is much harder to align the atoms. When the magnetizing force is removed, many atoms stay aligned and the material retains a greater amount of magnetism.

7.3.2.6 Leakage Fields

The basic law of magnetic attraction states that unlike magnetic poles will attract one another and like magnetic poles will repel one another.

The concept of flux lines includes flow, distribution, direction, and attraction-repulsion properties. The flux lines always leave a magnet at right angles to the surface. When a piece of soft iron is placed in a magnetic field, it is drawn toward the magnetic source. As it approaches closer to the source, more flux lines flow through it. This concentrates the lines of flux into the easily traversed iron path rather than the high reluctance air path.

An example of this magnetic attraction is the attraction of a nail to a horseshoe magnet. This action causes magnetic particles to concentrate at leakage fields at discontinuities. The leakage field is jumping across a relativity high reluctance air gap at the discontinuity. Since the magnetic particles offer a lower reluctance path to the flux lines, they are drawn to the discontinuity and bridge the air gap.

7.3.2.7 Hysteresis Loop

The magnetic properties of ferromagnetic materials can be illustrated by considering the hysteresis curve (loop) for a ferromagnetic material. The hysteresis curve plots the flux density (B - in units of Gauss) against the Magnetizing Force (H - in units of Oersteds) as shown in Figure 7-5.

7.4 Producing Magnetic Fields

7.4.1 Induced Magnetic Fields

Magnetism may be induced into a material by placing the material in an already existing magnetic field. This can be illustrated by making a screwdriver magnetic by rubbing it against a permanent magnet. An easier method is through the use of electrical current. If a wire is wrapped around a screwdriver and electric current passes

through the wire, the screwdriver will become magnetized.

7.4.1.1 Permanent Magnets

Permanent magnets are sometimes used to induce magnetic fields within a test specimen. The use of permanent magnets for magnetization has many limitations; therefore, they are only used when these limitations do not interfere or prevent the formation of adequate leakage fields at the discontinuity.

Limitations of using permanent magnets include:

- The field strength cannot be varied.
- Large areas or masses cannot be magnetized with sufficient strength to form adequate leakage fields at discontinuities to form indications.
- There may be an excessive accumulation of magnetic particles at the pole of the magnet such that and indication of a discontinuity might be masked over.
- A very strong magnet may be difficult to remove from contact with the test specimen surface.

7.4.1.2 Electromagnets

Electromagnets can be created by inducing magnetic fields in ferromagnetic materials. Magnetic lines of force are always at right angles (90^{o}) to the direction of the current flow (Figure 7-6). Therefore, the direction of the magnetic field can be altered and is controlled by the direction of the magnetizing current. It is important to know how to use electric currents to induce the magnetic lines of force so that they intercept and are, as near as possible, at right angles to the discontinuity. Either circular or longitudinal magnetic fields can easily be created in a test specimen.

Basically two types of electric current are used as a magnetizing force. These are alternating current and direct current. The alternating current reverses direction of flow at regular intervals. Direct current, as the name implies, refers to an electric current flowing continually in one direction through a conductor.

7.4.2 Circular Magnetization

Circular magnetization derives its name from the fact that a circular magnetic field always surrounds a conductor such as a wire or a bar carrying an electric current (Figure 7-6). The direction of the magnetic lines of force (magnetic field) is always at right angles to the direction of the magnetizing current. An easy way to remember the direction of magnetic lines of force around a conductor is to imagine that you are grasping the conductor with your right hand so that the extended thumb points parallel to the electric current flow. The fingers then point in the direction of the magnetic lines of force. Conversely, if the fingers point in the direction of current flow, the extended thumb points in the direction of the magnetic lines of force (right-hand rule).

In circular magnetization, the lines of force, which represent the direction of the magnetic field, are circular within the part. The strength of the

magnetic field is dependent upon the current passing through the conductor.

Circular magnetization is used for the detection of longitudinal discontinuities that lie in the same direction as the current flow either in a part or in a part through which a central conductor passes. It is also used for the detection of radial discontinuities around edges of openings in parts.

Two techniques are used to obtain circular magnetization: direct magnetization caused by passage of electric current through the parts themselves, or indirect magnetization caused by passage of the current through a conductor that passes through an opening in the part.

7.4.2.1 Direct Magnetization

Direct contact to parts is generally made by clamping them between the contact heads (Figure 7-7). This is sometimes called the direct contact or head shot method. Lead face plates and/or copper braid pads must be used to prevent arcing and overheating of the parts. Contact surfaces must be clean and free of paint or similar coatings and have adequate pressure applied so as to achieve good electrical contact over a sufficient area of the contact's surfaces.

To create or induce a circular field in a part with stationary equipment, the part is clamped between the contact plates, and current is passed through the part. This sets up a circular magnetic field in the part that creates poles on either side of any crack or discontinuity which runs parallel to the length of the part. The poles attract magnetic particles, which form an indication of the discontinuity.

When direct current flows through a nonmagnetic conductor, the magnetic field (F) increases from zero at the center to a maximum at the surface of the conductor (Figure 7-8).

When direct current flows through a hollow nonmagnetic conductor, a different condition exists than for the solid, nonmagnetic conductor. The field strength gradient from inside to the outside surface is the same as for a solid conductor of the same diameter and same amount of current. However, there is no current flowing between a point on the inside surface and center of the hollow conductor as shown in Figure 7-9. The field strength outside the hollow, nonmagnetic conductor is the same as for the solid nonmagnetic conductor.

If the conductor is a solid magnetic material carrying the direct current, the same field distribution exists inside the material as for the nonmagnetic conductor; however, the field strength at the surface is greater. For a solid magnetic material, as illustrated in Figure 7-10, the field strength is zero at the center but at the surface it is $\mu \times F$, with μ being the material permeability factor. Outside the surface of the magnetic material the field strength decreases significantly. The maximum field strength at the surface of the magnetic conductor is approximately 1,000 to 2,000 times the field strength in a nonmagnetic material.

If the conductor is hollow magnetic material carrying direct current, the field strength will be zero on the inside surface, the same as for the nonmagnetic conductor. The field strength is

maximum at the surface, again μ x F.

This condition, as shown in Figure 7-11, illustrates that a circular field created by a head shot does not magnetize the inside diameter (ID) of the part. In order to perform an MT on the ID of a tubular part it is necessary to use the central conductor method.

7.4.2.2 Indirect Magnetization

A part can be circularly magnetized by passing electric current through a central conductor positioned through a hole or opening in the part (Figure 7-12). This is sometimes called the central conductor method. A magnetizing field exists outside a conductor carrying current so the tubing surrounding the central conductor becomes magnetized. Since the circular field is at right angles to the axis of the conductor, it is very useful for the detection of discontinuities that lie in a direction generally parallel with the conductor. The central conductor method must be used if longitudinal discontinuities on the inside of tubular or cylindrically shaped parts are to be detected. The central conductor method is also very useful for detecting discontinuities, usually cracks, which emanate radially out of holes in castings and other parts. On very large parts having large openings, the central conductor may be located close to the inside surface and several examinations made around the inside periphery. Placing the conductor close to the inside surface reduces the current requirements since the strength of the circular field decreases as the distance from the conductor increases. When this is done, only an area of 2D each side of the central conductor may be examined. D is the diameter of the central conductor. See Figure 7-27.

When direct current passes through a nonmagnetic conductor placed inside a hollow magnetic tube, the field strength decreases along the same curve through the air space between the current carrying conductor and the ID of the magnetic tube. At this point the field strength is multiplied by μ, and then continues to decrease on a curve to the outside surface of the tube. At the outside surface the field strength then drops to follow the same curve it was following inside the tube.

7.4.2.3 Equipment

The equipment listed below is commonly used for circular magnetization:

- Head shot,
- Central conductors,
- Multidirectional swinging field system,

- Prods, and
- Clamps or leeches.

7.4.2.4 Field Strength Calculations

In all cases the examiner must refer to the applicable code, procedure, or examination instruction sheet to determine the proper amperage to use for a given application. However, in the event the amperage is not specified, a number of factors must be considered when determining what current amperage to use for circular magnetization.

Some of the more important factors are:

- The type of discontinuity to be detected;
- The part's size, shape, and cross-sectional area through which the current will flow.

Over the years some rule of thumb values for suitable current testing have been used. They have been based on experience rather than on technical reasoning. They do not consider the varying shapes and magnetic properties of parts that will be magnetized. For example, the permeability of steel varies and a soft steel of high permeability requires a far lower magnetizing force to produce a suitable field than does a high carbon or alloy steel, which typically has very low permeability.

The formation of magnetic particle indications at discontinuities depends upon the strength of the leakage fields at the discontinuities. Since the leakage fields are a part of the field generated by the magnetizing current, the greater the magnetizing current the greater will be the strength of the leakage fields. Therefore, the sensitivity of an MT is directly related to the current amperage. Too low of an amperage may produce leakage fields too weak to form readily discernible indications. Too high of an amperage creates a heavy background accumulation of particles that may mask an indication. In circular magnetization, too high of an amperage may arc or burn a part. In actual practice, amperage requirements are normally calculated based upon the requirements of the applicable code or specification. In some case, the amperage may be established by experimentation.

7.4.2.5 Code Requirements-Circular

7.4.2.5.1 Direct Contact Technique (Head Shot)

Direct or rectified current is used with this technique. Current requirements specified in Article 7, Section V of the 2007 ASME Code with 2008 Addenda are:

- 300 amperes (amp) per inch to 800 amps per inch of outer diameter:
- Parts with geometric shapes other than round with the greatest cross-section diagonal in a plane at right angles to the direction of current flow shall determine the dimension to be used with the above amperage range.
- If the current as described above cannot be obtained, the maximum current obtainable must be used and the field adequacy demonstrated.
- For non-cylindrical and large parts, the magnetic field indicator (pie gage), a Hall Effect Meter or a QQI may be used to determine the feed adequacy.

7.4.2.5.2 Central Conductor

In accordance with Article 7, Section V, of the ASME Code, when using a single central conductor or a single turn central conductor (cable), the amperage is based on the same requirements as described in section 7.4.2.5. When using cables as the central conductor, the magnetic field strength increases in proportion to the number of times the central conductor cable passes through the part; therefore, the amperage is adjusted

accordingly. For example, if 6,000 amp was required to examine a part with a single turn conductor, then 3,000 amp would be used if the central conductor cable passes through the part twice, and 2,000 amp would be used if the central conductor cable passes through the part three times. The magnetic field adequacy should be verified by using the magnetic field indicator (pie gage).

7.4.2.5.3 Prods

When circular magnetization is accomplished using the contact prods, the amperage is based on the spacing of the prods and the thickness of the part. Typical requirements are 90 to 110 amp per inch of prod spacing for part thicknesses ¾ inch or less, and 100 to 125 amp per inch of prod spacing for part thicknesses greater than ¾ inch. Typical code specification requirements specify a prod spacing of 6 to 8 inches unless part size or configuration limits the spacing to less than 6 inches. In such cases, prods may be spaced as close as 2 inches.

The strength, direction, and distribution of magnetic fields are greatly affected by the type of current employed for magnetization. Therefore, a general understanding of the magnetizing characteristics of the current is important.

The magnetic fields created by alternating current and by direct current differ in many respects. The most important difference is that the magnetic field created by alternating current is confined near the surface of the part, while the magnetic field created by direct current penetrates the surface of the part to a limited extent.

This phenomenon whereby alternating current tends to flow along the surface layers of a metal conductor is referred to as the skin effect. Although this effect is not very noticeable in nonmagnetic materials until frequencies much greater than 60 Hz are reached, it is very noticeable in ferromagnetic materials even at frequencies below 60 Hz. As a result of this skin effect, magnetic fields created by alternating current also are confined to the surface layers of the material; therefore, alternating current is used primarily in surface discontinuities. Many applications, such as in-service examinations, only require detection of surface discontinuities such as fatigue cracks; therefore, magnetic fields confined to the surface of the material are more desirable than those that penetrate into the material.

7.4.3 Longitudinal Magnetization

Longitudinal magnetization is used for the detection of discontinuities that lie in the same direction as the coil orientation axis. Circumferential discontinuities around a cylinder, for example, are detected by magnetizing the cylinder longitudinally in a direction parallel with its axis. A portion of the longitudinal field crosses the discontinuities creating leakage fields that hold magnetic particles forming indications.

Longitudinal magnetization is accomplished in a number of ways; magnetization in a coil is the most widely used method. Parts can be magnetized longitudinally by placing them between a pair of electromagnets with the fields in the same direction through the part. Still another method is the magnetizing of parts between the legs of a yoke, either the electromagnetic or permanent

magnet type.

7.4.3.1 Coil Shot

The usual way to longitudinally magnetize a part is by the part in a rigid coil on a stationary magnetic particle inspection unit. Application of the rule of the thumb to the conductor at any point in the coil illustrated in Figure 7-13 shows that the field within the coil is longitudinal as indicated. The part can be positioned on the bottom surface of the coil where the field is strongest, or the part may be supported. In the coil by the contact heads of the unit, special supports are provided on some inspection units for long heavy parts permitting rotation of parts for examination. Coils are usually mounted on rails permitting movement along a long part for multiple examinations (multiple coil shots). Because the effective magnetic field extends only 6 to 9 inches on either side of a coil, multiple examinations are needed for long parts.

When a part made of magnetic material is placed inside a coil, the magnetic lines of force created by the magnetizing current concentrate themselves in the part and induce a longitudinal magnetic field. If there is a transverse discontinuity, it will attract magnetic particles, forming an indication. The strength of the magnetic field within a coil is dependent upon the current flowing through the coil, the number of turns in the coil, and the diameter (or opening) of the coil. See Table 7-1.

7.4.3.2 Cable Wrap

Wrapping a cable (Figure 7-14) around large or heavy parts is a common practice. A cable-wrapped coil is connected to the contact heads of the stationary unit. The type of power source to use depends upon the kind of current and amperage needed to accomplish the particular examination. The number of turns used is kept low (from three to five turns) to minimize cable resistance.

Multiple examinations spaced approximately 15 to 18 inches along the length of a long part are preferable to one examination using one long coil of many turns.

When longitudinal magnetization is accomplished using a hand-held coil or by wrapping cables around the part to fashion a coil, the required field strength is determined in the same manner as that described in section 7.4.3.6.

7.4.3.3 Quick Break Technique

A characteristic of longitudinal magnetization when using a coil is the difficulty in producing good indications near the ends of the part. This difficulty is caused by the leakage field that emanates from the part ends. The leakage field from these poles reduces the flux within the part, and because this leakage is at right angles to the surface, it reduces particle mobility. This holds particles in the form of background instead of permitting migration to form indications. Examination at the ends of cylindrically shaped parts is improved when the parts are magnetized using a very rapid decay of the coil field. The rapid decay of the field generates a pulse of induced current which in turn produces a strong field over most of the length of a part. This is referred to as the "Quick Break Technique."

7.4.3.4 Equipment

The equipment listed below is commonly used for longitudinal magnetization:

- Fixed rigid coil,
- Flexible coil,
- Hand portable coil,
- Electromagnetic yokes, and
- Rigid and flexible permanent magnet yokes.

7.4.3.5 Coil Field Strength Calculations

A number of factors must be considered when determining current amperage for longitudinal magnetization of parts. Some of the more important factors are:

- The coil diameter and the number of turns;
- The length to diameter (L/D) ratio of the part;
- The size, shape, and composition of the part;
- The orientation or position of the part within the coil; and
- The type of discontinuities to be detected.

The magnetizing field strength (H), in the magnetizing coil increases or decreases with either the current or number of turns. Also, the field strength decreases as the coil radius increases and vice-versa. The field is theoretically zero in the coil center and increases to a maximum value at the inside surface of the coil. Therefore, a part placed against the inside of a coil experiences a greater magnetizing field than when it is centered in the coil.

In all cases the examiner must refer to the applicable code, procedure, or examination instructions in order to determine the proper amperage for any given application.

7.4.3.6 Code Requirements - Longitudinal

In accordance with Article 7, Section V, of the ASME Code, the magnetizing current shall be within ± 10 percent of the ampere-turns value as determined by the following:

- Parts with L/D ratios equal to or greater than four:

$$\text{Ampere-turns} = 35{,}000/(L/D)+2 \qquad (7\text{-}1)$$

- Parts with L/D ratios less than four but not less than two:

$$\text{Ampere-turns} = 45{,}000/(L/D) \qquad (7\text{-}2)$$

NOTE: In both of the above L = the part length and D = the part diameter. When it is not practical to use the above because of the size or shape of the part, adequate magnetizing amperage can be determined by using the magnetic field indicator (pie gage).

Long parts must be examined in sections not to exceed 18 inches and that length (18 inches) would then be used as L in the L/D ratio for calculating the current to be used.

If the need arises to examine parts having L/D ratios of twp or less, the effective L/D ratio can be increased by placing the part between two ferromagnetic pole pieces while it is being

magnetized. The length dimension for the L/D ratio then becomes the length of the two pole pieces plus the part length. Such pole pieces must make good contact on each side of the part and must be made of ferromagnetic material.

There is no given method for field strength calculation for an alternating current or direct current yoke or permanent magnets. However, in an effort to obtain some verification of field strength and as a function check, it is required that the yoke be capable of lifting a minimum of 10 pounds (lb) for AC and 40 pounds for DC or permanent magnets before it can be used for examination.

7.4.4 Field Direction

The magnetic field must be in a favorable direction to produce indications. When the flux lines are oriented in a direction parallel to a discontinuity, the indication is weak or nonexistent. The best results are obtained when the flux lines are in a direction at right angles to the discontinuity. If a discontinuity is to produce a leakage field and a resultant indication, the discontinuity must intercept the flux lines at some angle. When magnetizing current is used, the best indications are produced when the path of the magnetizing **current** is flowing parallel to the discontinuity, because the magnetic flux lines are always at an angle of 90° to the flow of the current.

7.4.5 Multidirectional Magnetic Fields

Two separate fields, having different directions, cannot exist in a part at the same time. But two or more fields in different directions can be imposed upon a part sequentially in rapid succession. When this is done, magnetic particle indications are formed as long as the rapid alternations of field direction continue. This, in effect, acts as two or more fields in different directions at the same time, and enables the detection of discontinuities oriented in any direction in one operation.

7.4.6 Magnetizing Current

Although different types of magnetizing current can be used in MT, one type is generally best suited for a given application:

- Direct current or half-wave direct current (HWDC) is used for detection of either surface or slightly subsurface discontinuities, and
- Alternating current is only qualified for the detection of surface discontinuities.

Alternating current used for magnetizing purposes is taken from commercially available power lines and is usually 60 Hz frequency (Figure 7-15). When used for magnetizing purposes, the line voltage of 115, 220, or 440 volts (V) is stepped down by means of transformers to the 10 to 30 V required for the magnetizing unit.

Rectification - Rectified alternating current is by far the most satisfactory source of direct current. Both single phase and three phase alternating current are commercially available. Through the use of rectifiers, the constantly reversing alternating current can be converted to a unidirectional current. When three phase alternating current is rectified for magnetic particle purposes, the unidirectional direct current is almost

equivalent to straight direct current; the difference is a slight ripple in the value of the rectified current.

Rectification is achieved by single rectifier circuits may take the character of:

- Half wave rectified direct current (HWDC),
- Full wave rectified direct current (FWDC), or
- Three phase full wave rectified alternating current.

HWDC - When single phase alternating current is passed through a simple rectifier, current is permitted to flow in one direction only (Figure 7-16). The reverse half of each cycle is completely blocked out. The result is unidirectional current that pulsates. That is, it rises from zero to a maximum value and drops back to zero. During the blocked out reverse cycle, no current flows. Then the half cycle forward pulse is repeated, at the frequency of the alternating current being rectified.

FWDC - This source of pulsating unidirectional current is used for MT for certain special purpose applications (Figure 7-17). In general, FWDC possesses no advantage over half-wave and is not as satisfactory as three phase rectified current when straight direct current is required, because of its extreme ripple. Additionally, it draws a higher current from the alternating current line than does half-wave for a given magnetizing effect, which is a distinct disadvantage.

Three Phase - By far the most useful and most widely used source of direct current for MT is rectified three phase alternating current (Figures 7-18a and 7-18b). Three phase alternating current is generally used for power equipment in most plants and is preferred over single phase current because of more favorable power transmission and line load characteristics. From the MT point of view, it is also preferred because MT delivers, when rectified, current that for all practical purposes is direct current and produces all the effects which are required when direct current magnetization is indicated.

7.5 Techniques

Two major techniques of processing are used in magnetic particle examination - continuous and residual. The use of these techniques depends upon the retentivity of the parts being examined and the sensitivity of the examination to be achieved.

7.5.1 Continuous

In the continuous technique, which is required by the Code, magnetic particles are applied to a part while the part is being magnetized. Of the two techniques, continuous and residual, the continuous technique produces the greatest sensitivity for both surface and subsurface discontinuities for a given current. The magnetic field is always stronger while current is flowing as compared to after it stops.

7.5.2 Residual

In the residual technique, magnetic particles are applied to parts after they have been magnetized. Highly retentive parts can be effectively

examined using the residual technique. To use this technique parts must have sufficient retention. Because residual fields left in a part are always weaker than the applied fields which produce them, the residual technique is limited to the detection of surface discontinuities.

The residual technique can be used with both circular and longitudinal magnetization, direct or indirect methods. Detection of subsurface discontinuities is unreliable using the residual techniques. The residual technique permits the magnetizing of numerous parts at one time and the application of magnetic particles and examination at some subsequent convenient time. When the central conductor is used, holes or bores can be examined after removal of the central conductor.
As mentioned earlier, the ASME Code requires MT by the continuous technique.

7.6 Magnetic Particles

7.6.1 Visible Particles - Wet

In the past, the most common form of the particle concentrate was a paste. Today, the pastes have been almost exclusively reformulated and produced as dry powder concentrates. These powders incorporate the needed materials for dispersion, wetting, rust inhibiting, etc. The powders are much easier to use, as they need merely to be measured out and added directly to the agitated bath. The agitation system of the modern magnetic particle units pick up the powder and quickly disperse it in the bath in the ordinary process of circulation and agitation.

7.6.2 Fluorescent Particles - Wet

When exposed to near ultraviolet light (black light) fluorescent dye coated magnetic particles glow with a highly visible yellow-green color. Indications produced are easily seen and the fluorescent particles give more “seeable” indications of small discontinuities than do the ordinary visible magnetic particles. Examinations are faster and more reliable than with the visible particles.

Fluorescent particles have one major advantage over the visible particles. They give off a brilliant glow under black light, which serves three principle purposes:

- In a darkened room even very minute amounts of the fluorescent particles are easily seen, having the effect of increasing the apparent sensitivity of the process even though magnetically, the fluorescent particles are not superior to the visible particles.
- Even for discontinuities large enough to give good visible indications, fluorescent indications are much more easily seen and the chance of the examiner missing an indication is greatly reduced even when the speed of examination is increased.
- Inside drilled holes or cavities, or in sharp corners such as threads or keyways, the fluorescent indications are clearly and readily seen, while visible indications may be easily obscured.

7.6.3 Advantages of Wet Particles

The advantages of wet particles are summarized below:

- It is most sensitive for very fine surface cracks.
- It is the most sensitive method for very shallow surface cracks.
- It quickly and thoroughly covers all surfaces of irregularly-shaped parts, large or small, with magnetic particles.
- It is the fastest and most thorough method for the examination of large numbers of small parts.
- The magnetic particles have excellent mobility in liquid suspension.
- It is easy to measure and control the concentration of particles in the suspension, which makes for uniformity and accurate reproducibility of results.
- It is well adapted to the short, timed shot technique of magnetization for the continuous method.
- It is readily adaptable to automated examination.

7.6.4 Limitations of Wet Particles

The limitations of wet particles are summarized below:

- Usually wet particles are as reliable of finding discontinuities lying below the surface as dry particles.
- It is messy to work with, especially when used in the field testing.
- A recirculation system is required to keep the particles in suspension.
- It sometimes presents a post-examination cleaning problem.

7.6.5 Dry Particles

Dry particles are primarily used for the examination of welds and castings where the detection of discontinuities lying slightly below the surface is considered important. Dry particles are provided in powder form. They are available in red, black, yellow, and gray colors. The magnetic properties, particle size and shape, and coating method are similar in all colors making the particles equally efficient. The choice of powder is then determined primarily by which powder will give the best contrast and visibility on the parts being examined and the degree of sensitivity desired.

7.6.6 Advantages of Dry Particles

The advantages of dry particles are summarized below:

- Excellent for locating discontinuities which are slightly below the surface,
- Easy to use for large objects with portable equipment,
- Easy to use for field examinations with portable equipment,
- Good mobility when used with alternating current or HWDC,
- Not as messy as the wet particles, and
- Equipment usually less expensive.

7.6.7 Limitations of Dry Particles

The limitations of dry particles are summarized below:

- Not as sensitive as the wet method for very fine and shallow cracks;
- Not easy to cover all surfaces properly, especially of irregularly-shaped or large parts;
- Slower than the wet particles for large numbers of small parts; and
- Difficult to adapt to an automated test system.

7.6.8 Particle Characteristics

The particles used in MT are made of finely divided ferromagnetic materials, usually combinations of iron and iron oxides, having a high permeability and low retentivity. Other properties of importance that affect the sensitivity of the MT are the size, shape, density, mobility, and visibility or contrast of the particles.

7.6.8.1 Wet Particle Concentration

The strength or concentration of the particle suspension is a major factor in determining the reliability of the examination. Too heavy a concentration of particles in the suspension gives a confusing background and excessive adherence of particles at external poles, which might mask the indications of fine discontinuities. If the concentration of particles in the suspension is too low, then indications may not be formed at all. Many codes and specifications require a daily check of the concentration using a settling test (Figure 7-19).

Code required concentrations are as follows:

Visible Particles-1.2 to 2.4 milliliter (ml)/100ml of solution

Fluorescent Particles - 0.1 to 0.5ml/100ml of solution

7.6.8.2 Particle Size

Size plays an important part in the behavior of magnetic particles when in a magnetic field. A large, heavy particle is not likely to be attracted to and held by a weak field when the particles are flowing over the surface of a part. Fine powders are held by very weak fields, since their mass is small. Extremely fine particles may adhere to the surface where there are no discontinuities, especially if the surface is rough, and form confusing backgrounds.

7.6.8.3 Particles for Wet Suspensions

When the ferromagnetic particles are applied as a suspension in a liquid medium, much finer particles can be used. The upper limit of particle size in most wet method visible materials used for magnetic particle testing purposes is in the range of 20 to 25 microns (about 0.0008 to 0.0010 inch). Particles larger than this are difficult to hold in suspension, and even the 20 to 25 micron sizes settle out of suspension rather rapidly and are stranded as the suspension drains off. Such stranded particles often line up in what are called drainage lines to form a “high water mark” of particles that could be confused with indications of

discontinuities. With the finer particles, the stranding due to the draining away of the liquid occurs much later, giving the particles mobility long enough to reach the influence of leakage fields and accumulate to form the indications. The minimum size limit for particles to be used in liquid suspensions is indeterminate. Ferromagnetic materials commonly used include some exceedingly fine particles. In actual use, however, particles of this size never act as individuals because they are magnetized in use and actually become tiny magnets.

7.6.8.4 Particle Shape

The shape of the magnetic particles used for MT has a strong effect upon their behavior in locating discontinuities. In a magnetic field, the particles tend to align themselves along the lines of force, as illustrated in a magnetograph. This tendency is much stronger with elongated, rod-like particles than with more compact or globular shapes because the longer shapes develop stronger polarity. Because of the attraction exhibited by opposite poles, the pronounced north and south poles of these tiny magnets arrange themselves into strings much more readily than do globular shapes. The result is the formation of stronger patterns in weak leakage fields, as these magnetically formed strings of a particle bridge at the discontinuity.

The superior effectiveness of the elongated shapes over the globular shapes is particularly noticeable in the detection of wide, shallow discontinuities, or discontinuities that lie wholly below the surface. The leakage fields at such discontinuities are more diffuse, and the formation of strings because of the stronger polarity of the elongated shaped magnetic particles produces stronger patterns.

7.6.8.5 Magnetic Particle Properties

Magnetic particles should have as high a permeability as possible; they must be readily magnetized by the low-level leakage fields that occur in the vicinity of discontinuities.

Permeability is a desirable property for magnetic particles, but unless all other properties are in the proper range for the particular application, high permeability alone is of little value.

Low retentivity is a desirable property of magnetic particles. If the retentivity were high, the particles would become magnetized during manufacture or at first use, and become permanent magnets. Once magnetized, their tendency to be controlled by the weak fields at discontinuities would be overshadowed by their tendency to stick to the test surface. This would reduce mobility and form a high background that reduces contrast and makes indications more difficult to distinguish.

7.6.8.6 Particle Mobility

When the magnetic particles are applied to the surface of a magnetized part, they must move under the influence of the leakage field and gather at a discontinuity to form a readable indication. Any factor that interferes with the movement of the particles has a direct effect on the sensitivity of the powder and the test. Conditions promoting or interfering with mobility are different for dry and

wet method materials.

Dry powders should be applied in such a way that they reach the magnetized surface in a uniform cloud with a minimum of motion. When the particles are applied to a horizontal or sloping surface, they settle directly to the surface and do not have the same degree of mobility. Mobility can be achieved in this case, however, by tapping or vibrating the part. This jars the powder loose from the surface and permits it to move toward the leakage fields.

When alternating current, HWDC, or pulsating direct current is used for magnetization, the rapid variation in field strength, while the current is on, imparts motion to the surface of the part. The vibration of the particles gives them excellent mobility for the formation of indications. The coatings applied to some of the dry method powders to give color to the indications serve a double purpose in that they also reduce friction between particles and the surface of the part and contribute to mobility.

The suspension of particles in a liquid allows mobility for the particles in two dimensions when the suspension flows over the surface of the part; and in three dimensions, when the magnetized part is immersed in the suspension. Wet particles have a tendency to settle out of suspension, either in the tanks of the unit or somewhere on the test surface short of the discontinuity. To be effective, the magnetic particles must move along with the liquid and reach every surface that the liquid covers.

7.7 Stationary Equipment

A typical stationary wet horizontal unit of intermediate size is illustrated in Figure 7-20. The unit has two contact heads for either direct contact or use of a central conductor. This unit also contains a coil used for longitudinal magnetization. The coil and one contact head are movable on the rails. The other contact head is fixed; the contact plate on it, being air cylinder operated, provides a means for clamping the part. The unit has a self-contained power supply with all the necessary electrical controls. Magnetizing currents are usually three phase full-wave direct current or alternating current depending upon usage requirements. The units are made in several different sizes to accommodate different length parts and with various maximum output current. A full length tank with pump, agitation, and circulating system for wet suspension is located beneath the head and coil mounting rails. A hand hose with nozzle is provided for applying the suspension. On special units, automatic bath application facilities are provided.

This unit is used for the wet method with either the visible or the fluorescent magnetic particles. The unit is equipped with a black light seen mounted on the back rail, and a hood and curtains that may be drawn to exclude white light when fluorescent particles are used.

Direct current, derived from full wave rectified three phase alternating current, is delivered to the adjustable contact heads for circular magnetization. The coil is provided for longitudinal magnetization. This unit is equipped with the infinitely variable current control by means of a

saturable core reactor, and also with the self-regulating current control.

7.8 Portable Equipment

7.8.1 Yokes

Magnetic yokes are small and portable. They are very easy to use and are adequate when examining small parts and welds. They induce a strong magnetic field into that portion that lies between the poles or legs of the yoke. The induced field flows from one leg of the yoke to the other in an orientation as shown in Figure 7-21. Yokes are available with either fixed or articulated legs. Yokes are available for operation from a 115 V, 60 Hz alternating current outlet, and some are equipped with a rectifier so HWDC can be used. Permanent magnetic yokes are also available, which permit examinations to be performed without the need for electric current.

7.8.1.1 Electro-Magnet Yokes

Electro-magnetic yokes, sometimes referred to as AC yokes, are U-shaped cores of soft iron with a coil wound around the base of the U. When alternating current or rectified alternating current is passing through the coil the two ends of the core are magnetized with opposite polarity, the combination is an electromagnetic yoke with a magnetic field similar to that of a permanent horseshoe magnet. A yoke induces a longitudinal field in a part. Electrical current does not pass through the part.

The alternating current polarity reversal at the 60 Hz rate produces a vibratory action at the surface of the test part which increases particle mobility. Alternating current yokes also can be used for demagnetization.

7.8.1.2 Permanent Magnet Yokes

Permanent magnets are sometimes used to produce a distorted longitudinal field in the part being examined. The strong fields at the poles of the permanent magnet can create confusion due to the adherence of particles at the poles.

When the legs of a permanent magnet yoke are placed on the surface of the part, the field travels through the object from one pole to the other. Along a straight line drawn between the poles, the flux is relatively straight and is strongest near the poles of the yoke.

7.8.2 Prods

Circular magnetization can be accomplished by using mobile or portable units equipped with cables and contact prods.

7.8.2.1 Contact Prods

The contact prods (Figure 7-22) are placed in position on the surface to be examined. The magnetizing current passing through and between the two prods creates a circular field suitable for detecting discontinuities oriented along a line between the prods. Great care must be used to prevent local overheating, arcing, or burning the surface being examined, particularly on high-carbon or alloy materials where hard spots or

cracks could be produced.

7.8.2.2 Contact Clamps

Contact clamps can be used with cables instead of contact prods, particularly when the parts are relatively small in diameter. Parts like tubular structures can be examined by positioning the clamps so that current passes through the area under examination. Care must be used to avoid burning of the part under the contact pads. Burning and heating may be caused by dirty contacts, insufficient contact clamp pressure, or excessive currents.

7.8.3 Coils

7.8.3.1 Hand-Held Coil

For longitudinal magnetization of shafts (Figure 7-23), spindles, axles, and similar small parts, the hand-held coil offers a simple, convenient approach wherever a coil can be applied around the part. Parts may be magnetized and demagnetized with the same coil. Either dry powder or a wet particle suspension can be used.

7.8.3.2 Cable Wrap

Cable wrapping a coil around large or heavy parts is a common practice (refer to Figure 7-14). Flexible, insulated copper cables used with mobile or portable units are wrapped around the part to fashion a coil. One end of the flexile cable is connected to the common connector on the magnetizing unit, and the other end is connected to either the alternating current or the direct current connector. The electric current passing through the cable creates a longitudinal magnetic field in the part.

7.9 Applications

7.9.1 Solid Cylindrical Parts

For this technique, magnetization is accomplished by passing current through the part to be examined. This produces a circular magnetic field that is approximately perpendicular to the direction of current flow in the part. Direct or rectified (half-wave rectified or full-wave rectified) magnetizing current should be used.

7.9.2 Hollow Cylindrical Parts

For this technique, a central conductor is used to examine the internal surfaces of ring or cylindrically shaped parts. The central conductor technique may also be used for examining the outside surfaces of these shapes. Where large diameter cylinders are to be examined, the conductor should be positioned close to the internal surface of the cylinder. When the conductor is not centered, the circumference of the cylinder should be examined in increments, and a magnetic particle field indicator should be used to determine the extent of the arc that may be examined for each conductor position. Bars or cables passed through the bore of a cylinder may be used to induce circular magnetization.

The magnetizing current to be used should be as described in section 7.4.2.5. The magnetic field increases in proportion to the number of times a central conductor cable passes through a hollow part. For example, if 6,000 amp are required to

examine a part using a single central conductor, 3,000 amp are required when two turns of the through cable are used; and 1,200 amp are required if five turns are used. When the central conductor technique is used, magnetic field adequacy should be verified using a magnetic particle field indicator.

7.9.3 Welds

For the prod technique, magnetization is accomplished with the prods in contact with the surface in the area to be examined. To avoid arcing, a remote control switch, which may be built into the prod handles, should be provided to permit the current to be turned on only after the prods have been properly positioned and shut off before prod removal. Direct or rectified magnetizing current should be used. The current should be 100 amp (minimum) per inch to 125 amp (maximum) per inch of prod spacing for sections ¾-inch thick or greater. For sections less than ¾-inch thick, the current should be 90 to 110 amp/inch of prod spacing.

Prod spacing should not exceed 8 inches. Shorter spacing may be used to accommodate the geometric limitations of the area being examined or to increase the sensitivity, but prod spacing of less than 3 inches are usually not practical due to banding of the particles around the prods. The prod tips should be kept clean and dressed. If the open circuit voltage of the magnetizing current source is greater than 25V, lead, steel, or aluminum (rather than copper) tipped prods are recommended to avoid copper deposits on the part being examined. Alternating current yokes would be used in the same manner assuring complete coverage through overlaps.

7.9.4 Castings

The current and prod spacing should be as specified for welds. In order to assure complete coverage for large castings, it is recommended that a grid pattern be established. Alternating current yokes are also effective for the examination of castings.

7.10 Demagnetization

Any ferromagnetic material subjected to MT examination may require demagnetization, and the examiner should understand the reasons for this step, as well as the problems that may be encountered and how they may be solved.

The earth's field can effect the demagnetizing of parts. A long part to be demagnetized should be placed so that the axis of its longest member is in an east and west direction. A long part lying in a north and south direction can be difficult to demagnetize below the level of the earth's field. Rotating the part or structure on its east-west axis while demagnetizing often helps reduce the field in transverse members that are not lying east and west. Total removal of all residual magnetic fields is virtually impossible.

7.10.1 Principles of Demagnetization

Demagnetization may be accomplished in a number of different ways. One of the most common is to subject the magnetized part to a magnetizing force that continually reverses its

direction while it is gradually decreasing in strength. As the decreasing magnetizing force is applied, first in one direction and then in the opposite direction, the residual magnetization of the part is decreased. Generally, a high intensity demagnetizer is used as depicted in Figure 7-24a and 7-24b. AC demagnetization is most common but does not demagnetize as deep or complete as a DC step down unit.

This decreasing magnetization is accomplished by smaller and smaller hysteresis loops created by the application of decreasing current as shown in Figure 7-25. A smaller and narrower hysteresis loop is indicative of lower residual magnetism. All steels have a certain amount of coercive force, making it extremely difficult if not totally impossible to demagnetize them completely. In fact, the only way to completely demagnetize some materials is to heat them to their Curie point or above. Under normal conditions a part is considered to be satisfactorily demagnetized if, when checked with a field indicator, the magnetic field is below minimum limits.

The Code (Section V) requires demagnetization when the residual field in the part:

- Could interfere with subsequent processing or usage such as machining operations where chips will adhere to the surface of the part or the tip of a tool may become magnetized from contact with the magnetized part. Such chips can interfere with smooth cutting by the tool adversely affecting both finish and tool life.

Other reasons to demagnetize would be in cases where residual magnetism:

- May interfere with electric arc welding operations. Residual magnetic fields may deflect the arc away from the point at which it should be applied.
- May interfere with the functioning of the part itself, after it is placed into service. Magnetized tools, such as milling cutters, hobs, etc., may hold chips and cause rough surfaces, and may even be broken by adherent chips at the cutting edge.
- Moving parts, especially those running in oil, may hold particles; for instance, on balls or races of ball bearings, or on gear teeth causing wear.
- May hold particles that interfere with later applied coatings such as plating or paint.

Demagnetization may not be required where:

- Part material is a low carbon steel and has low retentivity.
- The material consists of structural parts such as weldments, large castings, boilers, etc., where the presence of a residual field would have little or no effect on the proper performance of the part.
- The part is to be subsequently processed or heat-treated and in the process will become heated above its Curie point, or about 770 °C (1390°F) for steel.
- A part is to be subsequently re-magnetized in another direction to the same or higher level at which it was originally magnetized as, for example, between the steps of circular and longitudinal magnetizing, for MT purposes.

- The magnetic field contained in a finished part is such that there are no external leakage fields measurable by ordinary means (i.e., circular magnetization).

7.10.2 Measuring Residual Fields

The field indicator, a pocket instrument, is used to determine the relative intensity of residual fields in a part.

When this field indicator is placed near a part that has been demagnetized, it indicates the relative field strength of the residual magnetism.

A Gauss meter or a compass can also be used sometimes to measure the presence of residual magnetic fields.

7.11 Procedure Requirements

Maximum sensitivity is achieved when discontinuities are oriented perpendicular to the lines of flux. For optimum effectiveness in detecting discontinuities, each area should be examined at least twice, with the lines of flux during one examination approximately perpendicular to the lines of flux during the other.

Examination procedures are commonly based on the following information:

- The materials, shapes, or sizes to be examined, and the extent of the examination;
- Magnetization techniques to be used;
- Equipment to be used for magnetization;
- Surface preparation (finishing and cleaning);
- Type of ferromagnetic particles to be used: manufacturer, color, wet or dry, etc.;
- Magnetization currents (type and amperage); and
- Demagnetization

Examinations are most commonly done by the continuous method; that is, the magnetizing current is on while the particles are being applied and while the excess particles are being removed.

7.12 Calibration

7.12.1 Frequency

Each piece of magnetizing equipment with an ammeter must be calibrated at least once a year, or whenever the equipment has been subjected to major repair, periodic overhaul, or damage. If equipment has not been in use for a year or more, calibration should be done prior to first use.

7.12.2 Tolerance

The unit's meter reading should not deviate by more than ±10 percent of full scale, relative to the actual current value as shown by the test meter.

NOTE: When measuring half-wave rectified current with a direct current test meter, readings shall be multiplied by two.

7.12.3 Procedure

The accuracy of the unit's meter should be verified annually by equipment traceable to a national standard. Comparative readings should

be taken for at least three different current output levels encompassing the usable range.

7.12.4 Yoke Calibration

The Code requires yokes to be checked at least once a year or whenever a yoke has been damaged.

- Each AC yoke must be capable of lifting at least 10 pounds at the maximum pole spacing that will be used.
- Each direct current yoke or permanent magnet yoke must be capable of lifting at least 40 pounds at the maximum pole spacing that will be used.

7.13 Surface Preparation

Satisfactory results are usually obtained when the surfaces are in the as-welded, as-rolled, as-cast, or as-forged conditions. However, surface preparation by grinding or machining may be necessary where surface irregularities could mask indications due to discontinuities.

Prior to MT examination, the surface to be examined and all adjacent areas within at least one inch, should be dry and free of all dirt, grease, lint, scale, welding flux and spatter, oil, or other extraneous matter that could interfere with the examination.

Cleaning may be accomplished using detergents, organic solvents, descaling solutions, paint removers, vapor degreasing, sand or grit blasting, or ultrasonic cleaning methods.

If coatings are left on the part in the area being examined, it must be demonstrated that indications can be detected through the maximum coating thickness applied. ASME Section V Article 7 Appendix I should be referred to for the MT examination of water surfaces.

7.14 Magnetic Field Verification

When it is necessary to verify the adequacy or direction of the magnetizing field, a magnetic field indicator, commonly referred to as the pie gage, shown in Figure 7-26 may be used. The indicator is positioned on the surface of the part being examined with the copper side up. Using the continuous method, the magnetic particles are applied to the copper face of the indicator. Formation of clearly defined indications across the copper face is evidence that the flux density, or field strength, is adequate and also indicates the direction of the magnetic field. A Hall Effect meter may be used and a minimum of 30 gauss to a maximum of 60 gauss is required. QQI's are also permitted to be used to verify the field adequacy.

7.15 Evaluation

7.15.1 Evaluation Terms

Several key terms relating to the evaluation of results are discussed in the following sections:

7.15.1.1 Indications

In MT examinations an indication is an accumulation of magnetic particles on the surface of a part. The indication may be caused by a discontinuity, by some other condition that produces a leakage field, by a surface contaminant, or they

may be held by gravity. As described in Chapter 3, false indications are held by mechanical forces and nonrelevant indications caused by part configuration.

A discontinuity indication is particle buildup, which is caused by an interruption in the normal physical structure or configuration of a part.

7.15.1.2 Nonrelevant Indications

Magnetic Writing - This is a condition caused by a piece of steel rubbing against another piece of steel that has been magnetized. Since either or both pieces contain some residual magnetism, the rubbing or touching creates magnetic poles at the points of contact. These local magnetic poles are usually in the form of a line or scrawl and for this reason the effect is referred to as magnetic writing.

Cold Working - Cold working consists of changing the size or shape of a metal part without raising its temperature before working. When a bent nail is straightened with a hammer, the nail is being cold worked. Cold working usually causes a change in the permeability of the metal where the working occurs. The boundary of the area of changed permeability may attract magnetic particles when the part is magnetized.

Hard or Soft Spots - If there are areas of the part which have a different degree of hardness than the remainder of the part, these areas will also exhibit a different permeability. When a part with such areas of different permeability is examined, the boundaries of the areas may create local leakage fields and attract magnetic particles.

Boundaries of Heat Treated Sections - Heat treating consists of heating a part to a high temperature and then cooling it under controlled conditions. The rate of cooling may be relatively rapid or slow, depending upon the desired characteristics of the material. Both hardness and grain size of a material can be changed by varying the temperature and the rate of cooling. On a cold chisel, the point is hardened to cut better and to hold an edge. The head of the chisel, which is the end struck by the hammer, is kept softer than the cutting edge so that it does not shatter and break. The edge of the hardened zone frequently creates a permeability change resulting in a magnetic particle indication.

Abrupt Change of Section - Where there are abrupt changes in section thickness of a magnetized part, the magnetic field may be said to expand from the smaller section to the larger. Frequently this creates local poles due to magnetic field leakage or distortion. If there is a crack or discontinuity in that area of change, it will usually produce an indication which is sharper and it probably will not extend the entire length of the abrupt change.

On parts with keyways, a circular magnetic field can also create nonrelevant indications. The magnetic field is forced out of the part by the thinner section at the keyway.

A gear with a spline magnetized circularly by passing current through a central conductor, as a result of the reduced cross section created by the spline, constricts the magnetic lines of force and some of them break the outer surface. Particles gather where the magnetic lines of force break through the surface thereby creating indications.

7.15.1.3 Interpretation of Nonrelevant

It may at first appear that some types of non-relevant indications discussed and illustrated in the preceding material would be difficult to recognize and interpret. However, there are several characteristics of nonrelevant indications that enable the operator to recognize them in the example cited and under most other conditions. These characteristics of nonrelevant indications are:

- On all similar parts, given the same magnetizing technique, the indications occur in the same location and have identical patterns.
- The indications are usually uniform in direction and size.
- The indications are usually “fuzzy” rather than sharp and well defined.
- Nonrelevant indications can always be related to some feature of configuration or cross section; this accounts for the leakage field creating the indication.

7.15.1.4 True Discontinuity Indications

If the indication is caused by a discontinuity at the surface of the part, the particles are usually tightly held to the surface by a relatively strong magnetic leakage field and are sharp and well defined.

If the indication is caused by a discontinuity below the surface, it will be a broad and fuzzy accumulation of particles. The particles in such an indication are less tightly held to the surface because the leakage field is weaker.

Indications

The various referencing Code sections specify evaluation of indications based on whether they are linear or rounded and their dimensions.

7.15.2 Evaluation Guide

As a guide, the following basic considerations may be used in the evaluation of indications:

- A discontinuity of any kind lying at the surface is more likely to be harmful than a discontinuity of the same size and shape that lies below the surface.
- Any discontinuity having a principal dimension or a principal plane that lies at right angles or at a considerable angle to the direction of principal stress, whether the discontinuity is surface or sub-surface is more likely to be harmful than a discontinuity of the same size, location, and shape lying parallel to the stress.
- Any discontinuity that occurs in an area of high stress must be more carefully considered than a discontinuity of the same size and shape in an area where the stress is low.
- Discontinuities that are sharp, such as cracks, are severe stress-risers and are more harmful in any location than rounded discontinuities such as porosity.
- Any discontinuity which occurs in a location close to a keyway or fillet must be considered to be more harmful than a discontinuity of the same size and shape that occurs away from such a location.

7.16 Recording

A technique sketch is normally prepared for each different part examined, showing the part geometry; MT equipment, arrangement, and connections; magnetizing current; and the areas of examination. Other examination data in addition to the technique sketch should also be recorded including:

- Equipment used,
- Techniques,
- Current,
- Type of particles,
- Surface conditions,
- Results of examinations,
- Demagnetization results, and
- Other pertinent information.

7.17 Advantages and Limitations of MT Examination

7.17.1 Advantages

The advantages of MT are summarized below:

- MT can detect surface and near surface discontinuities not detectable visually.
- Surface preparation usually is not as critical as for Penetrant Examinations.
- Surfaces that have thin coatings can usually be examined.
- Size and configuration of the part is usually not a limiting factor.
- MT is a fast and simple examination.
- MT can be automated to some extent.
- Some equipment is portable and can be used in remote locations.
- Direct indications are produced.
- Minimum post cleaning is necessary.

7.17.2 Limitations

The limitations of MT are summarized below:

- MT can only be used effectively on ferromagnetic material.
- Detection sensitivity decreases rapidly with discontinuity depth.
- Good electrical contact is necessary for some techniques.
- Orientation of magnetic field in relation to discontinuity is important.
- High electrical currents are required for some applications.
- Improper technique may result in overheating of parts and arc strikes on the part surface.
- Demagnetization may be required.
- MT is not reliable for detection of fine porosity.

Table 7-1 Typical Coil Shot Currents (amperes) for a Five Turn Coil

(L) PART LENGTH IN INCHES	(D) PART DIAMETER IN INCHES	L/D RATIO	AMPERE-TURNS REQUIRED	AMPERES REQUIRED
8	4	2	22,500	4,500
12	3	4	11,250	2,250
12	2	6	7,500	1,500
16	2	8	5,625	1,125
10	1	10	4,500	900
18	1.5	12	3,750	750
14	1	14	3,214	643

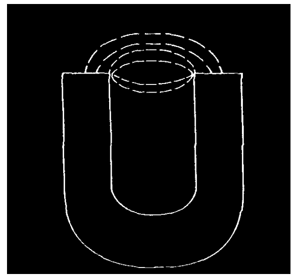

Figure 7-1a Horseshoe Magnet

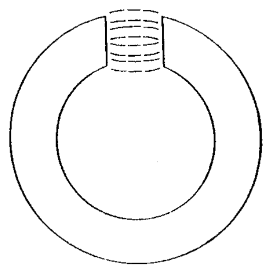

Figure 7-1b Horseshoe Magnet with Poles Close Together

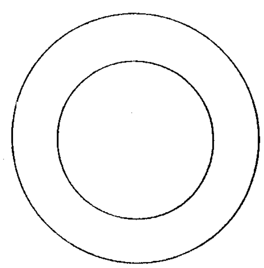

Figure -1c Horseshoe Magnet Fused into Ring

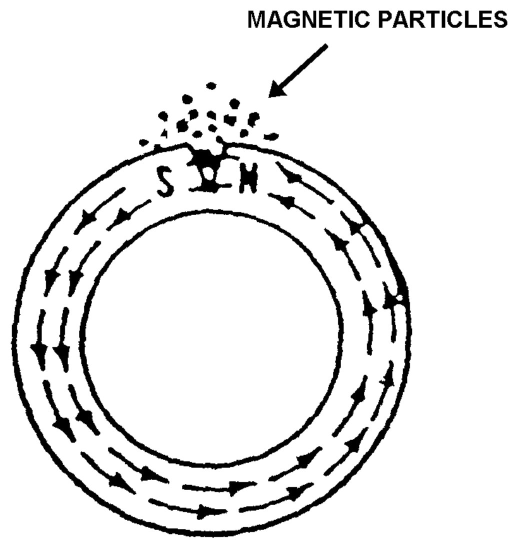

Figure 7-2 Crack in Fused Horseshoe Magnet

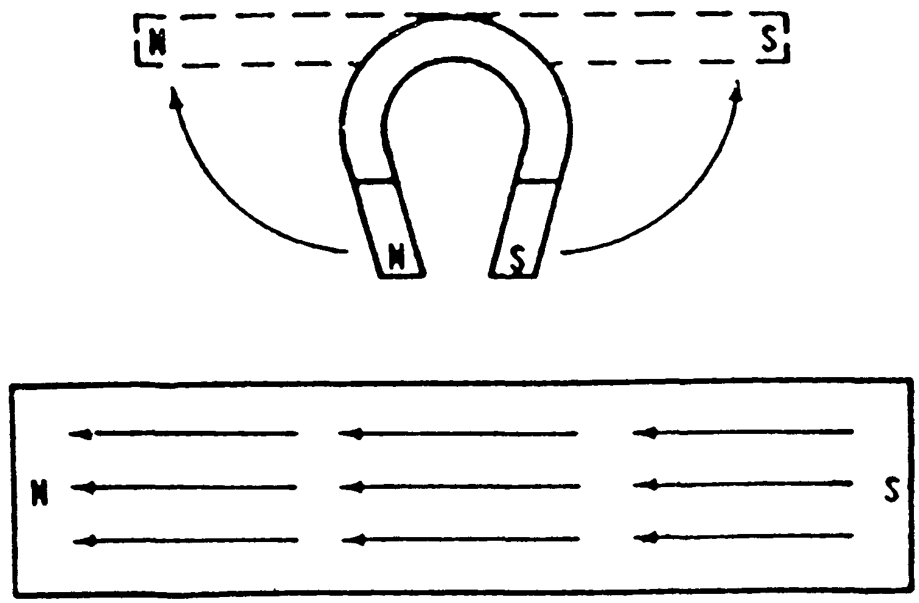

Figure 7-3 Horseshoe Magnet Straightened To Form Bar Magnet

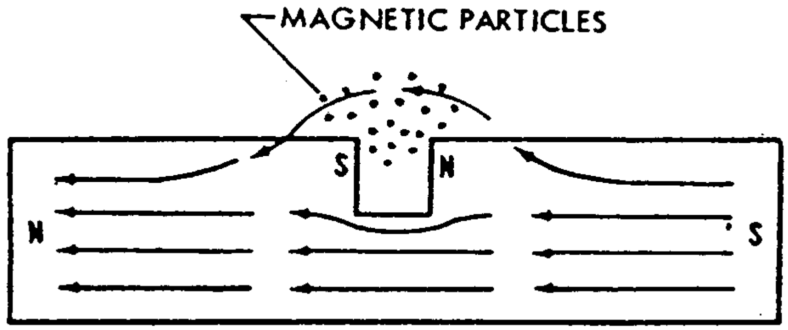

Figure 7-4a Slot in Bar Magnet Attracting Magnetic Particles

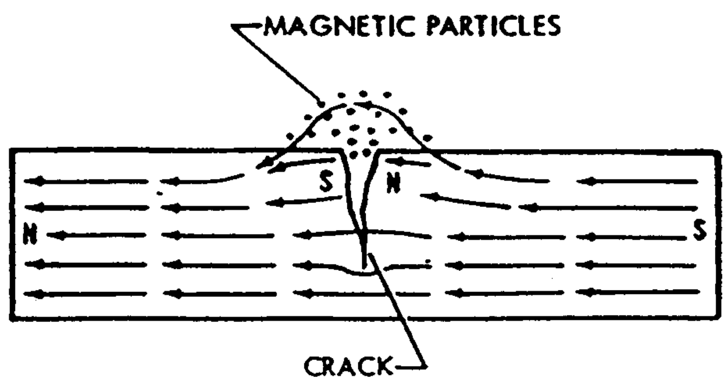

Figure 7-4b Crack in Bar Magnet Attracting Magnetic Particles

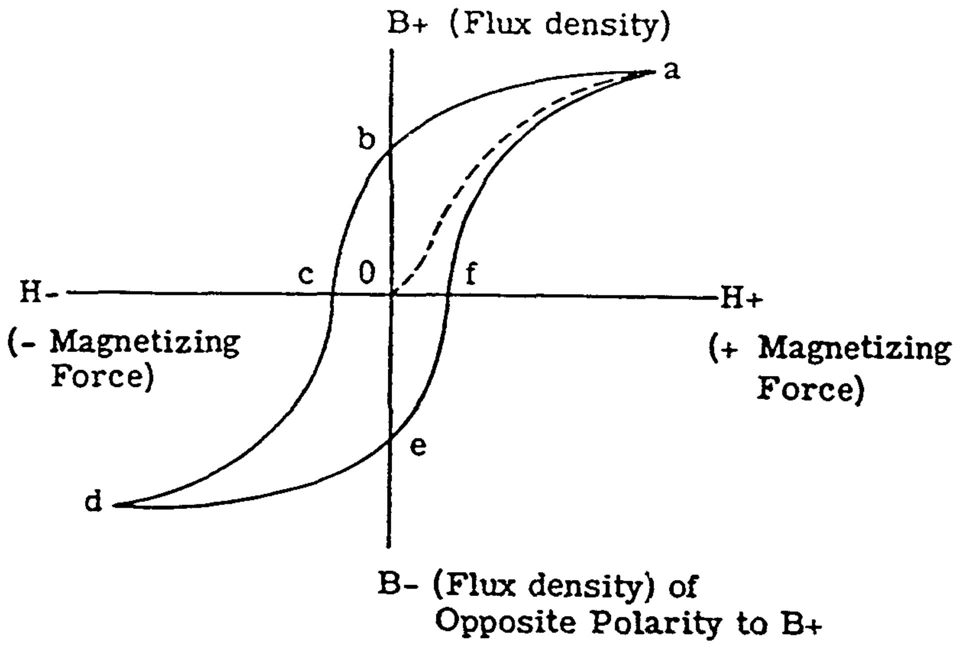

Figure 7-5 The Hysteresis Loop

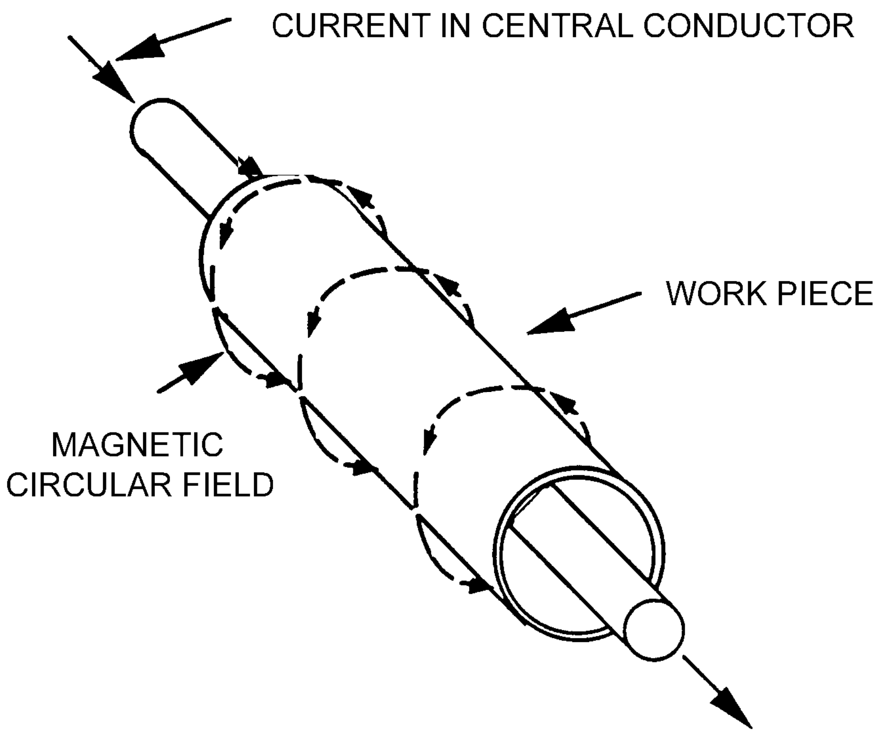

Figure 7-6 Magnetic Field in a Part

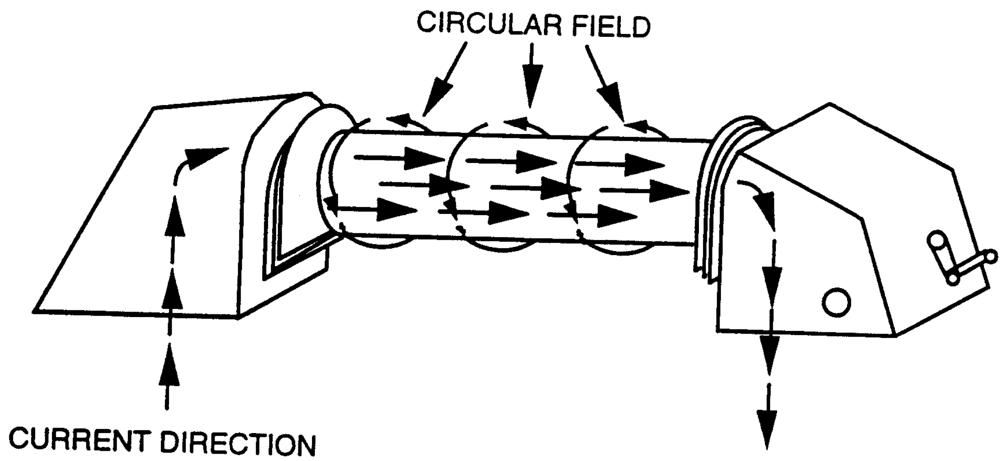

Figure 7-7 Direct Magnetization - Head Shot

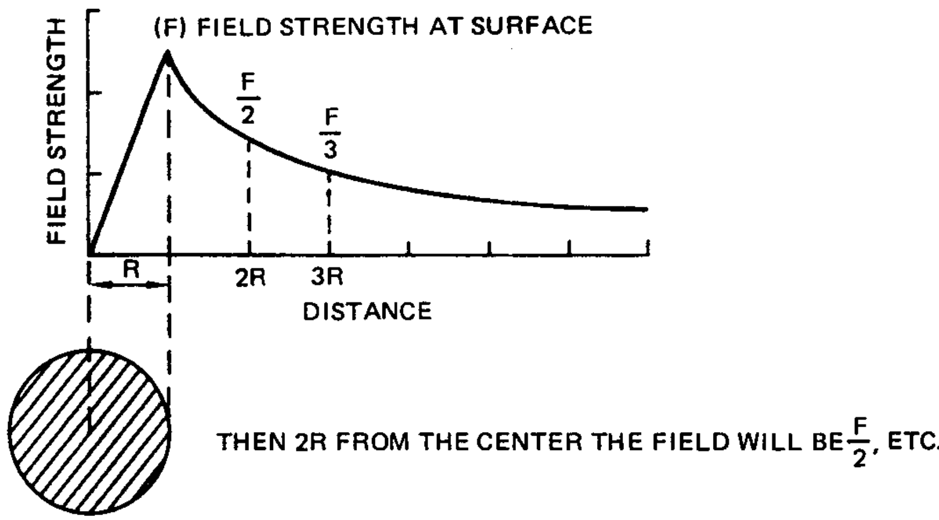

Figure 7-8 Magnetic Field Distribution for a Solid Nonmagnetic Conductor Carrying Direct Current

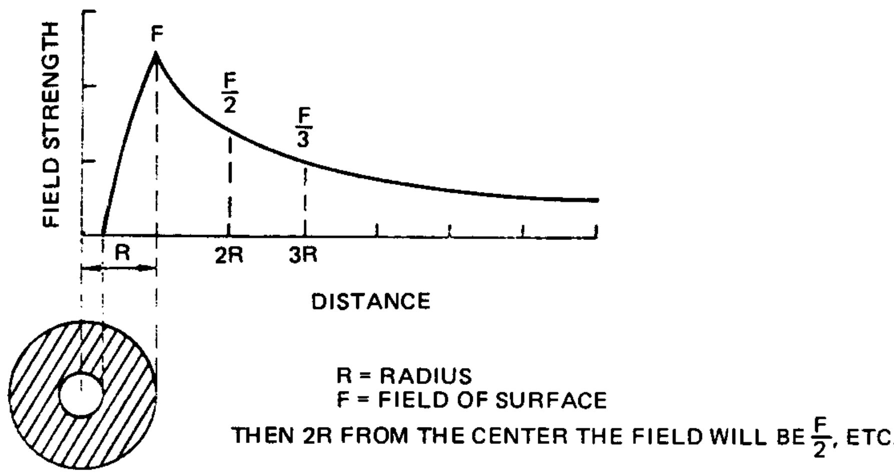

Figure 7-9 Magnetic Field Distribution for a Hollow Nonmagnetic Conductor Carrying Direct Current

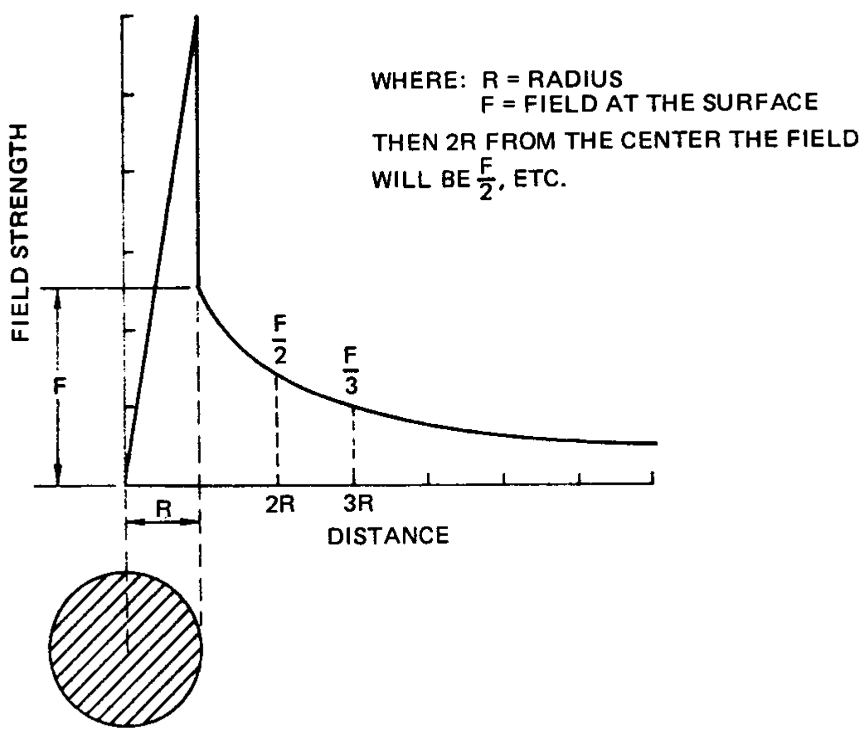

Figure 7-10 Magnetic Field Distribution for a Solid Magnetic Conductor Carrying Direct Current

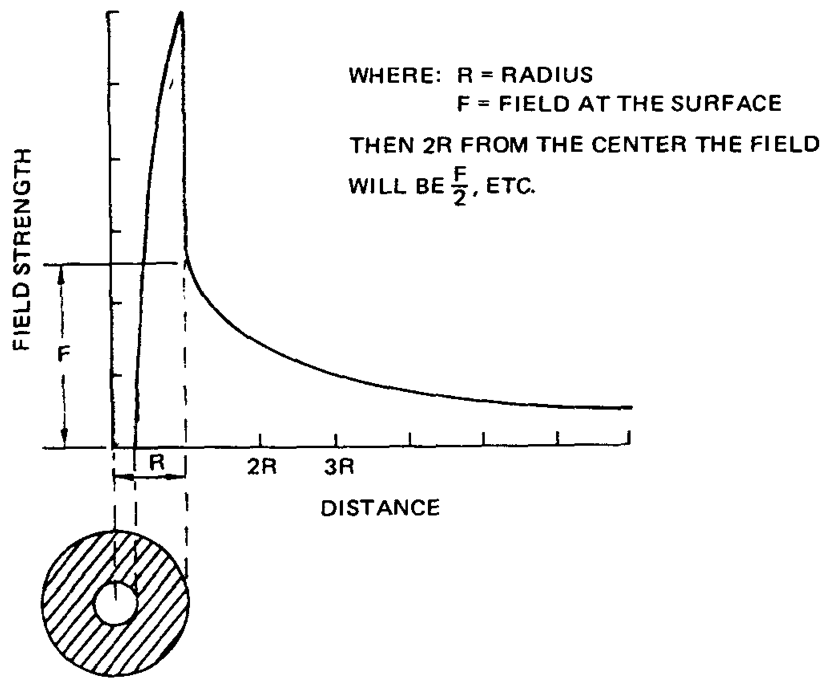

Figure 7-11 Magnetic Field Distribution for a Hollow Magnetic Conductor Carrying Direct Current

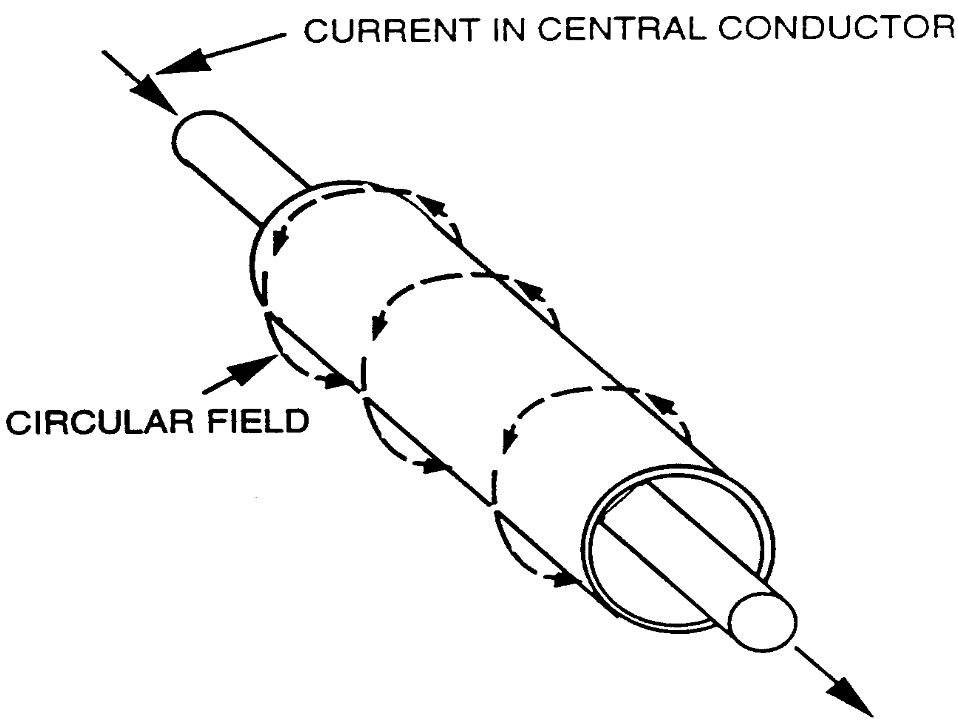

Figure 7-12 Central Conductor Technique

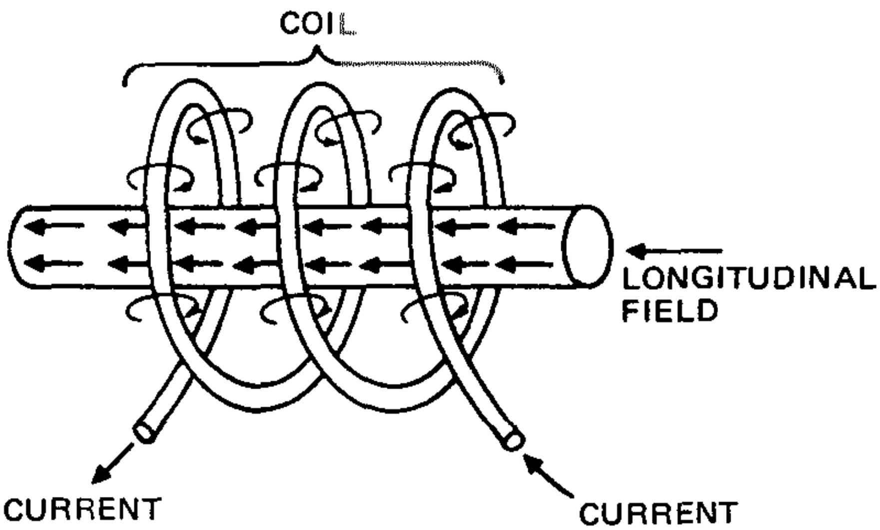

Figure 7-13 Longitudinal Magnetization - Coil Shot

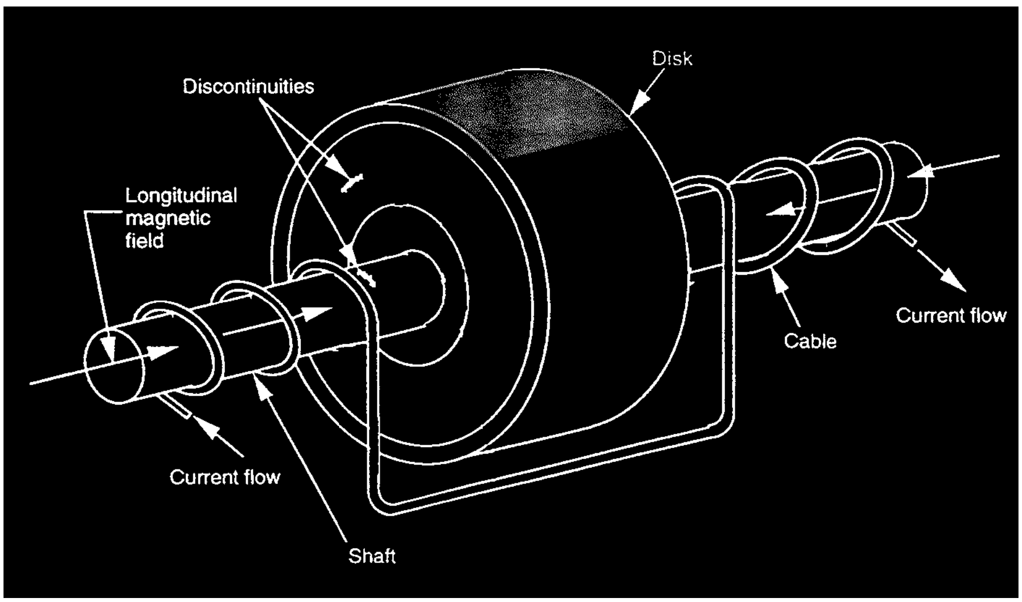

Figure 7-14 Cable Wrap Technique

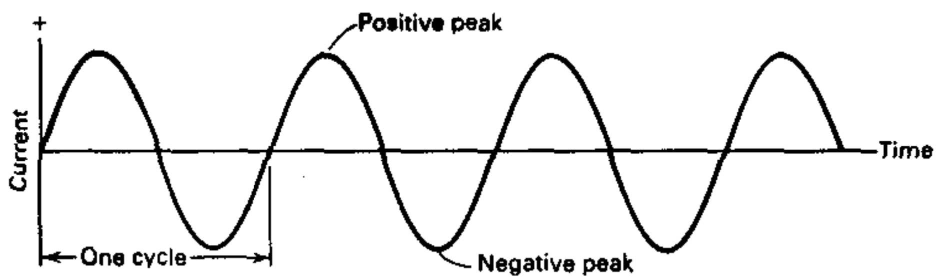

Figure 7-15 Single Phase Alternating Current Wave Forms

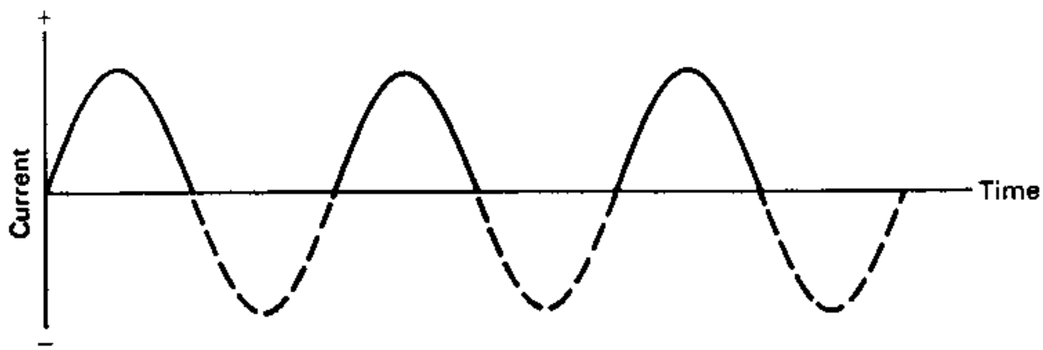

Figure 7-16 Rectification of Alternating Current to Half Wave Direct Current

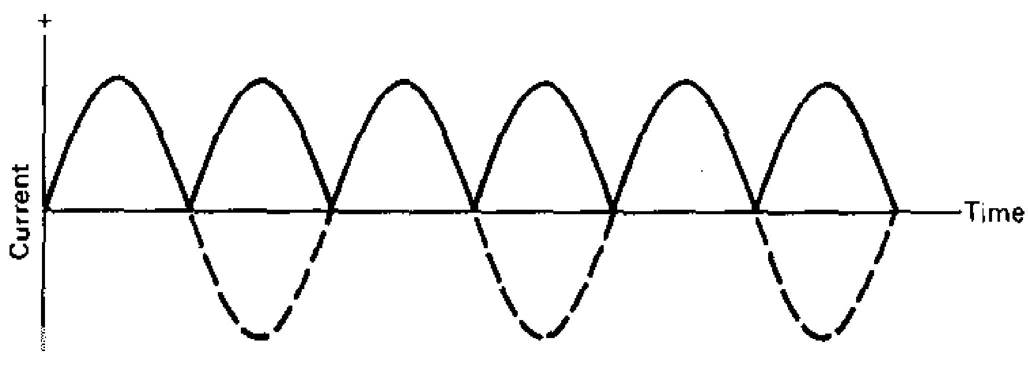

Figure 7-17 Full Wave Direct Current

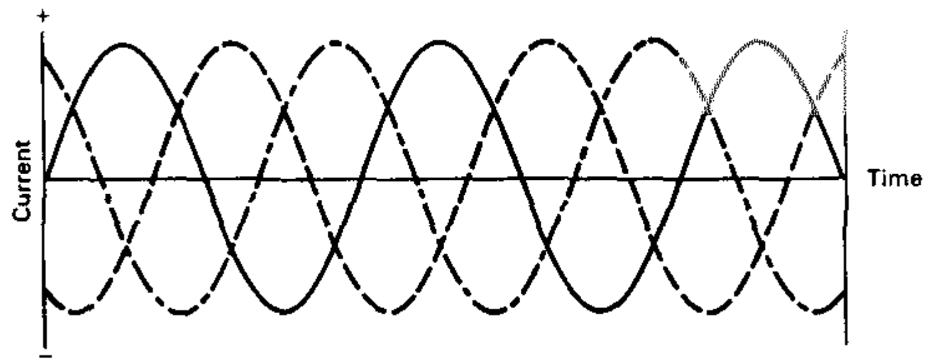

Figure 7-18a Three Phase Alternating Current

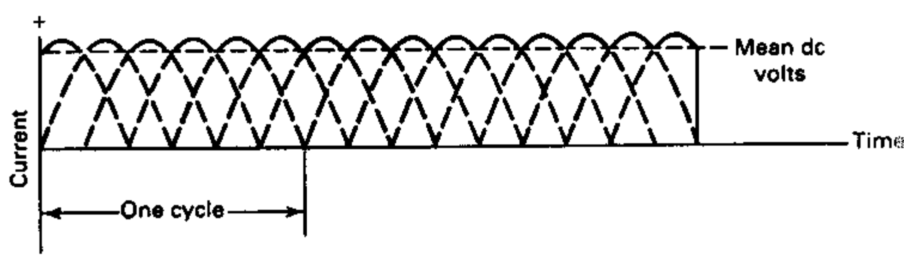

Figure 7-18b Three Phase Full Wave Rectified Direct Current

Figure 7-19 Settling Test Setup

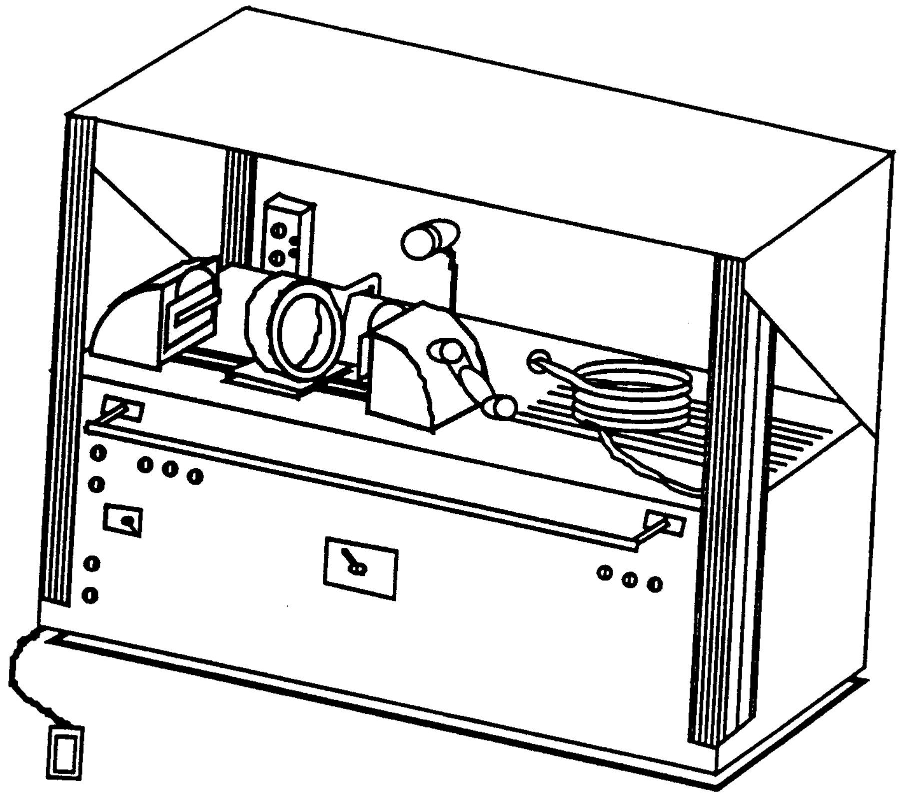

Figure 7-20 Wet Horizontal Unit

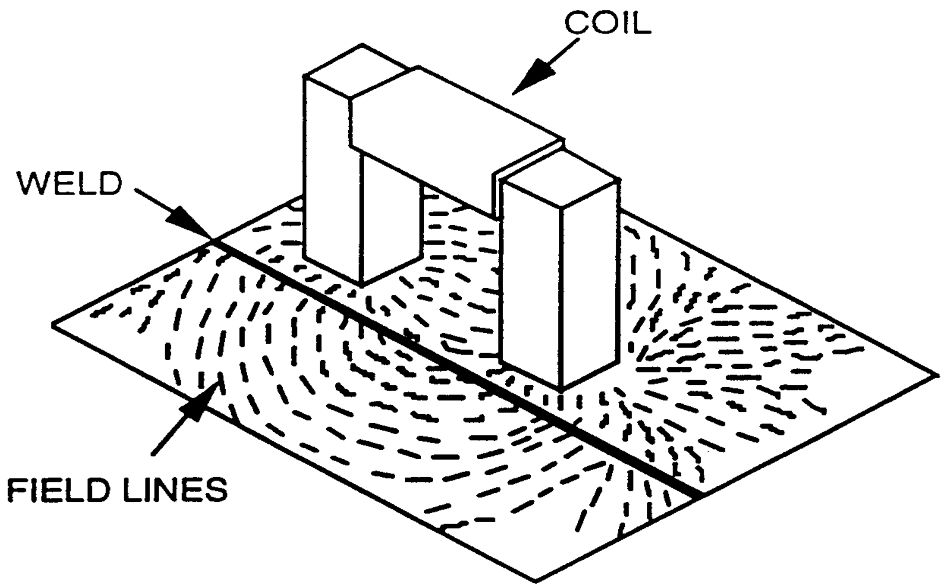

Figure 7-21 Yoke Magnetization

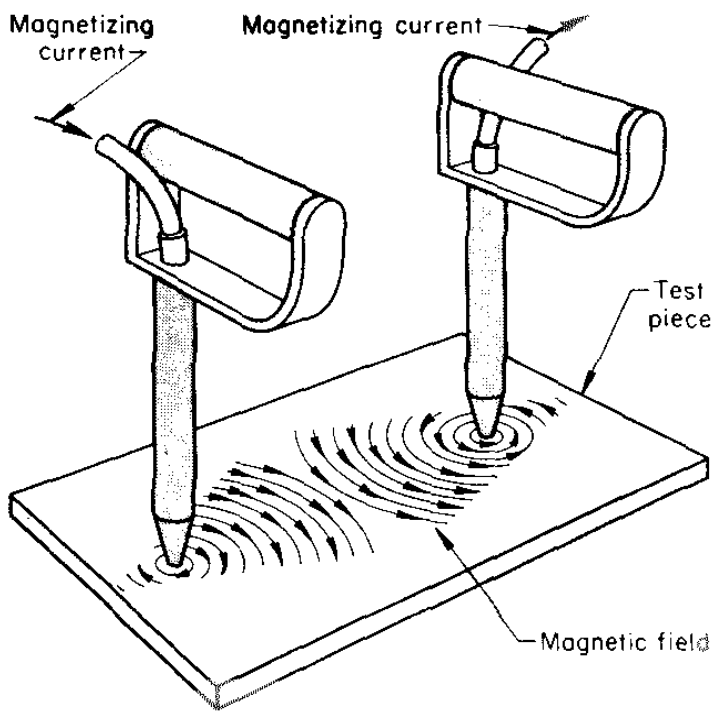

Figure 7-22 Circular Magnetization Using Contact Prods

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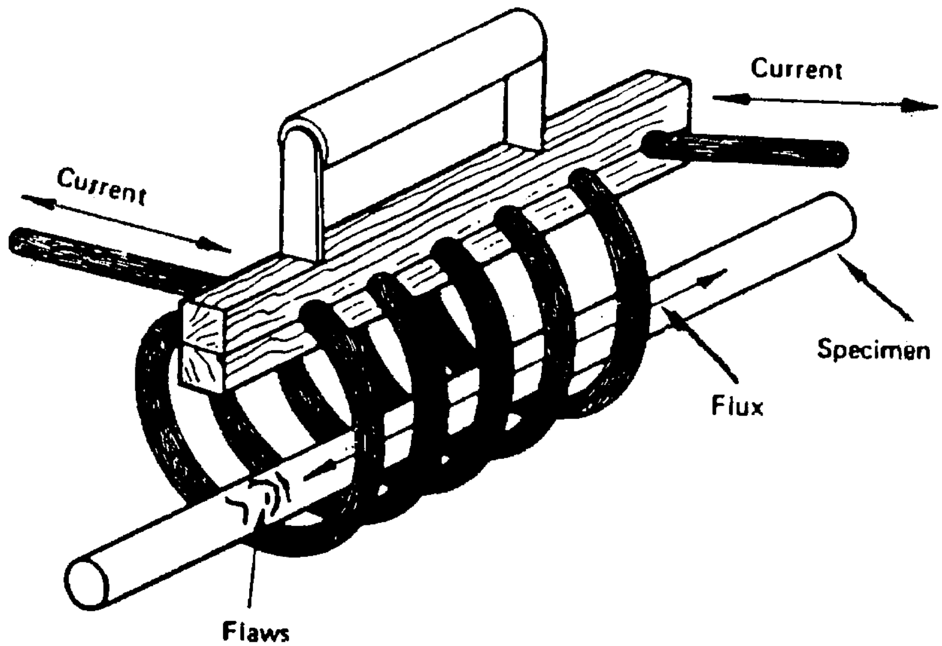

Figure 7-23 Coil Technique

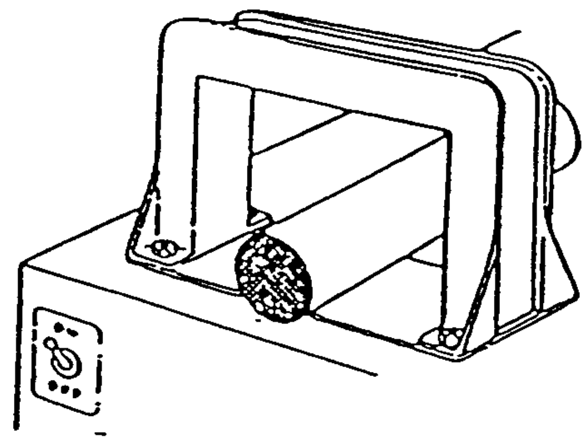

Figure 7-24a Part in Demagnetized Coil

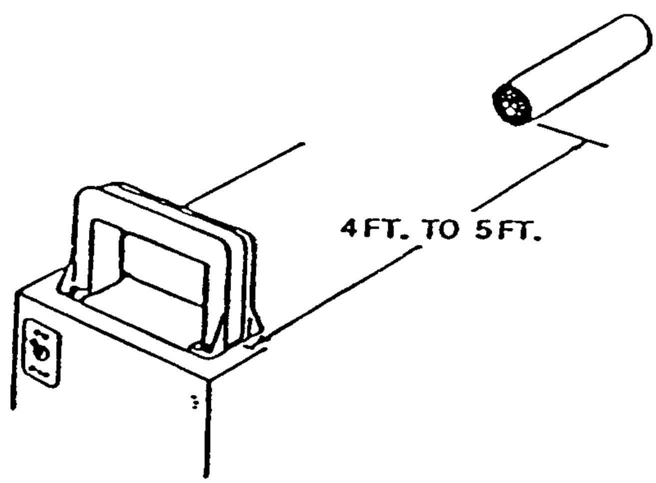

Figure 7-24b Part Withdrawn from Coil

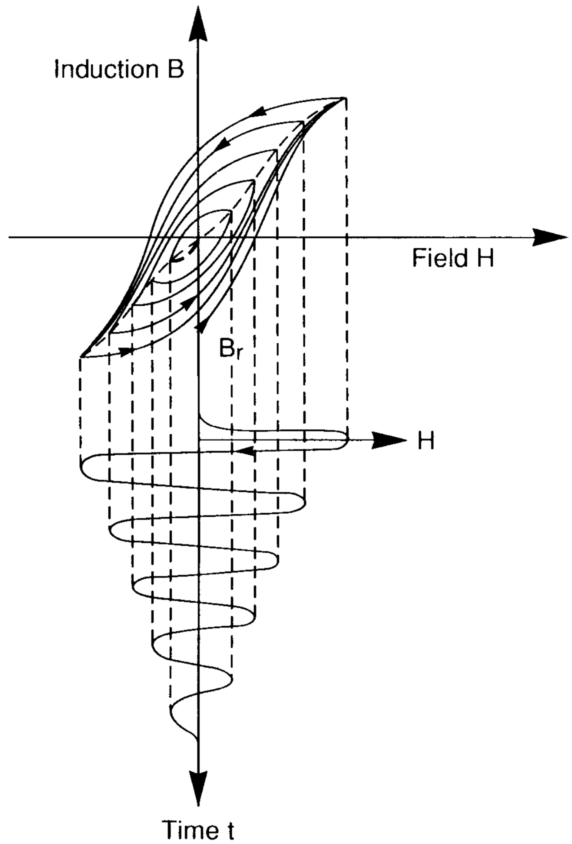

Figure 7-25 Demagnetization Curves Showing the Effect of a Reversing and Decreasing Current

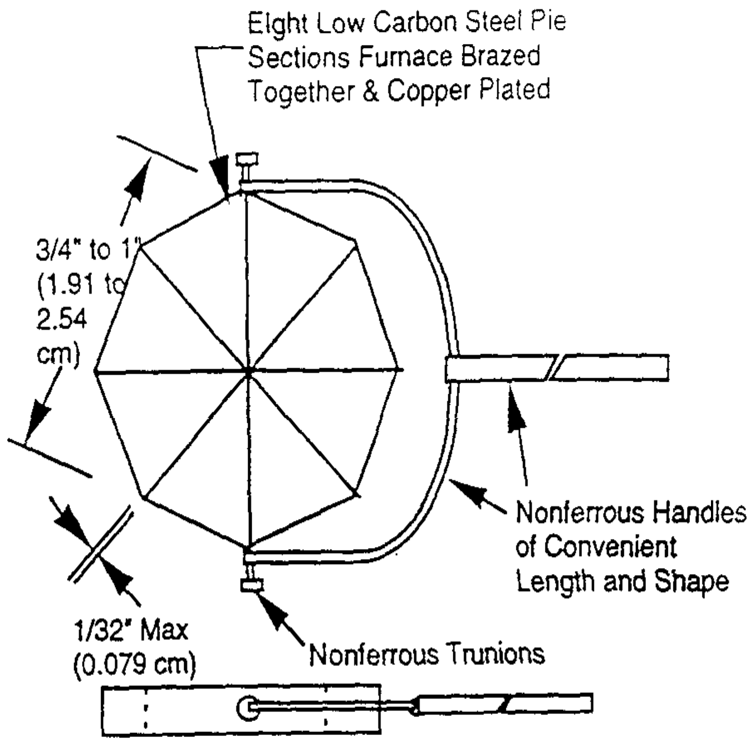

Figure 7-26 Pie Gage

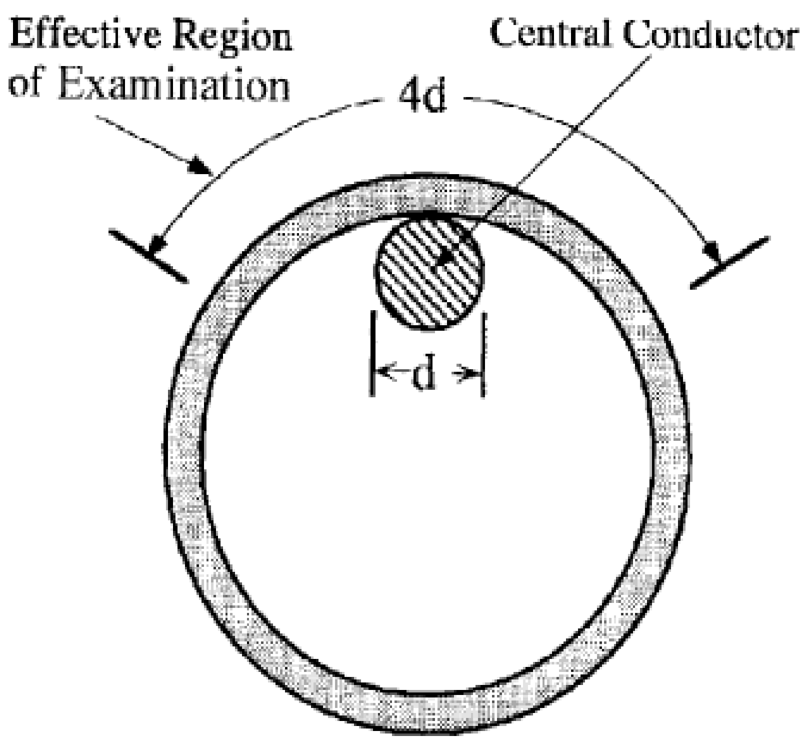

FIG. 3 The Effective Region of Examination When Using an Offset Central Conductor is Equal to Four Times the Diameter of the Conductor as Indicated

Figure 7-27 Central Conductor Coverage