CHAPTER 3

MAGNETIC PARTICLE INSPECTION METHOD

SECTION I MAGNETIC PARTICLE (MT) INSPECTION METHOD

3.1 GENERAL CAPABILITIES OF MAGNETIC PARTICLE INSPECTION.

NOTE

The terms MPI, MPT, and MT are used interchangeably in this chapter.

3.1.1 Introduction to Magnetic Particle Inspection (MPI). Magnetic particle inspection is an NDT method used to reveal surface and near surface discontinuities in magnetic materials. This inspection method can only be used on materials that can be magnetized (known as ferrous). The MPI process, when properly performed, establishes a field leakage site on the surface of the part below which the flaw lies. This chapter presents theory and practical guidance for the performance of magnetic particle inspection. Process control and basic inspection procedures are located in TO 33B-1-2.

3.1.2 Benefit of Magnetic Particle Inspection. MPI is the method of choice on ferrous materials instead of liquid penetrant because it is faster, requires less surface preparation, and in some instances is able to locate subsurface flaws.

3.1.3 Basic Concept of Magnetic Particle Inspection. MPI relies on the principle of magnetism (paragraph 3.2.1). Very small ferrous particles, which are suspended in a bath of oil or water, are attracted to magnetic field leakage sites, just as iron filings are attracted to the poles of a magnet. Cracks and similar types of discontinuities cause disruptions in the magnetic field of magnetized parts, in turn attracting these ferrous particles to the leakage site. This allows the inspector to visualize where the discontinuities are located in the part. The keys to a successful magnetic particle inspection are the correct amount of magnetization of the part, in an optimum direction with respect to flaws, and adequate contrast between the part's surface and the particles used to identify the flaw. The particles used are precipitated soft iron, and are stained or dyed in various colors, usually with a fluorescent dye or a red dye. Fluorescent dyes on particles in a liquid suspension are used to find very tight surface flaws. Visible dyes on dry particles are less sensitive to tiny surface defects, but are better for finding subsurface flaws. The type of flaw and/or the inspection environment determines selection of the color or type of particles.

3.1.3.1 The following paragraphs describe in detail the standard terminology used, the theory of magnetism, MPI magnetization and demagnetization techniques, process controls, and safety concerns.

SECTION II MAGNETIC PARTICLE PRINCIPLES AND THEORY

3.2 PRINCIPLES AND THEORY OF MAGNETIC PARTICLE INSPECTION.

3.2.1 Principles of Magnetization. When parts made of ferrous materials, such as iron, are placed in a strong magnetic field or have electric current flowing through them, they will become "magnetized." The degree of magnetization is affected by the strength of the magnetizing field or the amount of current flow. How strongly the ferrous part will be magnetized after the magnetizing force is removed is called "retentivity." Permanent magnets have high retentivity and conductors normally have low retentivity. When a surface or near-surface discontinuity interrupts the magnetic field in a magnetized part, some of the field is forced into the air above the discontinuity resulting in a leakage field. The size and strength of the leakage field depends on the size and proximity of the discontinuity to the magnetic field. The discontinuity is detected by the use of finely divided iron particles applied to a part’s surface and attracted to the leakage field. This collection of particles indicates the presence and location of the discontinuity.

3.2.2 Basic Terminology. The following terms and definitions are basic to an understanding of the MPI method.

NOTE

Letters in parentheses refer to the hysteresis curve (Figure 3-17).

3.2.2.1 Coercive Force. The negative or reverse applied magnetizing force (H) necessary to reduce the residual magnetizing force (B) to zero in a ferromagnetic material, after magnetic saturation has been achieved. The line (O/G) represents the magnitude and direction of this force.

3.2.2.2 Direct Contact Magnetization. Use of current passed through the part via contact heads or prods to produce a magnetic field.

3.2.2.3 Ferromagnetic. A term that describes a material which exhibits both magnetic hysteresis and saturation, also whose magnetic permeability is dependent on the magnetizing force present. In magnetic particle testing, we are concerned only with ferromagnetic materials.

3.2.2.4 Circular Magnetic Field. A circular magnetic field is a magnetic field surrounding the flow of the electric current. For magnetic particle testing, this refers to current flow in a central conductor or the part itself.

3.2.2.5 Longitudinal Magnetic Field. A longitudinal magnetic field is a magnetic field wherein the flux lines transverse the component in a direction essentially parallel with its longitudinal axis.

3.2.2.6 Magnetic Field. The term used to describe the volume within and surrounding either a magnetized part or a current-carrying conductor wherein a magnetic force is exerted.

3.2.2.7 Magnetic Leakage Field. The magnetic field outside of a part resulting from the presence of a discontinuity, a change in magnetic permeability, or a change in the part’s cross-section.

3.2.2.8 Magnetic Flux Density (B). The strength of a magnetic field is expressed in flux lines per unit cross-sectional area.

3.2.2.9 Flux Lines or Lines of Force. A conceptual representation of magnetic flux illustrated by the line pattern produced when iron filings are sprinkled on paper laid over a permanent magnet.

3.2.2.10 Magnetic Hysteresis. The phenomenon exhibited by a magnetic system wherein its state is influenced by its previous history.

3.2.2.11 Induced Current Magnetization. Use of an externally applied magnetic field to induce current in a part to produce a magnetic field having the flux direction needed for the inspection. Useful for parts where flowing current directly through the part would risk damaging the part.

3.2.2.12 Magnetizing Current (I). The electric current passed through or adjacent to an object that produces a magnetic field in the object.

3.2.2.13 Magnetizing Force (H). The magnetizing field applied to a ferromagnetic material to induce magnetization.

3.2.2.14 Magnetic Permeability (u). Magnetic permeability is the ease with which a ferromagnetic part can be magnetized. It is equal to the ratio of the flux density (B) produced to the magnetizing force (H) inducing the magnetic field. It changes in value with changes in the strength of the magnetizing force. A metal easy to magnetize, such as soft iron or low carbon steel, has a high permeability or is said to be highly permeable.

3.2.2.15 Residual Magnetism. This is the magnetic field that remains in the part when the external magnetizing force has been reduced to zero.

3.2.2.16 Retentivity. The property of a metal that remains magnetized after the magnetizing force has been removed. A metal, such as hard steel has a high percentage of carbon, and will retain a strong magnetic field after removal of the magnetizing current. Hard steel has high retentivity, or is said to be highly retentive.

3.2.2.17 Magnetic Saturation. This is the level of magnetism in a ferromagnetic material where the magnetic permeability is equal to one. This is characterized as that level where an increasing in magnetizing force (H) results in no greater increase in magnetic field (B) than would occur in a vacuum or air.

3.2.3 Magnetic Field Characteristics.

3.2.3.1 Horseshoe Magnet. A familiar type of magnet is the horseshoe magnet (Figure 3-1). Like a bar magnet, this is a permanent magnet and possesses residual magnetism. It will attract iron filings to its ends where a leakage field occurs. By convention, these ends are commonly called "north" and "south" poles, indicated by N and S on the diagram. Continuous magnetic flux lines, or lines of force in leakage fields, flow from the north to the south pole. In an ideal horseshoe magnet, the flux lines leave only at the poles and consequently an external magnetic force capable of attracting magnetic materials exists only at the poles. This action provides an example of a longitudinal magnetic field. In a real horseshoe magnet very small discontinuities are distributed throughout creating small, weak, localized leakage fields distributed over the surface of the magnet.

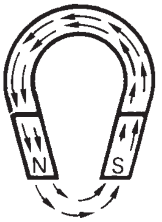

Figure 3-1. Horseshoe Magnet

3.2.3.1.1 If the shape of an ideal horseshoe magnet is changed (Figure 3-2), the ends will still attract iron filings. However, if the ends of the magnet are fused or welded into a continuous ring as shown (Figure 3-3), the magnet will no longer attract or hold exterior magnetic materials. This is because the north and south poles no longer exist; thus a leakage field does not exist. The magnetic field will remain as shown by the arrows, but no iron filings are attracted.

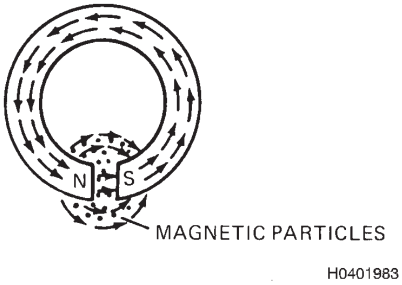

Figure 3-2. Horseshoe Magnet With Poles Close Together

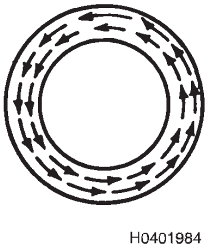

Figure 3-3. Horseshoe Magnet Fused Into a Ring

3.2.3.1.2 A transverse crack in the fused magnet or circularly magnetized part Figure 3-4) will create a leakage field with north and south poles on either side of the crack. Some of the magnetic flux (lines of force) will exit the metal and form a leakage field. The leakage field created by the crack, forming an indication of the discontinuity in the metal part, will attract ferrous particles. This is the principle whereby magnetic particle indications are formed.

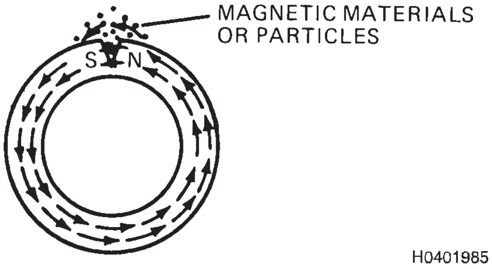

Figure 3-4. Crack in Fused Horseshoe Magnet

3.2.3.2 Bar Magnet. If a horseshoe magnet is straightened, a bar magnet is created (Figure 3-5). The bar magnet has poles at either end and the magnetic lines of force flow through the length, returning around the outside. Magnetic particles SHOULD be attracted only to the poles (in the ideal case). Such a part is said to have a longitudinal field, or is longitudinally magnetized.

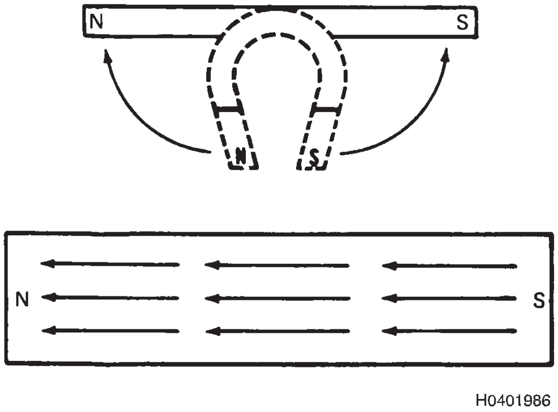

Figure 3-5. Horseshoe Magnet Straightened to Form a Bar Magnet

3.2.3.2.1 A transverse slot or discontinuity in the bar magnet that crosses the magnetic flux lines will create north and south poles on either side of the discontinuity (Figure 3-6). The resulting leakage field will attract magnetic particles. In a similar manner, a crack, even though it is very fine, will create magnetic poles as indicated in (Figure 3-7). These poles will also produce a leakage field that can attract magnetic particles. The strength of the leakage field will be a function of the number of flux lines (e.g., the strength of the internal field), the depth of the crack, and the width of the air gap at the surface. The strength of this leakage field, in part, determines the number of magnetic particles gathered to form indications. Clear indications are found at strong leakage fields, while weak indications are formed at weak leakage fields.

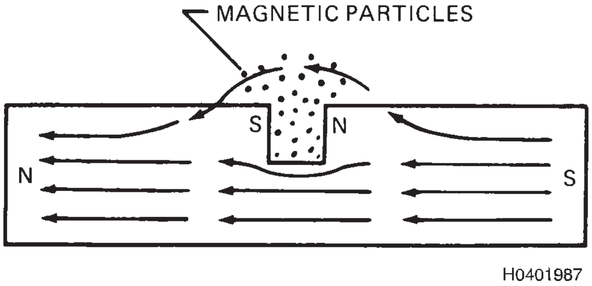

Figure 3-6. Slot (Keyway) in Bar Magnet Attracting Magnetic Particles

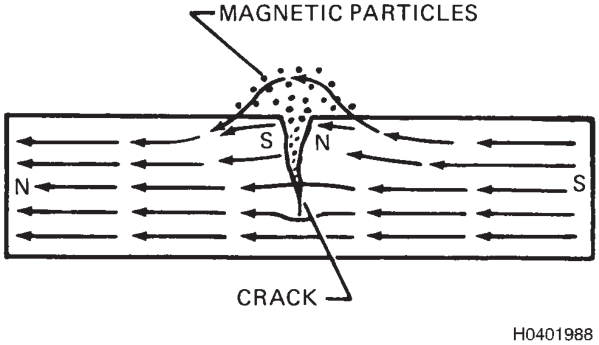

Figure 3-7. Crack in Bar Magnet Attracting Magnetic Particles

3.2.3.3 Electricity and Magnetism. Electric current can be used to create or induce magnetic fields in parts made of ferromagnetic materials. Magnetic lines of force are always aligned at right angles (90°) to the direction of electric current flow. It is possible to control the direction of the magnetic field by controlling the direction of the magnetizing current. This makes it possible to induce magnetic lines of force so they intercept defects at right angles.

3.2.3.4 Magnetic Attraction. Magnetic attraction can be explained by using the concept of flux lines or lines of force. Each flux line forms a closed continuous loop, which is never broken. For a circularly magnetized object, the flux lines are wholly contained in the object (ideal case). No external magnetic poles are present and therefore there is no attraction for other ferromagnetic objects. For a longitudinally magnetized object, the flux lines leave and enter at magnetic poles. They always seek the path of least resistance (e.g., maximum permeability and minimum distance). When a piece of soft iron is placed in a magnetic field it will develop magnetic poles. These poles will be attracted to the poles of the magnetic object that created the initial field. As it approaches closer to the source of the original field, more flux lines will flow through the piece of iron, thus creating stronger magnetic poles and further increasing the attraction. This concentrates the lines of flux into the easily traversed high permeability (iron path) rather than the alternative low permeability (air paths). This is magnetic attraction and is the reason magnetic particles concentrate at leakage fields. The leakage field is established across an air gap of relatively low permeability at the discontinuity. Since they offer a higher permeability path for the flux lines, the magnetic particles are drawn to the discontinuity and bridge the air gap to the extent possible.

3.2.3.5 Effects of Flux Direction. The magnetic field must be in a favorable direction, with respect to a discontinuity, to produce an indication. When the flux lines are parallel to a linear discontinuity, the indications formed will be weak. The best results are obtained when the flux lines are perpendicular (at right angles) to the discontinuity.

NOTE

When an electrical current is used for magnetizing, the best indications are produced when the path of the magnetizing current is parallel to and in-line with the discontinuity.

3.2.3.6 Circular Magnetization. A circular magnetic field always surrounds a current carrying conductor, such as a wire or a bar (Figure 3-8). The direction of the magnetic lines of force (magnetic field) is always at right angles to the direction of the magnetizing current. Field orientation and magnitude are based on the direction and amount of current flow.

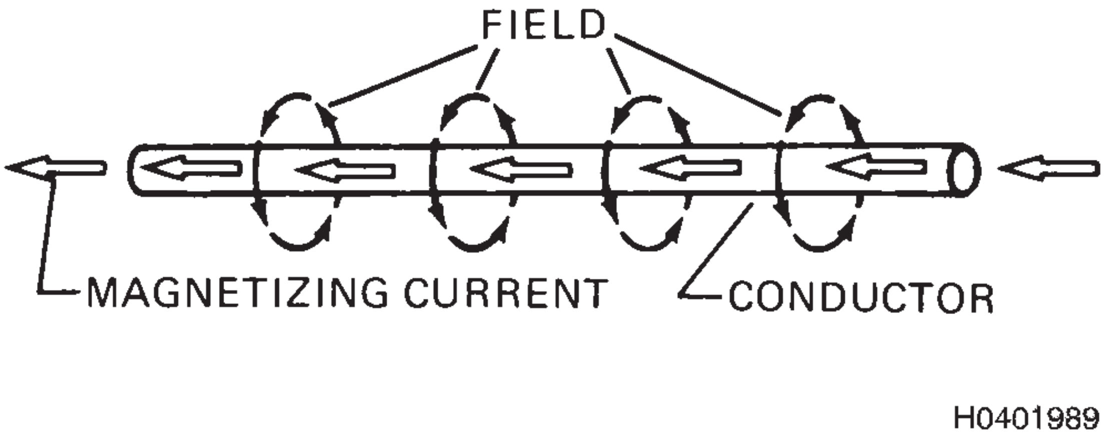

Figure 3-8. Magnetic Field Surrounding an Electrical Conductor

3.2.3.6.1 Since metals are conductors of electricity, an electric current passing through a metallic part creates a magnetic field (Figure 3-9). The magnetic lines of force are at right angles to the direction of the current. This type of magnetization is called circular magnetization because the lines of force, which represent the direction of the magnetic field, are circular within the part.

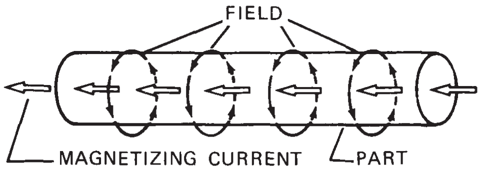

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Figure 3-9. Magnetic Field in a Part Used as a Conductor

3.2.3.6.2 Circular Magnetization with Inspection Equipment. One method of creating or inducing a circular field within a part with stationary MPI equipment is to clamp the part between two contact plates and pass current through the part as indicated in (Figure 3-10). If a longitudinally aligned crack or discontinuity exists within the part, a leakage field will be established at the site of each crack or discontinuity. The leakage field will attract magnetic particles to form an indication of the discontinuity.

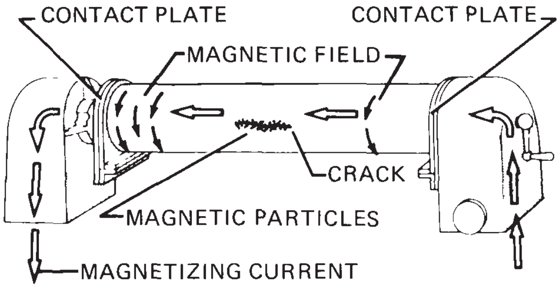

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Figure 3-10. Creating a Circular Magnetic Field in a Part

3.2.3.6.2.1 For hollow or tube-like parts, it is often important to inspect both the inside and outside surfaces. When such parts are circularly magnetized by passing the magnetizing current through the part ends, the magnetic field on the inside surface is smaller and opposite than what is produced on the outside surface. To produce a stronger magnetic field on both the inner, and outer surface of the part, a separate conductor, such as a copper rod, is positioned inside the hollow part (see Figure 3-11 and Figure 3-12). Since a circular magnetic field surrounds such conductors when an electric current is passed through them, it is possible to induce a satisfactory magnetic field on the inside surface and depending on the thickness of the part, the outside surface as well.

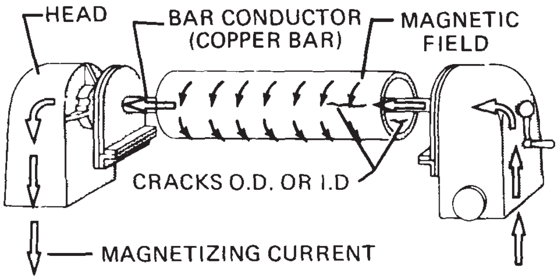

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Figure 3-11. Using a Central Conductor to Circularly Magnetize a Cylinder

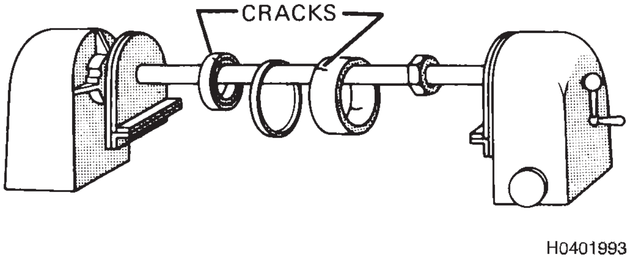

Figure 3-12. Using a Central Bar Conductor to Circularly Magnetize Ring-Like Parts

3.2.3.7 Longitudinal Magnetization. Electric current can also be used to create a longitudinal magnetic field in a test part with a current carrying encircling coil. Based on the perpendicular direction of magnetism to current direction, any segment of a coiled conductor will show the field within the coil consists of contributions from each turn of the coil and is aligned lengthwise as indicated (Figure 3-13).

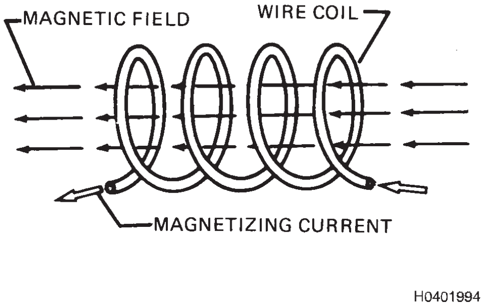

Figure 3-13. Magnetic Lines of Force (Magnetic Field) in a Coil

3.2.3.7.1 If a part is placed inside a coil (Figure 3-14), the magnetic lines of force created by the coil are aligned along the longitudinal axis of the coil. If the part is ferromagnetic, the high permeability concentrates the lines of flux within the part and induces a strong longitudinal magnetic field.

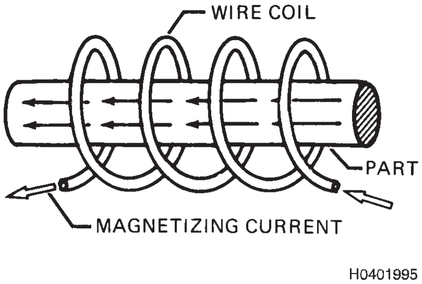

Figure 3-14. Longitudinal Magnetic Field Produced in a Part Placed in a Coil

3.2.3.7.2 Longitudinal Magnetization with Inspection Equipment. Inspection of a solid bar part using longitudinal magnetization is shown (Figure 3-15). When a transverse discontinuity exists in the part, as in the illustration, a magnetic leakage field is formed at the crack location. This attracts magnetic particles, forming an MPI indication of the transverse discontinuity. Compare (Figure 3-15) with (Figure 3-10), and note in both cases, a magnetic field has been induced in the part at right angles to the defect. This is the most desirable condition for reliable inspection.

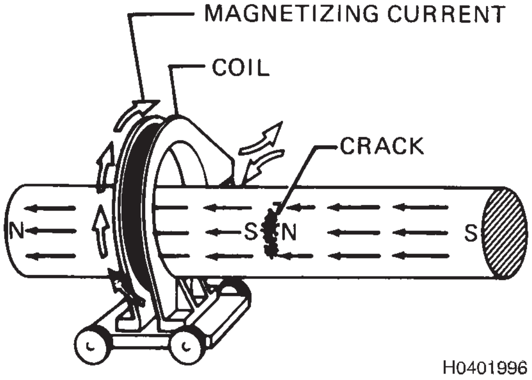

Figure 3-15. Longitudinal Field Produced by the Coil Generates an Indication of Crack in Part

3.2.3.8 Multi-Directional Magnetic Field. Two separate fields, having different directions, cannot exist in a part at the same time. However, two or more fields in different directions can be imposed upon a part sequentially in rapid succession. When this is done, magnetic particle indications can be formed when discontinuities are located favorably with respect to the directions of any of the applied fields, and will persist as long as the rapid alternations of field direction continue. Indications can only be formed if the part is pre-wetted with magnetic particles. This enables the detection of defects oriented in any direction in one operation. The indications must be viewed when the fields are being applied because they are weakly held after the current is discontinued and can be easily dislodged.

3.2.3.9 Parallel Current Induced Magnetic Field. If a ferromagnetic bar is placed alongside, and parallel to, a conductor carrying current, a magnetic field will be set up in the bar more transverse than circular (Figure 3-16). Such a field is of very little use for magnetic particle testing. Operators have tried to use this method as a substitute for a headshot for the purpose of producing circular magnetization, but the field produced is not circular and is extremely limited in the transverse direction when inspecting for defects such as seams. Furthermore, the external field around the conductor and the bar can attract magnetic particles and produce confusing backgrounds.

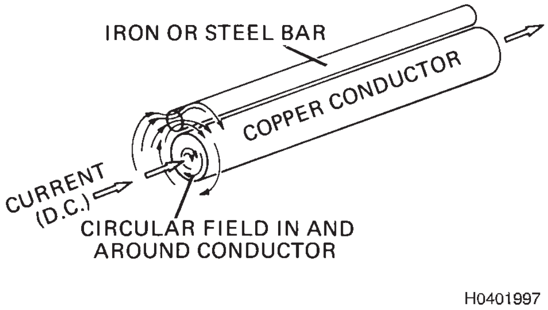

Figure 3-16. Field Produced in a Bar by a "Parallel" Current

3.2.4 Currents Used to Generate Magnetic Fields. There are several types of current used in MPI. These are Straight Direct Current (DC), Single-Phase Alternating Current (AC), Three-Phase AC Current, Half-Wave Rectified Alternating Current (HWRAC or HWDC), Full-Wave Rectified AC Current, and Three-Phase Full-Wave Rectified AC Current (commonly known as DC). Of these, three types of magnetizing current are most often used in magnetic particle inspection. Only one type of current is best suited for each type of inspection to be performed. Alternating current (AC) is preferred for the detection of surface discontinuities. Direct current (DC), full-wave direct current (FWDC), or half-wave direct current (HWDC) can be used for both surface and subsurface discontinuities. Detail on each current follows:

3.2.4.1 Alternating Current (AC). Alternating current, which is single phase when used directly for magnetizing purposes, is taken from commercial power lines, or portable power sources, and can be 50 or 60-hertz. Magnetizing currents up to several thousand amperes are used, derived from step-down transformers connected to common line voltages (e.g., 115, 230, or 460-volts).

3.2.4.2 Direct Current (DC). Rectified alternating current is by far the most satisfactory source of direct current. By the use of rectifiers, commercially available single and three-phase AC can be converted to a unidirectional current. Rectified three-phase AC is equivalent to straight DC, but exhibits a slight ripple.

3.2.4.3 Half-Wave Rectified Single-Phase Alternating Current. Half-wave rectified single-phase Alternating Current, also called Half-Wave Direct Current (HWDC), results in a pattern of unidirectional current flow made up of positive half cycles of the original AC waveform. The negative (reverse) half of each cycle is completely blocked out resulting in a pulsating unidirectional current. That is, the current rises from zero to a maximum and drops back to zero (replicating the AC’s half cycle). This is blocked during the reverse cycle (no current flows), and then repeats the first half cycle.

3.2.4.4 Full Wave Rectified Single-Phase Alternating Current. This pulsating unidirectional current is sometimes used in MPI for certain special purpose applications. In general, however, it possesses no advantage over single-phase half-wave rectified waveforms. Because of its extreme "ripple," it is not as satisfactory as rectified three-phase current when DC is required. It is also more costly since it draws a higher average current from the AC line than does rectified half-wave AC for a given magnetizing strength.

3.2.4.5 Induced Current. When direct current in a circuit is instantly cut off, the field surrounding the conductor collapses, or falls rapidly to zero. If an electrically conductive ferromagnetic material is present in such a field, the collapse of that field will induce a current in the material the same direction as present in the neighboring conductor before cut-off. This phenomenon can be used to solve specific magnetizing problems that have no other practical solution. A useful application of the collapsing field technique has been found in the inspection of ring-shaped parts, such as bearing races, without the need to make direct contact with the surface of the part. Regardless of the type of magnetizing current employed, whether AC, DC, or half-wave, the induced current technique is usually faster and more satisfactory than the contact method. Only one operation is required, and the possibility of damaging the part due to arcing is completely eliminated since no external contacts are made on the part.

3.2.5 Ferromagnetic Material Characteristics.

NOTE

Refer to the hysteresis curve for the letters in parentheses (Figure 3-17).

All ferromagnetic materials, after having been magnetized, will retain some residual magnetic field. The strength and direction of the residual field depends upon all the magnetizing forces applied since the material was last demagnetized, and the retentivity of the material. The manner in which ferromagnetic materials respond to magnetizing forces is most often portrayed in a plot of the flux density (B) as a function of the magnetizing force (H). The flux density (B) is the number of magnetic lines of flux formed per cross-sectional area as a result of the magnetizing force (H). For an encircling coil, the magnetizing force is the accumulative effect of each turn of the coil and the current passing through it. Therefore, (H) is proportional to the current passing through the coil, multiplied by the number of turns in the coil. A typical (B/H) curve for a ferromagnetic material starting in a demagnetized condition and then cycled to saturation in two opposite directions is shown (Figure 3-17).

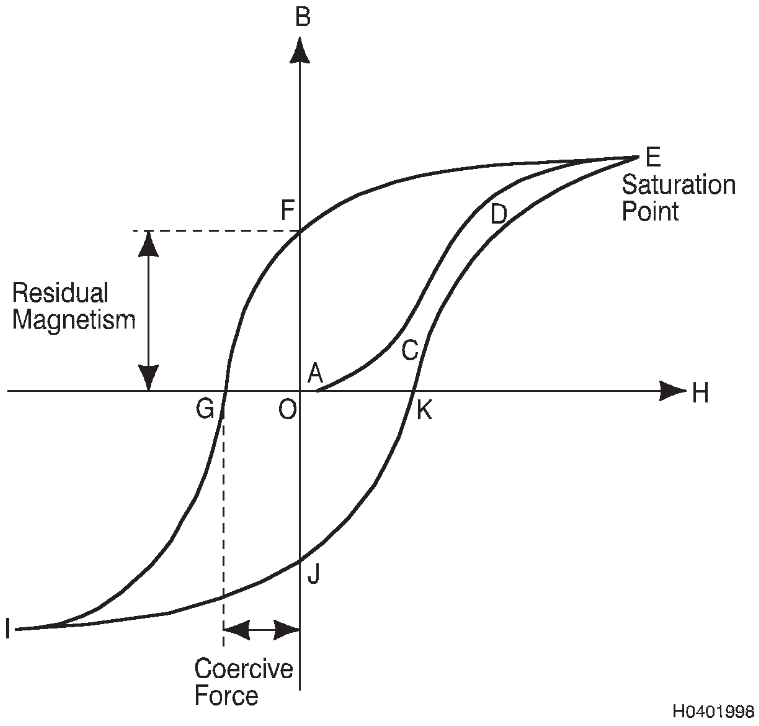

Figure 3-17. Hysteresis Curve for a Ferromagnetic Material

3.2.5.1 Hysteresis Curve.

NOTE

Refer to the hysteresis curve for the letters in parentheses (Figure 3-17).

The magnetic field within an unmagnetized piece of steel is zero. As the magnetizing force (H) is increased from zero, the flux density (B) within the part will also increase from zero. The curve from points (A/E) illustrates this behavior. In the region of point (E), the flux density increases up to a point and then tends to level off; this condition is called magnetic saturation and for a magnetically saturated ferromagnetic material the relative permeability (u) is approximately equal to one. When the magnetizing force is reduced to zero, the flux density does not return to zero. Instead, the flux density returns to a value shown at point (F). This is the amount of residual magnetism resulting from the applied magnetizing force (H) that reached point (E) in the hysteresis curve. As the magnetizing force (H) is increased from zero in the opposite direction, the flux density (B) will decrease to zero, as shown at point (G), and then start to increase to point (I). The magnetizing force (H) represented by the distance (O/G) on the (H) axis is called the coercive force. It represents the strength of the magnetizing force (H) required to reduce the flux density (B) to zero in a saturated ferromagnetic material. A further increase in the magnetizing force (H) to the point (I) results in saturation of the material in a direction opposite to that represented by point (E). Reduction of the magnetizing force (H) to zero from point (I) will reduce the flux density (B) to the value represented by point (J). Application of a magnetizing force (H) in the original direction will change the flux density (B) as shown in the portion (J/K) of the hysteresis curve. Increasing the magnetizing force (H) sufficiently will return the material to saturation as illustrated at point (E).

3.2.5.2 Magnetic Domains in Ferromagnetic Material. The behavior of ferromagnetic materials resulting in properties evidenced by hysteresis curves can be explained in terms of magnetic domains. Domains are small regions within a ferromagnetic material that have a permanent magnetic flux density (B) not equal to zero. In a completely demagnetized ferromagnetic material, the domains are randomly oriented resulting in an overall flux density of zero. When saturated, the domains are all aligned in the direction of the applied field. When the applied field is removed, after saturation, some domains return to their previous orientation, but most remain aligned in the direction of the previously applied field. This results in the residual magnetism observed in ferromagnetic materials. The magnetic behavior then is a result of behavior of the domains within the ferromagnetic material. Magnetization is the alignment of domains in a single direction; demagnetization is a random arrangement of the domains resulting in a zero net residual magnetism.

3.2.5.3 Demagnetization of Ferromagnetic Material. All parts SHOULD be demagnetized after MPI. Demagnetization may be easy or difficult depending on the type of material, part geometry, and magnetic field orientations used. Demagnetization involves subjecting a magnetized part to a continuously reversing magnetic field that gradually decreases in strength. This action reduces the strength of the residual magnetic field in the part. Although some residual magnetization will remain, this method can reduce the residual magnetic field to acceptable levels.

3.2.5.3.1 There are a number of methods of demagnetization available with varying degrees of effectiveness and they can be explained with the hysteresis curve shown in (Figure 3-17). Nearly all are based on the principle of subjecting a part to a continually reversing magnetic field that gradually reduces in strength down to zero. This principle is illustrated in (Figure 3-18). The waveform is shown at the bottom of the graph of the reversing current used to generate the hysteresis loops. As the current diminishes in value with each reversal, the loop shrinks and traces a smaller and smaller path.

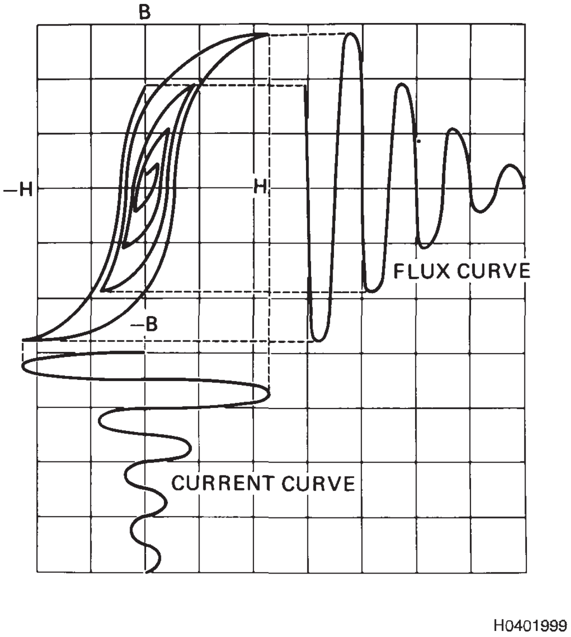

Figure 3-18. Flux Waveform During Demagnetization, Projected from the Hysteresis Loop

3.2.5.3.1.1 The waveform at the upper right (Figure 3-18) represents the flux in the part as indicated on the diminishing hysteresis loops. Both current and flux waveforms are plotted against time, and when the current reaches zero the residual field in the part will also have approached zero. Precautions to be observed in the use of this principle are:

- Be certain the magnetizing force is high enough at the start to overcome the coercive force, and to reverse the residual field initially in the part.
- The decrease between successive reductions of current is small enough so the reverse magnetizing force will be able, on each cycle, to reverse the field remaining in the part from the previous reversal.

3.2.5.3.1.2 Frequency of reversals is an important factor affecting the success of this method. With high frequency of current reversals, the field generated in the part does not penetrate deeply into the part section since penetration decreases as frequency increases. At a frequency of perhaps one reversal per second, penetration of even a large section is probably near 100-percent. For moderately sized parts, the 50 or 60-hertz commercial frequencies of alternating current give quite satisfactory results.

NOTE

Materials heated above their Curie temperature become nonmagnetic, thus offering another method of demagnetization. However, this is not useful for field application to aircraft components as heating to the Curie temperature, or above, may damage the part.

3.2.5.3.2 Limitations of Demagnetization. "Complete" demagnetization is usually not possible, even though it is often specified. All practical demagnetization methods leave some residual field in the part. Therefore, demagnetization is either the best effort that existing means permit or reduction in magnetism to a residual level considered permissible in the particular part involved. It is extremely difficult to bring the steel back to the original zero point by any magnetic manipulation. In fact, it is so difficult that for all practical purposes, it may be said the only way to completely demagnetize a piece of steel is to heat it to its Curie temperature or above, and cool it with its length directed east and west in order to avoid magnetization by the earth's natural magnetic field, north/south. This method of demagnetization is never used because it is not only impractical, but such heating will alter the properties of the part.

3.2.5.3.2.1 Remember, the earth's magnetic field can determine the lower limit of practical demagnetization. Long parts, or assemblies of long parts, such as welded tubular structures, are especially likely to remain magnetized at a level determined by the earth's natural magnetic field, in spite of the most careful demagnetization technique.

3.2.5.3.2.2 Many articles and parts become quite strongly magnetized from the earth's natural magnetic field alone. Handling of parts, such as transporting from one location to another, may produce this effect. Long bars, demagnetized at the point of testing, have been found magnetized at the point of use. It is not unusual to find steel aircraft parts are magnetized after having been in service for some time, even though they may never have been near any intentionally produced magnetic field. Parts may also become magnetized by being near electric lines carrying heavy currents, or near some form of magnetic equipment.

3.2.5.3.2.3 The limits of demagnetization may be considered to be either the maximum extent to which the part can be demagnetized by available procedures, or the level to which the terrestrial (earth's) field will permit it to become demagnetized. These limits may be further modified by the practical degree or limit of demagnetization actually desired or necessary.

SECTION III MAGNETIC PARTICLE INSPECTION EQUIPMENT

3.3 MAGNETIC PARTICLE INSPECTION EQUIPMENT AND MATERIALS.

3.3.1 Selection of Magnetic Particle Inspection Equipment. When selecting magnetic particle inspection equipment, the inspector must consider the type of current to be used and the location and nature of inspection.

3.3.1.1 A variety of equipment is available which can be used for either circular or longitudinal magnetization. The equipment ranges in size from small, general-purpose portable units capable of being carried by hand to large, custom-built stationary units with separate power supplies.

3.3.2 Categories of Magnetic Particle Inspection Equipment.

3.3.2.1 Stationary Equipment. A variety of stationary, bench-type MPI units are available, with many characteristics that fit different testing requirements. The smaller size units are used for small parts easily transported and handled on the unit by hand. The larger ones are used for heavy parts such as long engine crankshafts, where handling must be by crane. Such units are made to deliver AC or DC with various types of current control.

3.3.2.1.1 A typical stationary horizontal wet magnetic particle inspection unit has two contact heads (headstock and tailstock) for either direct contact or central conductor, circular magnetization using a copper rod between the heads, or a cable connected to a contact block between the heads. Many of the units contain a coil used for longitudinal magnetization. The coil and one contact head are movable on 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 DC or AC depending upon usage requirements. The units are made in several different sizes to accommodate different length parts and with various maximum output currents. A full-length tank with pump, agitation and circulation system for wet inspection media is located beneath the head and coil mounting rails. A hand hose with nozzle is provided for applying the bath. On special units, automatic bath application facilities are provided.

3.3.2.2 Mobile Equipment. The distinguishing feature of mobile equipment is the wheels the unit is mounted on. Mobile units can be easily moved to any inspection site where suitable line input voltages and current capacity are available. Mobile inspection units are available in several sizes ranging from 3000 to 6000-amperes of AC and half-wave DC outputs. The units may have remote current output, ON/OFF and MAG/DEMAG controls that permit one-man operation at the site of inspection. The units can be used with either rigid or cable-wrapped coils for longitudinal magnetization and demagnetization. Cables connected to a part or passing through it are used for circular magnetization or demagnetization. This type of equipment is sturdy and well suited for both fabrication and overhaul inspections.

CAUTION

Contact prods SHALL NOT be used on aerospace components or parts.

3.3.2.2.1 Both half-wave DC and AC outputs are included in most mobile and portable units to increase their versatility. Half-wave DC current and dry magnetic powder make the best combination for detecting subsurface flaws in welds, particularly when used with the prod method of inspection. Half-wave DC is also useful for detecting subsurface discontinuities when the wet method is used. The use of alternating current is limited to the detection of discontinuities that are open to the surface, such as cracks, and for demagnetizing parts.

3.3.2.3 Portable Equipment. Portable MPI equipment is manufactured in a variety of sizes, shapes, voltages, and current outputs. Portable equipment operates on the same principle as stationary and mobile equipment; however, the compactness allows areas to be inspected where larger equipment may prohibit access. Portable equipment is usually operated on 110 or 220 volt AC and is rated between 200 and 2 000-amperes. Portable equipment can be either AC, or a combination of AC and half wave DC. They can be used wherever an adequate 115-volt AC power source exists.

3.3.2.3.1 Portable equipment is suitable for examining small areas in large components where suspected cracks may be found. For example, critical engine mount fittings and landing gear assemblies, which are difficult to inspect in stationary units, can be examined quickly with minimum disturbance and with attention concentrated on points most subject to cracking. Portable equipment can be moved to large items in need of magnetic particle testing and inspections can often be performed without disassembly.

3.3.2.3.2 Categories of Portable Equipment.

3.3.2.3.2.1 Portable Power Pack. Portable power packs are high Amp output devices. Examples of this equipment are the Magnaflux P-1500 or DA-1500, which are capable of putting out 1500-Amps AC or HWDC fields. These power packs weigh in at 93-pounds and have a duty cycle of 2-minutes on and 2-minutes off. Field selection is determined by using the appropriate field cable connector. Current output is indefinitely variable from zero to maximum by use of the current control located on the front panel meter. The actual current output is determined by cable size and length. These units can also be found mounted to carts (e.g., KH-07).

3.3.2.3.2.1.1 Portable power packs are usually used with cables for cable-wrap generation of longitudinal magnetization and for demagnetization; or with prods, clamps, or magnetic leeches for generating circular magnetization. The portable power pack can also be used to provide current via the cables to a small stationary unit for head and coil shots.

3.3.2.3.2.2 Probes and Yokes. The term probe and yoke are virtually interchangeable in this discussion. Probes and yokes (e.g., Magnaflux DA-200 or Y-7) are versatile, lightweight (approximately 8-pounds) hand-held devices used for inspection of small parts and localized inspections of large parts. Probes and yokes are easily used and often provide adequate inspections. They are essentially U-shaped laminated cores of soft iron with a coil wound around the base of the U. Probes and yokes are capable of putting a strong magnetic field into that portion of the part that lay between the poles of the probe or yoke. When electrical current is passing through the coil, the two ends of the core are magnetized with opposite polarity and the combination is an electromagnet similar to a permanent horseshoe magnet. They are capable of putting out constant AC or pulsed DC fields with the flip of a switch. A probe or yoke may be used to induce only a longitudinal field in a part. No electrical current passes through the part. They also have a duty cycle that will be defined in the operating instructions for the specific yoke. As an example, for the DA-200, duty cycle is 2 minutes on and 2 minutes off.

3.3.2.3.2.2.1 Probe and Yoke Current Induction.

3.3.2.3.2.2.1.1 Alternating Current (AC) Probes and Yokes. Alternating current, which is single phase when used directly for magnetizing purposes, usually has a frequency of 50 or 60-hertz. The AC longitudinal magnetizing field induced in the part is restricted to the surface due to its skin effect. AC provides a very desirable field for maintenance and overhaul inspection work due to its high sensitivity to surface defects. The peak AC current produces a surge peak in the magnetic field well above the average DC current required to develop a field of equivalent strength.

3.3.2.3.2.2.1.1.1 AC magnetic fields form eddy currents that tend to guide or restrict the magnetic lines of flux into a narrow pattern between the poles. Alternating magnetic fields cause surface vibration that adds mobility to the inspection particles to form larger and more distinct build-up of particles at the defect.

3.3.2.3.2.2.1.1.2 An AC magnetic field can be used when it is necessary to discriminate between surface indications and subsurface defects that might be revealed with a DC magnetizing field. Yokes utilizing AC magnetization also have the additional advantage of being readily used for demagnetization.

3.3.2.3.2.2.1.2 Direct Current (DC) Probes and Yokes. An electro-magnet powered by DC provides a very strong magnetic field. However, being a constant field and lacking any vibratory action, it is sometimes difficult to gather enough particles at the defect to form a visible indication. To overcome this difficulty, full-wave or half-wave rectified single-phase alternating current is used. This adds mobility to the magnetic inspection particles comparable to that produced by AC.

3.3.2.3.2.2.1.3 Permanent Magnet Yokes. Permanent magnets can also be used to magnetize parts in MPI. This method of magnetization has severe limitations and is properly used only when these limitations do not prevent the formation of satisfactory leakage fields at discontinuities. Permanent magnet yokes create longitudinal fields. The poles created on the parts may result in confusing particle indications. Control of field direction is possible only over a limited area. If you stand a permanent bar magnet on end on a steel plate, it will create a radial field in the plate around the pole in contact with the plate as shown (Figure 3-19). The flux produced by this radial field travels a distance from this point of contact until it leaves the surface of the plate, only to return to the pole at the opposite end of the magnet. Cracks crossing such a field pattern may be seen provided the field produced in the plate is sufficiently strong and properly oriented. The flux generally follows along a straight line drawn between the poles, and is strongest near the poles of the yoke and weakest at the point midway between the poles. The magnetic field strength within the part depends on the strength of the yoke magnetization and the distance between the poles. Outside this limited area, the field spreads out, and cracks favorably located with respect to field direction may or may not be shown. This method of magnetization SHALL NOT be used unless the inspector is aware of, and understands the limitations of this technique.

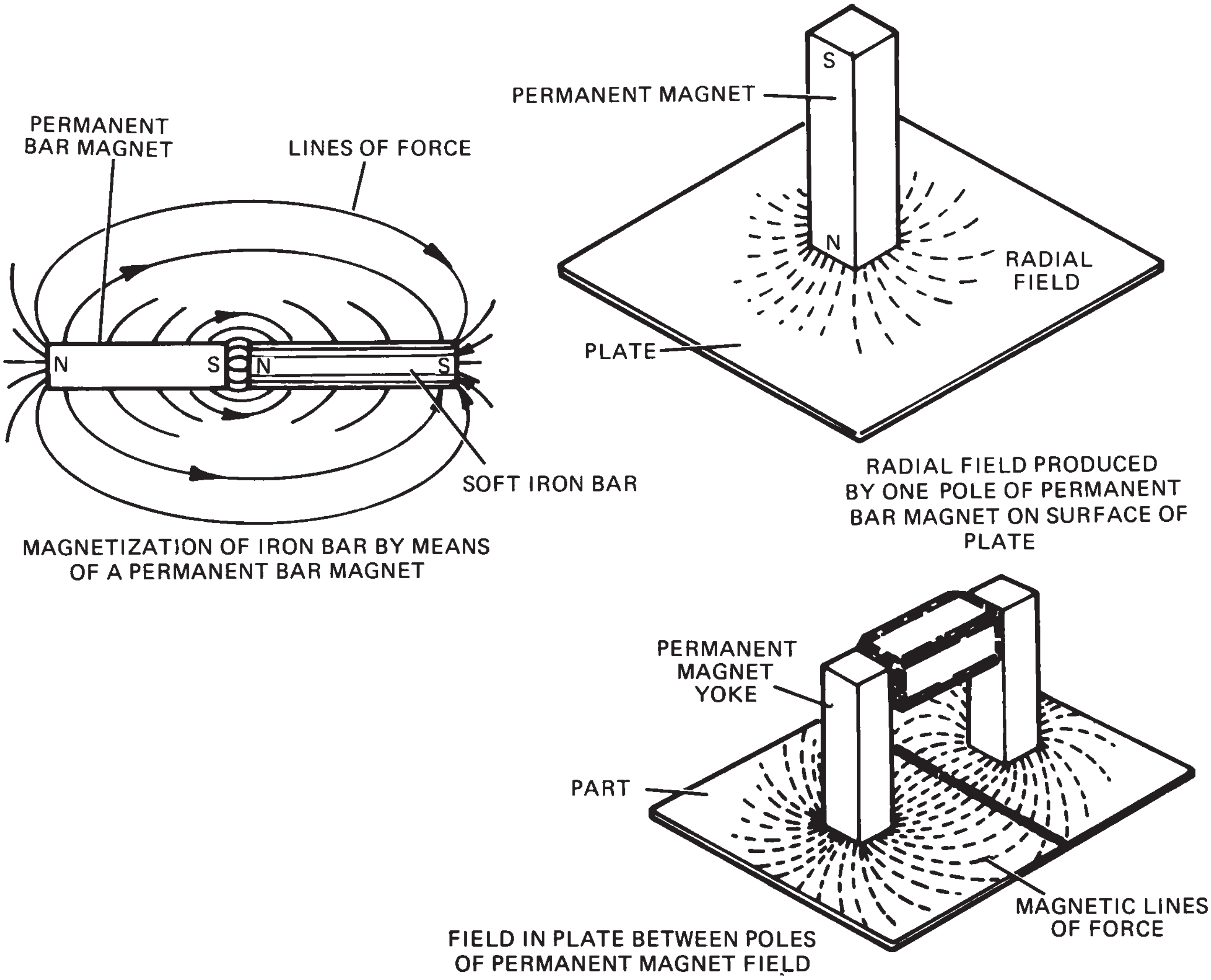

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Figure 3-19. Magnetization With a Permanent Magnet

3.3.2.3.2.2.1.3.1 Some of the other drawbacks when using permanent magnets are:

- The strength of the field is not continuously variable.
- Large areas or masses cannot be magnetized with enough field strength to produce a satisfactory crack indication.
- It may be difficult to remove a strong magnet once it is in contact with the part.

3.3.2.3.2.2.2 Probe and Yoke Leg Configuration.

3.3.2.3.2.2.2.1 Fixed Leg Probe/Yoke. The legs of a fixed leg yoke are spaced approximately 5-inches apart providing a usable magnetic field area of approximately 25 in ^{2}. Fixed leg probes can be used on flat, contoured, or irregular surfaces. However, the fixed leg position might preclude their use on some parts of a complex configuration, unless special pole pieces are available to adapt the legs to the part's surface.

3.3.2.3.2.2.2.2 Articulated Leg Probe/Yoke. An articulated or movable-leg yoke contains all the features of a fixed-leg yoke. They are, however, more versatile in their use and application because of the movable legs. The legs may be moved inward to the decreased position or extended outward to the maximum position to obtain optimum contact, assuring a better induced magnetic field. When in the decreased position, the area of the usable magnetic field is decreased and the magnetic field is increased, permitting the detection of finer discontinuities. When in the extended position, the area of the usable magnetic field is increased though the field strength is weaker. Thus the discontinuities being sought must be larger. Movable-leg yokes are more suitable for demagnetization than fixed-leg yokes. The space between the poles or legs can be adjusted so the parts to be demagnetized pass snugly between them to obtain maximum demagnetization.

3.3.3 Inspection Equipment Accessories.

3.3.3.1 Contact Prods.

CAUTION

Contact prods SHALL NOT be used on aerospace components or parts.

When a non-aircraft part is too large to fit into a stationary unit, or if only mobile or portable equipment is available, then the part, or areas of the part, can be magnetized using cables and two hand-held prods. The current passing between the two contact prods creates a circular field. Great care SHALL be used to prevent local overheating, arcing, or burning the surface being inspected, particularly on high-carbon or alloy materials where hard spots or cracks could be produced.

3.3.3.2 Contact Clamps.

CAUTION

When parts are being magnetized by the use of spring loaded contact clamps using the direct contact method, excessively high field strength SHALL be avoided to prevent arcing, burning, or heating of the part that may ultimately impede the detection of discontinuities.

Contact clamps can be used with cables instead of contact prods, particularly when the parts are relatively small in diameter. Care SHALL be used to avoid burning of the part under the contact clamps. Dirty contacts, insufficient contact clamp pressure, or excessive currents may cause burning and heating. Cracks may be produced as a result of the transient heating. Position the clamps so it directs the current to pass through the inspection area. Make sure the circular field created is perpendicular to the direction you think cracks may be developing.

3.3.4 Special Purpose Equipment. Special purpose equipment is equipment which has been specifically designed to take care of unusual situations where standard units are inappropriate. These may be special as to the method of magnetization or particle application, or be designed to handle unusual size, shape, or number of parts. Also, these may be operated manually or automatically. Special purpose equipment can be further broken down into two groups:

- Specific Purpose Units. Equipment built to do a specific job or part, and may have no other possibility of a processing technique. This specific job may be a variation in a magnetization technique, in the way the magnetic particles are applied, or in the way parts are handled.
- Automatic Units. Automatic units are those in which part or all of the handling and processing steps are performed automatically. Either single-purpose or general-purpose units may be partly or entirely automatic. Even standard units, by addition of standard accessories, may be made automatic in some of their functions. The principal purpose of automatic units is to speed up the inspection cycle. This is accomplished through automation of one or more of the important steps involved in any given testing operation.

3.3.4.1 Multidirectional Magnetization Equipment. Complex-shaped parts can be inspected rapidly with equipment capable of producing magnetic fields in two mutually perpendicular directions in rapid succession. For large parts such as shipyard castings, the equipment produces three-phase full-wave rectified AC and rapidly switches it between several different magnetizing modes. An alternate approach, used for smaller parts, is to use each of the three phases, either rectified or unrectified, for a separate magnetizing mode. Such equipment can then apply up to three magnetizing modes in rapid succession to a part. The multidirectional units produce a multidirectional magnetization effect by rapidly changing the magnetizing directions. For equipment utilizing the switched mode of operation, the switching can be on the order of 0.1 seconds. For the other type of equipment, the magnetizing modes are out of phase by 120-degrees. For 60-hertz current this is equivalent to switching magnetization directions in less than 0.006-seconds. These units are capable of producing indications of discontinuities with widely differing orientations in a single operation, thus saving the time to conduct two or more separate inspections with different magnetic field excitation setups. It is not possible to estimate the required magnetizing currents before hand to produce the required magnetic field strengths and directions. Consequently, sensors SHALL be used to determine the resulting strength and orientation of the magnetic fields in order to develop valid inspection techniques with multidirectional magnetization methods.

3.3.4.2 Induced Current Magnetization Equipment. When inspecting ring-like parts for defects in a circumferential direction, the induced current technique can sometimes be used. As an example, a ring-shaped part is placed inside and concentric to a magnetizing coil being excited with AC (Figure 3-20). A laminated ferromagnetic core is placed inside the part and parallel to the axis of the coil in order to concentrate the magnetic field. The time-varying AC induces eddy currents in the test piece, which in turn induce a circular magnetic field within the test part. Such a field is used to detect circumferential defects within the test part. The core piece used SHOULD be laminated and made of low retentivity iron. If the part is ring-shaped, the core length should be approximately equal to the ring diameter or longer, but SHALL NOT be less than six inches, and SHALL be centered in the part. For a disc-shaped part with no bore, shorter core pieces SHOULD be placed on either side of the disc so they are parallel to the axis of the part. In some cases it is advantageous to shape the ends of the core pieces adjacent to the part to facilitate bath application. Since the induced current method does not require contacting the part, there is no danger of local part overheating.

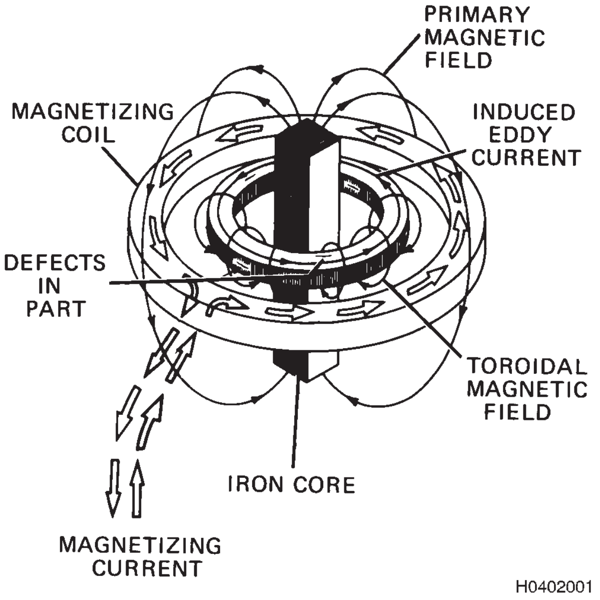


Figure 3-20. Current and Field Distribution in a Bearing Race Being Magnetized by the Induced Current Method

3.3.4.3 Hand-Held Coil. For longitudinal magnetization of shafts, spindles, rear axles, and similar small parts, the hand-held AC coil offers a simple and convenient method of inspecting for transverse cracks. Parts are magnetized and demagnetized with the same coil.

3.3.4.4 Special Demagnetizing Equipment. The most common type of demagnetizing equipment consists of an open, tunnel-like coil through which AC is passed at the line frequency, usually 60-Hertz. The larger type equipment is frequently placed on its own stand, incorporating a track or carriage to facilitate moving large and heavy parts through the demagnetizing equipment. The demagnetizing equipment can also include tabletop units, yokes, or plug-in coils more suited for the demagnetization of small parts. However, the large stationary type equipment is preferable when geometrically complex parts are involved.

3.3.5 Field Strength Measurement Devices. Equipment used for testing/measuring field strength is a: dial probe, field indicator, compass indicator, steel wire indicator, Hall-effect Gauss/Tesla Meter, and Quantitative Quality Indicators (QQI).

3.3.5.1 Field Indicator.

CAUTION

> Field indicators SHALL be kept away from fields strong enough to damage the needle because of rapid or violent deflection beyond full-scale reading. Field indicators, SHALL NOT be stored within the influence of magnetizing or demagnetizing magnetic flux.

The field indicator, a pocket instrument, is used to determine the comparative intensity of leakage fields emanating from a part. A typical field indicator is shown (Figure 3-21). The theory of operation is quite simple. When a field indicator is placed in a magnetic field, it responds to that portion of the magnetic field that passes through the sensing element of the indicator. The indicator responds to the magnetizing force of the leakage field passing through its sensing element, rather than the flux density in the part from which the leakage field emanates. When measuring the strength of the leakage field emanating from a part, the indicator senses only the field at some distance from the part. This distance is from the center of the sensing element to the bottom of the indicator when it is placed on the part’s surface. The flux density of the field in the part will be greater than indicated by the field indicator. How much greater will depend upon the permeability of the part, shape of the part, and the effect of distance from the part to the sensing element in the indicator. Since these variables have an effect on determining flux density, it is recommended the field indicator be used only as a comparative indicator of the flux leakage from a part. The sensing element in newer indicators is of a ceramic-like material, which is very resistant to demagnetization.

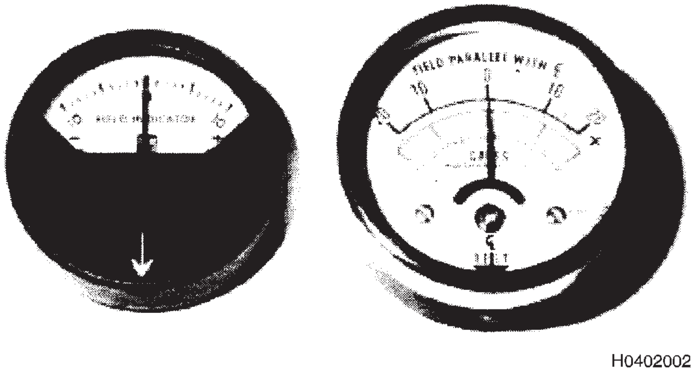
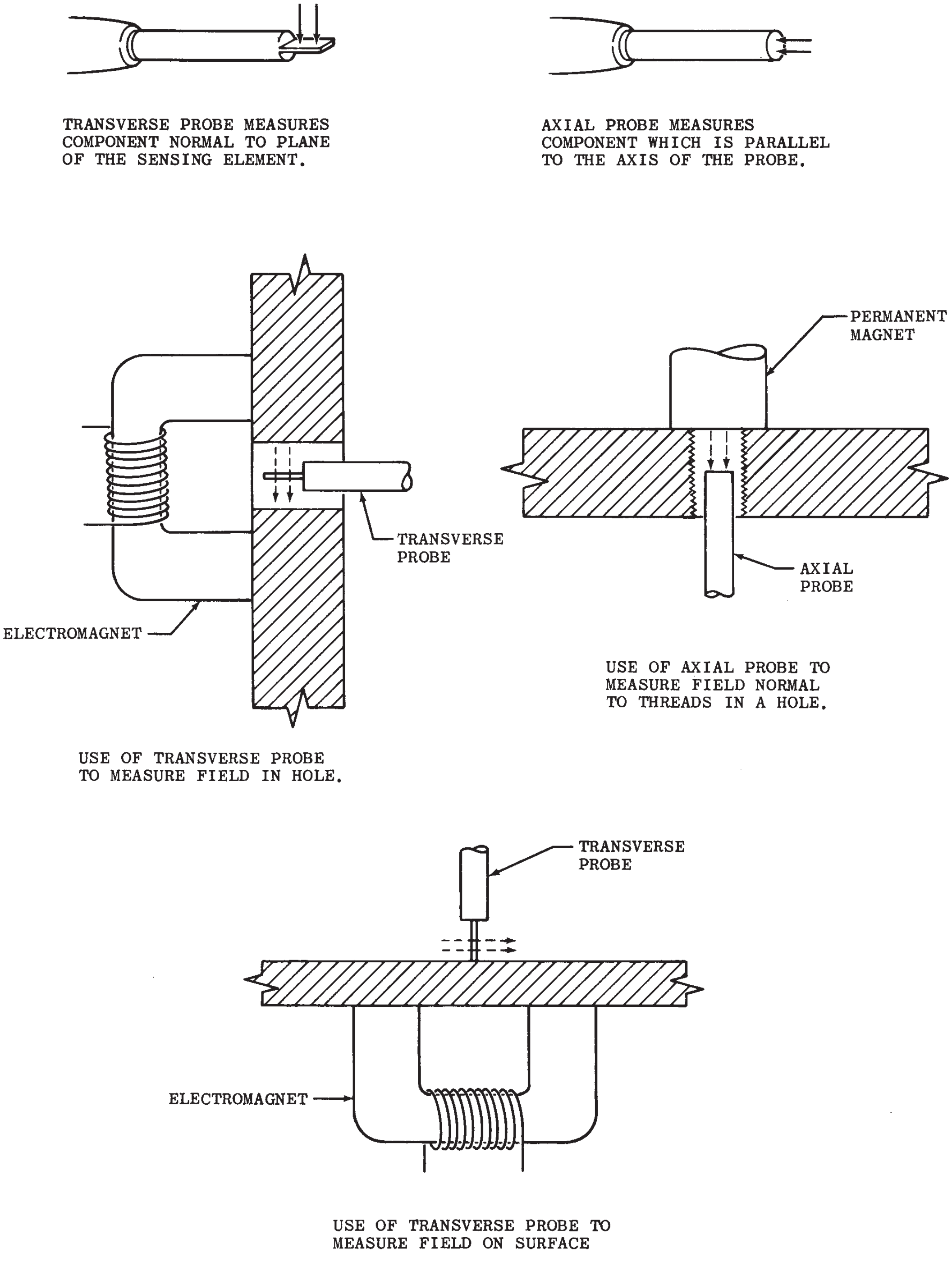


Figure 3-21. Typical Field Indicators

3.3.5.2 Compass Indicator. A compass is sometimes used for indicating the presence of external leakage fields. A compass can be placed upon a nonmagnetic surface and a magnetized part (aligned due east and west) moved slowly toward the east or west side of the compass case. The presence of an external leakage field from the part can cause the compass needle to deviate from its normal north-south alignment. However, demagnetized parts will cause the needle to deviate from its normal position if the compass case is not approached from an easterly or westerly direction. The theory of operation is very similar to the field indicator since the compass needle is a permanent bar magnet.

3.3.5.3 Steel Wire Indicator. A piece of iron or steel wire can be fashioned into a fair detector when nothing else is available. By forming a loop at one end of a piece of tag wire approximately 6-inches long, it can be suspended from a second wire supported in the horizontal plane. The part in question is then brought into contact near the free end of the vertically suspended wire. The presence of leakage fields will cause the wire to deviate from its normal vertical position as the part is slowly withdrawn in a horizontal direction. Care SHALL be taken to demagnetize the vertically suspended wire between each test. Small pieces of tag wire about 1-inch long can also be used to indicate the presence of leakage fields. The piece of demagnetized wire is placed upon a horizontal nonmagnetic surface, and the part in question is placed on top of it. If the piece of tag wire can be lifted off the surface as the part is slowly raised, the leakage fields are excessive.

3.3.5.4 Gauss Meter. The Hall-effect Gauss (Tesla) Meter has interchangeable probes to permit measurement of the magnetic field either parallel or perpendicular to the axis of the probe. Place the probe in the hole or on the surface as shown (Figure 3-22).



TRANSVERSE PROBE MEASURES COMPONENT NORMAL TO PLANE OF THE SENSING ELEMENT.

AXIAL PROBE MEASURES COMPONENT WHICH IS PARALLEL TO THE AXIS OF THE PROBE.

USE OF TRANSVERSE PROBE TO MEASURE FIELD IN HOLE.

USE OF AXIAL PROBE TO MEASURE FIELD NORMAL TO THREADS IN A HOLE.

USE OF TRANSVERSE PROBE TO MEASURE FIELD ON SURFACE

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Figure 3-22. Typical Use of Gauss Meter Probes

3.3.6 Understanding and Selecting Magnetic Particle Inspection Materials.

3.3.6.1 General. An important consideration in the magnetic particle testing process is the use of the proper type of materials to secure the best possible indications of the particular type of defect being sought under a given condition. The choice of which materials to use is important, since the appearance of the particle patterns at discontinuities will be affected by this choice, even to the point of whether or not a pattern is even formed. Since the results of magnetic particle tests depend on the interpretation of the particle pattern, the appearance of this pattern is of fundamental importance. The reproducibility of results by inspectors at different locations is dependent on the same type of particles being used by each inspector, and the same magnetizing procedure.

3.3.6.1.1 There are two basic classes of magnetic particles available for use, wet and dry. The wet method particles use a liquid vehicle for suspension; the dry method particles are borne by air. Either water or oil may be used as a vehicle for the wet method. The particles are colored to provide good color contrast with the surface being inspected. The wet particles are best suited for the detection of fine surface cracks such as fatigue cracks. They are usually used with stationary equipment where the bath can be reused until it becomes contaminated. For field applications, aerosol cans of magnetic wet bath are available. Dry particles are more sensitive for detecting defects beneath the surface and are usually used with portable equipment.

3.3.6.2 Particle Properties and Their Effects.

3.3.6.2.1 Particle Description. The particles used in the magnetic particle inspection process are finely divided ferromagnetic material, usually combinations of iron and iron oxides. Properties of these particles include the size, shape, density, magnetic properties, mobility, and color. These properties may vary depending on the application.

3.3.6.2.2 Particle Size. It is self-evident that size plays an important part in the behavior of magnetic particles in a magnetic field, which can be quite weak at a discontinuity. A large heavy particle is not likely to be arrested and held by a weak field when such particles are moving over a part surface. On the other hand, very weak fields will hold very fine powders, since their mass is very small. Consequently, extremely fine particles may adhere to the very weak leakage fields caused by acceptable surface and/or material variations. Particle size has a profound effect upon its mobility.

3.3.6.2.2.1 Dry Powder Particle Size. In general, for the dry powders, sensitivity to very fine defects increases as particle size decreases, but with definite limitations. If the particles are extremely small, on the order of a few microns, they behave like a dust. They accumulate and adhere even on very smooth surfaces. The particles will adhere at any damp or slightly oily area, whether or not leakage fields exist. Extremely fine powders, though undoubtedly sensitive to very weak fields, are not desirable for general use because they leave a heavy, dusty background. In some special applications, particles of a specific size range are used (e.g., where it is desired to detect rather large, coarse discontinuities, only large-sized particles are used). However, most dry ferromagnetic powders used for detecting discontinuities are mixtures of particles in a range of sizes. The smaller particles add sensitivity and mobility, while the large particles not only aid in locating large defects, but also by a sort of sweeping action, counteract the tendency of the fine ones to leave a dusty background. Thus, by including a wide size range, a balanced powder with sensitivity over most of the range of sizes of discontinuities is produced.

3.3.6.2.2.2 Wet Method Particle Size. When the ferromagnetic particles are applied as a suspension in some 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 left behind as the suspension drains off. Such particles often line up in what are called drainage lines to form a watermark that could be confused with indications of discontinuities.

3.3.6.2.2.2.1 In the case of 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, they become actual tiny magnets. Under conditions of quiet settling in a suspension, these particles are drawn together as a result of their retained magnetism to form clumps or aggregates of particles. These aggregations then tend to act as a unit when they are applied to the surface of parts for magnetic particle testing. The speed and extent to which this process takes place increases with the retentivity of the particle material. Agitating the suspension breaks up the aggregates, but they begin to form again as soon as agitation ceases. This happens when the suspension has been applied over the surface of the part, since the particles act as agglomerated units of varying size, and not as individual particles.

3.3.6.2.2.2.2 Advantages of an Agglomeration of Fine Wet Particles. This agglomeration of fine particles into larger clumps is advantageous as long as the size of the aggregate does not become larger than the limit mentioned in (paragraph 3.3.6.2.2.2). Individual particles of exceedingly small-size move very slowly through the liquid of the suspension under the influence of leakage fields at discontinuities. Unless special techniques are used, exceedingly small-size particles are not particularly useful for the location of very fine cracks until the process of agglomeration into somewhat larger units has taken place. In practical applications this process takes place while drainage of the suspension from the surface of the part is occurring. As the agglomeration proceeds the clumps formed will vary in size, and since these clumps act as individual units the effect is that of a particle size range from very fine to relatively coarse.

3.3.6.2.2.3 Fluorescent Particles. The information in (paragraph 3.3.6.2.2.2) applies primarily to magnetic particles not treated with fluorescent pigments. Fluorescent particles (or even colored visible particles) must be compounded and structured to produce a pigmented or colored coating that will not readily separate from the ferromagnetic core.

3.3.6.3 Particle Shape. The shape of the magnetic particles used for magnetic particle testing has a strong bearing on their behavior in locating defects. When in a magnetic field the particles tend to align themselves along the lines of force. This tendency is much stronger with elongated or rod-like particles than with more compact or globular shapes because the long shapes develop stronger polarity. Due to the attraction exhibited by opposite poles, the north and south poles of these tiny magnets arrange themselves into strings of particles, north to south, 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 particles bridge the discontinuity. The superior effectiveness of the elongated shapes over the globular shapes is particularly noticeable in the detection of wide, shallow discontinuities, or of those discontinuities, which lie wholly below the surface. The leakage fields at such defects are more diffuse, and the formation of strings due to the stronger polarity of the elongated-shaped magnetic particles makes for more visible indications in such cases.

3.3.6.3.1 Dry Powders and Particle Shape. In the case of the dry powders, there is another effect from the shape of the particles which must be taken into account. Dry particles are applied to the surfaces of parts by means of plastic powder bottles, rubber squeeze bulbs, or by the use of compressed air guns. The ability to flow freely and to form uniformly dispersed clouds of powder that will spread evenly over a surface is a necessary characteristic for rapid and effective dry powder testing. A powder composed only of elongated shapes tends to gather together in the container, and to be ejected in uneven clumps. When a powder behaves in this manner, the inspection becomes extremely slow and difficult. On the other hand, globular-shaped particles flow freely and smoothly under similar conditions. A dry powder must have free-flowing properties for easy application, yet have optimum shape for the greatest sensitivity for the formation of strong indications. These two opposing needs are met by blending particles of different shapes. A fair proportion of rod-like particles must be present for a sensitive blend. A sufficient proportion of more compact shapes must be present in order to have a powder that will flow well for easy and uniform application.

3.3.6.3.2 Wet Method Particle Shape. In the case of particles for the wet method of inspection, the individual particles are kept dispersed by mechanical agitation until they are applied to the surface of the magnetized part. Therefore, no need exists to incorporate unfavorable shapes merely for the purpose of improving the flow of the particles. Long, slender particles, with otherwise desirable characteristics, could be used exclusively.

3.3.6.3.2.1 Because wet method particles are suspended in a liquid medium, which is much denser and more viscous than air, they move in the leakage fields much more slowly than the dry powders. Therefore, they accumulate much more slowly at discontinuities. In the vicinity of leakage fields, they can be seen to line up to form minute elongated aggregates. Even the unfavorable aggregate shapes, formed by simple agglomeration in suspension, will line up into magnetically held elongated aggregates under the influence of local, low-level leakage fields. This effect contributes to the high sensitivity of the fine particles comprising wet method materials.

3.3.6.4 Particle Density. Most ferromagnetic materials have fairly high densities. The densities of the materials in common use vary from around 5 to nearly 8 times the density of water. Large, heavy particles will settle out of a suspension faster than smaller, lighter particles. This constitutes one more reason for requiring magnetic particles to be small. The density of many ferromagnetic particles is lowered somewhat by compounding or coating them with pigment with densities lower than the particles; with the obvious advantage of the particles remaining suspended longer than uncoated particles. This is true of both the dry, pigmented powders and the fluorescent particles in liquid suspension.

3.3.6.5 Particle Permeability. Magnetic particles used for magnetic particle testing should have the highest permeability and the lowest retentivity possible. This is so the low-level leakage fields that occur in the vicinity of a discontinuity can easily magnetize the particles. These fields will draw the particles to the discontinuity itself and form a visible indication. However, there is little connection between permeability and sensitivity for magnetic powders. For instance, the iron-based dry-method powders have permeabilities higher than the oxides used in the wet method. Yet a typical dry powder has less ability in detecting the extremely fine surface cracks than the wet-method particles. This is because the higher permeability is insufficient to overcome the handicaps of the other less desirable characteristics of the dry powders. Unless all other factors are in the proper range for the application at hand, high permeability alone is of little value.

3.3.6.6 Coercive Force and Retentivity Properties of Particles. As a general principle, low coercive force and low retentivity are desirable properties for magnetic particles. If these values were high in a dry powder, the particles would become magnetized during manufacture or in first use, and thus become small, strong, permanent magnets. Once magnetized, their tendency to be controlled by the weak fields at discontinuities would be overshadowed by their tendency to stick magnetically to each other and to the test surface. This acts to reduce mobility of the powder, and also to form a high level of background that obscures defect indications.

3.3.6.6.1 Wet method particles that could become strongly magnetized because of high coercive force would also form this same objectionable background. In addition, such particles would stick to any iron or steel in the tank or plumbing of an inspection unit, and cause heavy settling-out losses that would have to be made up by frequent additions of new particles to the bath. Another undesirable feature displayed by highly retentive wet method particles is their tendency to clump together quickly in large aggregates on the test surface. Excessively large clumps of material have low mobility and indications are distorted or obscured by the heavy, coarse-grained backgrounds. Therefore, particles having high coercive force and retentivity are not desirable for wet method use either.

3.3.6.6.2 Both theory and experience have shown low coercive force and retentivity are advantageous. But low does not necessarily mean minimum or none. Dry powders with some residual magnetism appear more sensitive, especially in the diffuse leakage fields formed by defects lying wholly below the surface. The reason may be the small amount of polarity established in weakly magnetized, elongated particles aid in lining them into strings when the leakage fields of discontinuities act upon them. The action is similar to the compass needle swinging in the very weak field of the earth. Similarly, wet-method particles benefit from the higher than minimum values of retentivity and coercive force. These ultra-fine particles begin to collect at discontinuities as soon as they are applied to the test surface once the agitation from the bath ceases. With insufficient retained magnetism, the particles remain fine and migrate very slowly through the liquid, due to the weak leakage fields, and the viscosity of the liquid suspending medium. The indications of discontinuities will build up, but very slowly, taking as long as five to ten-seconds. On the other hand, if excessively magnetized particles are used, the test surface is covered with large immobile clumps as soon as the bath is applied. Particles having intermediate magnetic properties collect into clumps more slowly while the indications are forming. The leakage field, strongest at the actual discontinuity, draws particles toward it, while the particles themselves are constantly enlarging due to agglomeration. At the same time, they sweep up the ultra fine particles as they move toward the defect. In this way, all the magnetic fields present work together.

3.3.6.7 Particle Mobility. When magnetic particles are applied over the surface of a magnetized part, they must move and gather at a discontinuity under the influence of the leakage field to form a visible indication. Any factor that interferes with this required movement of the particles will have 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.

3.3.6.7.1 Dry Powder Mobility. Dry powder SHOULD be applied in such a way the particles reach the magnetized surface in a uniform cloud with a minimum of motion. When this can be done, the particles come under the influence of the leakage fields while suspended in air, and have three-dimensional mobility. This condition can be approximated when the magnetized surfaces are vertical or overhead. When the particles are applied on a horizontal or sloping surface they settle directly to the surface and do not have the same degree of mobility. Tapping or vibrating the part, which jars the powder loose from the surface and permits it to move toward the leakage fields, can achieve mobility in this case. When AC or half-wave rectified AC (pulsating DC) is used for magnetization, the rapid variation in field strength while the current is on, imparts a vibratory motion to the magnetic particles on the surface of the part. This gives the particles excellent mobility for the formation of indications. The coatings applied to some of the dry-method powders to give color to the indications, also reduce friction between particles and the surface of the part, thus aiding mobility.

3.3.6.7.2 Wet Method Mobility. The suspension of particles in a liquid, which may be water or a petroleum distillate, allows mobility for the particles in two dimensions when the suspension is flowed over the surface of the part, and in three dimensions when the magnetized part is immersed in the suspension. Wet method particles readily settle out of suspension.

To be effective, the magnetic particles must move with the liquid and reach every surface the liquid covers without settling out somewhere along the way. Particles settle out of suspension at a rate directly proportional to their size and density, and inversely proportional to the liquid's viscosity. While it must be balanced against many other properties, mobility is one of the factors which is important to wet method results. The viscosity of the suspension medium is also important to mobility. In thicker liquids, the magnetic particles migrate to the leakage field more slowly. If the suspension liquid is too viscous and the magnetizing cycle too short, the indication may not form adequately. As a practical rule for sensitive inspection, the viscosity of the suspension medium SHOULD NOT exceed 3-centistokes.

3.3.6.8 Visibility and Contrast.

3.3.6.8.1 Dry Powder Visibility and Contrast. These are important properties that have a great deal to do with making a magnetic powder suitable for its intended purpose. Size, shape, and magnetic properties of a particle may be adequate, but if the indication is not visible to the inspector the inspection fails.

3.3.6.8.1.1 Visibility and contrast are promoted by choosing colors of particles easy to see against the color of the surface of the test part. The natural color of the metallic powders is silver-gray. The colors in the iron oxides commonly used as the base for the wet method materials is limited to black and red. Coloring the powder particles in some way can increase visibility against certain colors. By use of pigments the silvery iron particles are colored white, black, red, or yellow, all with comparable magnetic properties. One or another of these colors gives good contrast against the surfaces of most of the parts tested. Among the dry powders, the gray-white powder gives good contrast against the surfaces of many test parts. It fails to give good visibility, however, against the silver-gray of a sand- or grit-blasted surface, or against bright machined or ground surfaces. Choice of colors SHALL be made by the inspector to provide the best possible visibility against the surfaces of the test part under the conditions of shop lighting that prevail. Similarly, the choice of either the black or the red wet method material is made to suit particular lighting conditions.

3.3.6.8.1.2 In some cases it has been found advantageous to coat the part being tested with a color to improve contrast. Chalk or whiting in alcohol has been used in the past for the inspection of large castings and weldments when lighting conditions were poor in the areas where the inspection was being conducted. Aluminum paint has been similarly used. Color contrasting is rarely used today, because the fluorescent materials now available solve the problem in a much better way.

3.3.6.8.2 Wet Method Visibility and Contrast. The ultimate in visibility and contrast is achieved by coating the magnetic particles with a fluorescent pigment (usually available in wet method materials only). The search for indications is conducted in total or semi-darkness, using ultraviolet light to activate the fluorescent dyes used. When indications glow in the dark, it is almost impossible for an inspector not to see them. Magnetically, these fluorescent materials are less sensitive than uncoated particles, but this reduction in magnetic sensitivity is more than offset by the fact patterns of particles can be readily seen even when only a few such particles make up the indication. A fluorescent indication easily visible under UV-A is often quite impossible to see when viewed in white light. The advantage in visibility and contrast of the fluorescent materials is so great, they are being used in a very high percentage of all applications.

3.3.6.9 Media Selection.

3.3.6.9.1 Dry Method Versus Wet Method. Principally, the following influences the choice between the dry and wet methods:

- Type of Defect (surface or subsurface). Dry powder is usually more sensitive for detection of subsurface defects.
- Size of Surface Defect. The wet method is usually best for locating very fine and shallow defects.
- Convenience. Dry powder, with a portable half-wave unit, is easy to use on large parts in the shop or for field inspection work.

3.3.6.9.1.1 The dry powder method is superior for locating defects lying wholly below the surface because of the high permeability and the favorably elongated shape of the particles. These form strings in a leakage field and bridge the area over a defect. AC with dry powder is excellent for surface cracks, which are not exceedingly fine, but it is of little value for defects lying even slightly below the surface. When the requirement is to detect very fine surface cracks, the wet method is considered superior regardless of the form of magnetizing current used. In some cases, direct current is considered advantageous for use with the wet method to get better indications of discontinuities that lie just below the surface. The wet method offers the advantage of easy complete coverage of the surface of parts of all sizes and shapes. Dry powder is often used for spot inspections.

3.3.6.9.2 Visible Particles Versus Fluorescent Particles. Selection of the color of particles to use is essentially a matter of obtaining the best possible contrast with the background of the surface of the part being inspected. The differences in visibility among the black, gray, and red particles are considerable on backgrounds which may be dark or bright and which may be viewed in various kinds of light. Black stands out against most light colored surfaces, gray against dark colored ones. Red is more visible against silvery and polished surfaces especially when the lighting is from incandescent lamps. If the indication is hard to see, the inspector should try some other color of powder. In the case of the wet method, the ultimate in visibility and contrast is obtained by the use of fluorescent particles. The fluorescent wet method has been used in increasing numbers of inspection applications for many years, principally because of the ease of seeing the faintest indication.

3.3.6.9.3 Fluorescent Particle Characteristics. When exposed to near ultraviolet light UV-A fluorescent magnetic particles emit a highly visible yellow-green color. Indications produced are easily seen, and the fluorescent particles provide much stronger indications of very small discontinuities than do the non-fluorescent magnetic particles. The differences between the wet visible method and the wet fluorescent method are comparatively minor regarding suspension characteristics, maintenance and application, as well as the inspection variables and demagnetization techniques. The following applies only to the wet fluorescent method.

3.3.6.9.3.1 Advantages and Limitations. Fluorescent particles have one major advantage over the untreated or visible particles, their ability to give off a brilliant glow under UV-A illumination. This brilliant glow serves three principal purposes:

- In semi- or complete darkness even smallest 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 uncolored particles.
- Even on discontinuities large enough to give good visible indications, fluorescent indications are easier to see and the chance of the inspector missing an indication is reduced, even when the speed of inspecting parts is increased.
- Concurrent with the greater visibility of indications formed by fluorescent particles, the background caused by excessive magnetization is also more severe. Consequently, greater care SHALL be exercised in selection of the particle concentrations and magnetization levels for the inspection with fluorescent particles.

3.3.6.9.3.2 The fluorescent particle technique is faster, more reliable, and more sensitive to very fine defects than the visible colored particle method in most applications. Indications are easier to detect, especially in high volume testing. In addition, the fluorescent method has all the other advantages possessed by the wet visible suspension technique.

3.3.6.9.3.3 The wet fluorescent technique also shares the disadvantages found with the wet visible technique. In addition, there is a requirement for both a source of UV-A, and an inspection area from which the white light can be excluded. Experience has shown that these added requirements are more than justified by the gains in reliability and sensitivity.

3.3.6.9.4 Media Selection. NDI laboratories SHALL include the following supplemental information on the purchase order or contract when requesting new media.

- Suspension vehicle for magnetic particle inspection SHALL comply with A-A-59230 (Table 3-1).

Table 3-1. Requirements for Magnetic Particle Wet Method Oil Vehicle (A-A-59230)

Test	Requirement		Specification/Standard
	Minimum	Maximum	
Flash Point, °C (°F)	94 (200)	—	ASTM D 93
Odor	—	None	DOD-F-87395
ASTM Color	—	1.0	ASTM D 1500
Background Fluorescence	Less than the standard		DOD-F-87395
Viscosity Centistokes	—	3.0	ASTM D 445
Particulate Matter, mg/L	—	0.5	ASTM D 2276
Total Acid Number, mg KOH/L	—	0.015	ASTM D 3242

- Magnetic particles SHALL comply with ASTM E 1444 and the specific Aerospace Material Specification (AMS) (Table 3-2).

Table 3-2. Procurement Data for Magnetic Particles per ASTM E 1444

Type of Particles (Specification Title)	Specification
Magnetic Particle Inspection Material, Dry Method	AMS 3040
Magnetic Particles, Wet Method, Oil Vehicle	AMS 3041
Magnetic Particles, Wet Method, Dry Powder	AMS 3042
Magnetic Particles, Wet Method, Oil Vehicle Aerosol Canned	AMS 3043
Magnetic Particles, Fluorescent, Wet Method, Dry Powder	AMS 3044
Magnetic Particles, Fluorescent, Wet Method, Oil Vehicle	AMS 3045
Magnetic Particles, Fluorescent, Wet Method, Oil Vehicle, Aerosol Canned	AMS 3046

SECTION IV MAGNETIC PARTICLE INSPECTION APPLICATIONS

3.4 MAGNETIC PARTICLE INSPECTION APPLICATION METHODS.

3.4.1 Inspection Preparation.

3.4.1.1 Disassembly Requirements. There are situations when disassembly of the item is required prior to inspection:

3.4.1.1.1 Disassembly eases accessibility to most if not all surfaces, thus permitting a more thorough inspection.

3.4.1.1.2 Boundaries between two ferrous pieces, or between a ferrous and a nonferrous piece, will create a leakage field that may confuse inspection.

3.4.1.1.3 It is usually easier to handle disassembled parts for pre-cleaning, inspection, and post-cleaning.

NOTE

If the critical area of an assembly is completely accessible for inspection without any disassembly, and if the inspection medium (magnetic powder or paste) can be removed after inspection, then it is acceptable to inspect those areas or parts in place without disassembly. For example, steel propeller blades may be inspected in the blade area while they are in place on the aircraft, but to inspect the shank area, which is concealed by the hub, it is necessary to disassemble.

3.4.1.2 Plugging and Masking. When it is possible for the inspection media to become entrapped or to damage components, plugging and/or masking SHALL be used. Plug small openings and holes with hard grease or similar nonabrasive readily soluble material. This prevents the accumulation of the magnetic particles and carrier liquid where it cannot be completely and readily removed by conventional cleaning and air blasting.

3.4.1.3 Pre-Cleaning. Pre-cleaning is the removal of all foreign material (paint, grease, oil, corrosion, layout dye, wax crayon markings, etc.,) which may interfere with magnetic particle testing that has accumulated since the general cleaning operation but prior to inspection.

3.4.1.3.1 Parts or surfaces SHALL be clean and dry before they are subjected to any magnetic particle inspection process. The cleaning process used SHALL NOT reduce the effectiveness of the inspection process. The cleaning process is required to remove all contaminants, foreign matter, and debris that might interfere with the application of current or the movement of the magnetic particles on the test surface.

NOTE

Thin coatings such as cadmium, chromium, or a single coat of paint, if in good condition, will not interfere with the inspection process, and do not necessarily have to be removed. Parts that have been repainted or touched up may have thicker than normal paint which may require stripping.

3.4.1.4 Selecting a Cleaning Process. The cleaning process SHALL be chosen with knowledge of the contaminant, the reaction of the cleaning process to the metal, the accessibility of the part to be inspected, whether it’s on or off the aircraft, along with other specific safety precautions. No single cleaning method can assure removal of all types of contaminants and most methods are limited to the removal of only a few types of contaminants. Further, some cleaning methods require equipment that may not be adaptable to the specific job conditions (e.g., such as cleaning large parts or cleaning in place on an aircraft). Finally, some processes may cause corrosion of the part to be inspected.

3.4.1.5 Typical Cleaning Methods.

CAUTION

Only trained and qualified personnel SHALL prepare a part (e.g., chemical/mechanical striping), which requires anything more than a simple wipe down. Improper cleaning procedures and/or materials may cause severe damage to the material. Residues from cleaning processes can remain on the part surface and contaminant the inspection. Paint removers may leave residues that either trap particles or contaminate recirculating baths. Air Force personnel SHALL refer to TO 1-1-691. Navy personnel SHALL refer to NA 01-1A-509. Army personnel SHALL refer to TM1-1500-344-23.

3.4.1.5.1 Alkaline Cleaning. Alkaline cleaners are nonflammable water solutions containing alkaline detergents that can remove certain types of oils by saponifying (converting the oil to soap) or displacement. They can be used hot or cold, as a dip or as a spray.

3.4.1.5.2 Solvent Cleaning. Solvent cleaners are an efficient and practical means of removing light preservatives and soil from parts taken out of storage or accumulate during transit and handling from the cleaning shop prior to the inspection process. Solvent cleaners dissolve oil, wax, grease, and some other contaminants and can be applied by spraying, wiping, or dipping.

3.4.1.5.3 Paint Strippers. Paint removers can be a solvent, bond release agent, softening agent, or combination.

3.4.1.5.4 Steam Cleaning. Steam cleaning is a form of alkaline or detergent cleaning and can remove loosely bound inorganic contamination and many organic contaminants from the test surfaces.

3.4.1.5.5 Ultrasonic Cleaning. Ultrasonic cleaning combines solvent or detergent cleaning with very vigorous mechanical action to loosen contaminants.

3.4.1.5.6 Mechanical Cleaning. Mechanical methods, such as wire brushing or abrasive blasting, can be used to remove rust or other corrosion deposits. These methods, if used improperly, can damage parts and conceal discontinuities (especially on soft metals) and SHOULD only be used as directed.

3.4.1.6 Preparation of Part Surface. In general, the same requirements apply for the wet method as for the dry method. Dirt, corrosion, loose scale, oil, or grease SHALL be removed. The oil bath will dissolve oil or grease, but this builds up the viscosity of the bath and shortens its useful life. With a water bath, oil on the surface of the part makes wetting more difficult, although the conditioners in the bath are usually sufficient to take care of a slight amount of oil. Excessive oil on part surfaces contaminates the water bath. Nonferromagnetic coatings, both nonmetallic (e.g. paint) and metallic (e.g. chrome), if over 0.003-inch thick, may have to be stripped. Tests have shown nonmagnetic coatings of any kind, in excess of 0.003-inch in thickness, can seriously interfere with the formation of magnetic particle indications of small discontinuities. Ferromagnetic coating (e.g. nickel) will have an even greater effect on sensitivity and may need to be stripped where they exceed 0.001 inch thick.

NOTE

When preparing for contact testing, nonconductive coatings SHALL be removed from the contact areas.

3.4.1.6.1 Surface Preparation for the Dry Powder Method. In general, the smoother the surface of the part and the more uniform its color, the more favorable are the conditions for the formation and the observation of indications. This statement applies particularly to inspections being made on horizontal surfaces. Dry powder may not be held in place on very smooth, sloping/vertical surfaces by a weak leakage field. The surface SHALL be clean, dry, and free of oil and/or grease. The dry particles will stick to wet or oily surfaces and not be free to move over the surface to form indications. This may completely prevent the detection of significant discontinuities by obscuring the flaw indications with a heavy background. On surfaces cleaned of grease by wiping with a rag soaked in a petroleum distillate, a thin film of unevaporated solvent can remain, sufficient to interfere with the free movement of the powder. This film can be removed by wiping the surface with a clean, dry cloth, flushing with alcohol, or dusting the surface with chalk or talc from a shaker can, and then wiping the surface with a clean dry cloth. An initial application of the dry magnetic powder itself, followed by wiping, can also provide a surface over which a second application of powder will move readily. Vapor degreasing (if available), will provide a dry, oil-free surface.

3.4.1.6.1.1 Any loose dirt, paint, rust, corrosion, or scale can be removed with a wire brush, by shot or grit blasting, or other allowable means. Cleaning with shot or grit blasting may cause a peening effect (especially on softer steels), which may close up fine surface discontinuities. The effect is more pronounced with shot than with grit, but if these cleaning methods are used the operator SHALL be aware of the danger of missing very fine cracks. A thin, hard, uniform coating of corrosion or scale will not usually interfere with the detection of any but the smallest defects. The inspector SHALL be aware of the smallest size defect he/she must consider, in order to judge whether or not such a coating of rust or scale should be removed.

3.4.1.6.1.2 Paint or plating on the surface of a part has the effect of making a surface defect behave like a subsurface defect. The relative thickness of the plating or paint film and the size of the defects sought, determine whether or not the coatings should be stripped. The dry method is more effective than the wet method in producing indications through such non-magnetic coatings. If fine cracks are suspected, the surface SHALL be stripped of the coating if its thickness exceeds 0.003-inch. Most coatings of cadmium, nickel, or chromium are usually thinner than this and the plating makes an excellent background for viewing indications. Hot galvanized coatings are thicker than 0.003-inch, and in general SHOULD be removed before inspections unless only gross discontinuities are important. Broken or patchy layers of heavy scale or paint also tend to interfere by holding powder around the edges of the breaks or patches and SHOULD be removed if they are extensive enough to interfere with the detection of discontinuities.

3.4.1.6.2 Surface Preparation for the Wet Suspension Method. In general, the same requirements apply for the wet method as for the dry technique (paragraph 3.4.1.3.1). Dirt, corrosion, loose scale, paint, oil, and grease SHALL all be removed prior to inspection. When preparing for contact testing, nonconductive coatings SHALL be removed from the contact areas. The test surface SHALL be free of contaminants that can dissolve into the inspection bath.

3.4.1.6.2.1 Insoluble particulate contaminants, such as corrosion, sand, and grit left on the part surface may accumulate in a recirculating wet bath. This accumulation may interfere with the formation and visibility of indications and force the bath to be discarded sooner than normal.

3.4.1.6.2.2 The removal of surface oil and grease is very important when preparing the part prior to wet fluorescent magnetic particle inspection. Oil or grease can harm aqueous inspection baths in several ways. Their presence on the test surface can either prevent the bath from wetting and covering the entire surface, or it can cause the bath to peel off the surface, stripping any indications off with it. The oil can also be emulsified in an aqueous bath, and again coagulate the magnetic particles. Such dissolved contaminants may also become concentrated in a recirculating test bath, increasing its viscosity. Most petroleum distillates, lubricating oils, and grease fluoresce.

3.4.1.6.2.3 Moisture on the test surface can be emulsified into an oil bath causing the magnetic particles to coagulate and settle out of the bath, where they are no longer available to form indications. This contamination will gradually retard the forming of indications and make them increasingly difficult to see.

3.4.2 Magnetic Particle Inspection Techniques. There are several techniques associated with the magnetic particle inspection process. Each technique has its benefits and detriments.

3.4.2.1 Determining the Choice of Technique. The choice of technique for a particular magnetic particle inspection depends upon:

- The type of discontinuity or defect being sought.
- The part's material, shape, and size.
- The magnetic particle inspection equipment available.

3.4.2.2 Technique Variations. The following variations SHALL be considered and the appropriate alternatives selected to achieve a particular inspection result:

- Type and amount of magnetizing force required producing adequate magnetization.
- The estimated flaw size and flaw orientation.
- Type of defect; surface or subsurface.
- The magnetic particles best suited for the inspection (e.g., fluorescent, red, black, etc.).
- The method of particle application best suited for the inspection (e.g., wet, dry, or magnetic rubber).

3.4.2.3 Sensitivity Level. Any factor that affects the formation of magnetic indications at a discontinuity affects the sensitivity of that magnetic particle inspection. Three of the most important factors are: "field direction," "current level," and "control of the magnetic particle inspection media."

3.4.2.3.1 Effect of Field Direction on Sensitivity Level (paragraph 3.4.4.1).

3.4.2.3.2 Effect of Current Level on Sensitivity Level. The formation of magnetic particle indications at discontinuities depends upon the strength of the corresponding leakage fields. Since the strength of the leakage field results from the field generated by the magnetizing current, the greater the magnetizing current, the greater will be the strength of the leakage field. Thus, the sensitivity of a magnetic particle inspection is directly related to the applied current. A current level too low produces leakage fields too weak to form readily discernible indications; and a current level that is too high creates a heavy background accumulation of particles that masks an indication. In circular magnetization, a high current level may also burn the contact points of a part.

3.4.2.3.3 Effect of Inspection Media on Sensitivity Level. Sensitivity level is affected not only by the current amperage, but also by the type of magnetic particle inspection media, its applications, and its control.

3.4.2.3.3.1 The smaller particle sizes within liquid suspensions are the most sensitive for the detection of surface discontinuities while dry powders are better for detecting subsurface defects. Fluorescent materials have a higher apparent sensitivity than do those used with visible light, such as the black and red particles.

3.4.2.3.3.2 Inspection of parts which are only moderately retentive requires careful control of the way the inspection media is applied. Usually, maximum sensitivity is obtained by applying the media while a part is being magnetized and ending it before the magnetizing field is removed, commonly known as the continuous method (paragraph 3.4.6.4.7.3.2). This is also true in the case of automatic wet-method inspection in which the main bath stream is shut off shortly before the magnetizing current is ended to avoid washing off indications already formed.

3.4.2.3.3.3 Particle concentration in the baths SHALL be closely controlled if maximum sensitivity is to be obtained. Sensitivity is lowered if concentration of particles is too low. If concentrations are too high, fine indications may be masked by heavy background accumulations.

3.4.2.3.3.4 Contaminants, particularly in wet baths, can result in lowered sensitivity. Lubricating oils and greases for example, cause a blue background fluorescence that reduces contrast, causing fluorescent particle indications to be less visible.

3.4.2.3.3.5 Sensitivity of dry powders depends upon: "type of powder selected," "how carefully it is applied," and its "color." Most powders are made for general use and have a wide mix of particle sizes to aid in the detection of both fine surface and deep subsurface discontinuities. A powder color is usually selected which will provide the best contrast against the color of the surface upon which it is being used. Care SHALL be exercised when applying powder media. Light tossing and/or air-blowing actions are needed to allow the particles to migrate to and be held by the leakage fields at discontinuities. Excessive application of powder can cause indications to be lost in background accumulation.

3.4.2.3.3.6 The dry powder method is superior for locating defects lying entirely below the surface. This is due to the high permeability and the favorably elongated shape of the particles. These form strings in a leakage field and bridge the area over a defect. However, when the problem is to find very fine surface cracks, there is no question as to the superiority of the wet method, regardless of the form of magnetizing current used. In some cases, direct current is selected for use with the wet method to obtain the advantage of improved indications of discontinuities that lie just below the parts surface, especially on bearing surfaces and aircraft parts. The wet method offers the advantage of easy, complete coverage of the entire surface of parts. Dry powder is often used for localized inspection areas.

3.4.3 Selecting a Magnetizing Current.

3.4.3.1 Alternating Current (AC). AC in magnetic particle inspection is effective only for the detection of surface discontinuities. These types of discontinuities comprise the majority of service-induced defects. Fatigue, overload, and stress-corrosion cracks are examples of cracks usually open to the surface.

3.4.3.1.1 The shallow penetration of AC fields into the part at the usual power line frequencies of 50 and 60 hertz hinders the use of AC for the detection of subsurface discontinuities. This shallow penetration is due to a skin effect. Skin effect is the crowding of magnetic flux or electric current outward and away from the part center. Self-induced flux or currents that reduce the interior density of the flux or current causes this crowding phenomenon. Skin effect is the reason AC is recommended when inspecting for service-induced surface defects. However, the skin effect of AC is less at lower frequencies, resulting in deeper penetration of the lines of force. At 25 hertz, the penetration is considerably deeper, and at frequencies of 10 Hz and less, the skin effect is almost nonexistent.

3.4.3.1.2 The alternating currents used in magnetic particle inspection have low excitation voltages. Currents from stationary equipment range from about 100 amperes to 10,000 amperes depending upon the test part and the magnetization technique. The high currents are obtained by using step-down transformers that reduce line voltages to about 20 volts. Lower amperages are available from hand-held devices that operate from standard 115-volt outlets. Alternating current (AC) and half-wave direct current (HWDC) are obtained from single-phase systems or from one phase of three-phase systems. Full-wave direct currents (DC) are usually obtained from three-phase systems using full-wave, three-phase bridge rectifiers.

3.4.3.1.3 If the defects sought are at the surface, AC has several advantages. The rapid reversal of the field imparts mobility to the particles, especially to the dry powders. Dry powder particles in the presence of AC or HWDC fields have mobility on a surface due to the pulsating character of the fields. Particle mobility aids considerably in the formation of particle accumulations (indications) at discontinuities. The "dancing" of the powder helps it to move to the area of leakage fields and to form stronger indications. This effect is less pronounced in the wet technique.

3.4.3.1.4 Alternating current has another advantage in the magnetizing force is determined by the value of the peak current (at the top of the sine wave of the cycle). The peak current is 1.41 times greater than the current value read on the meter. Alternating current meters read more nearly the average current for the cycle rather than the peak value.

3.4.3.2 Direct Current (DC). Magnetic fields produced by direct current penetrate deeper into a part than fields produced by alternating current, making the detection of subsurface discontinuities possible. For longitudinal magnetization DC magnetizes the entire part’s cross-section more or less uniformly. For direct contact (circular) magnetization a straight-line gradient of field strength (from a maximum at the surface to zero at the center) is experienced. Direct current generally is used with wet magnetic particle techniques. In the presence of DC fields, dry powder particles are relatively immobile and tend to remain wherever they happen to land on the surface of a part.

3.4.3.2.1 Pure direct current can be obtained from automotive type storage batteries. Today this technique is seldom used except in emergencies when a battery may be used to power a hand-held magnetizing device. The disadvantages of using batteries are their weight (since a number of them must be used to obtain high currents), the frequent maintenance required, their limited life cycle, and replacement cost. An advantage is the line power requirements are far less to keep the batteries charged than to power a system operating directly from line power.

3.4.3.2.2 The prevailing approach for obtaining direct current for magnetic particle inspection is through rectification of alternating current using solid-state rectifiers. A rectifier (diode) is a device that allows electric current to flow through it in only one direction. By proper connection of rectifiers, the back and forth flow of alternating current is converted to a current flow in only one direction, which is a form of direct current. A rectifier circuit which converts both alternations (back and forth flow) of the alternating current to one direction of current flow is called a full-wave rectifier.

3.4.3.2.3 Single-phase alternating current can be rectified using a full-wave rectifier circuit to obtain direct current for magnetic particle inspection. Single-phase rectification, however, is seldom used to obtain direct current, except in the case of small hand-held magnetizing devices. Since three-phase power is so readily available in industry, direct current for magnetic particle inspection units is usually obtained using three-phase full-wave rectifiers.

3.4.3.3 Comparison of Results Using Different Currents. A comparison of indications showing the same set of fine surface cracks on a ground and polished piston pin (Figure 3-23), is obtained by using 60 cycle AC, DC from storage batteries (straight DC), and DC from rectified three-phase 60 cycle AC respectively. Four values of current were used in each case with a central conductor to magnetize the hollow pin. The indications produced with AC are heavier than the DC indications at each current level, although the difference is most pronounced at the lower current values. Straight DC and rectified AC are comparable in all cases. The AC currents are meter (R.M.S. or Root Mean Square) values, so peak of cycle currents, and therefore magnetizing forces, are 1.41 times the meter reading shown.

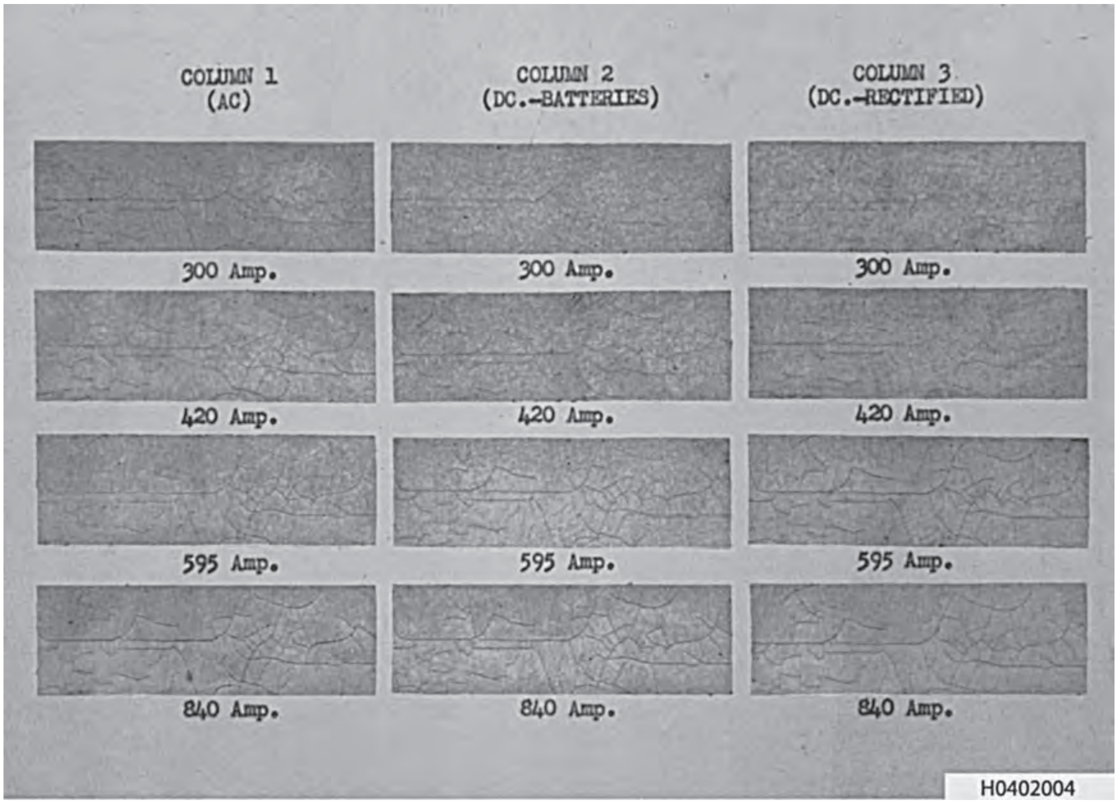
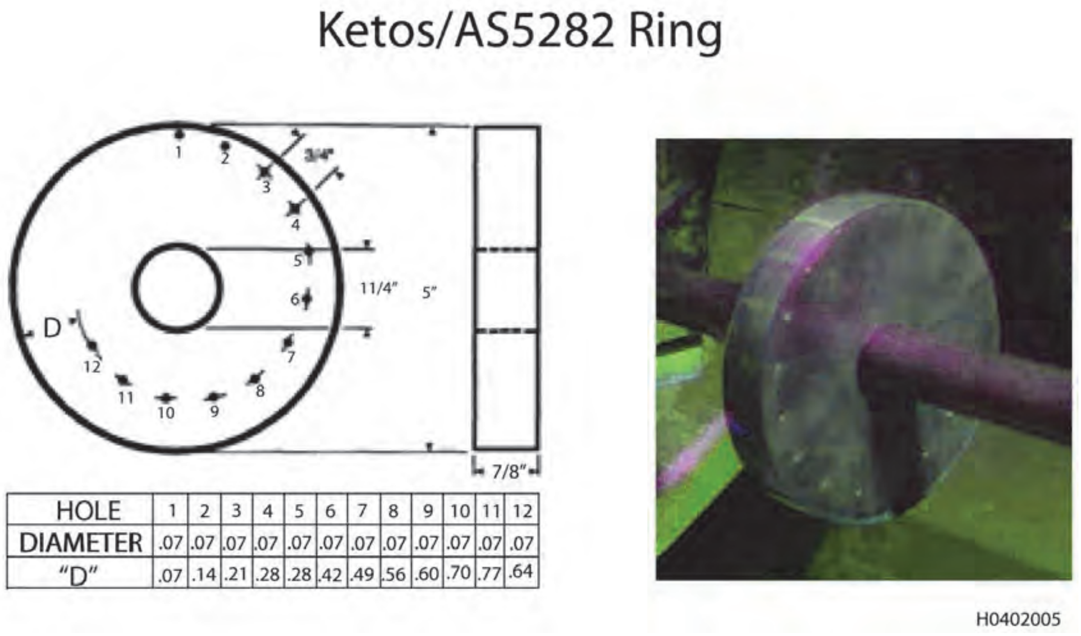


Figure 3-23. Comparison of Indications of Surface Cracks on a Part Magnetized With AC, DC, and Three-Phase Rectified AC

3.4.3.3.1 A similar comparison can be made using the Ketos ring specimen, the drawing for this is shown (left side of Figure 3-24). The specimen, made of unhardened (annealed) tool steel (0.40 percent carbon), is 7/8 inch thick. Holes, 0.07 inch in diameter and parallel to the cylindrical surface, are located at increasing depths below the surface.



HOLE	1	2	3	4	5	6	7	8	9	10	11	12
DIAMETER	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07
"D"	.07	.14	.21	.28	.28	.42	.49	.56	.60	.70	.77	.64

Figure 3-24. Drawing of a Tool Steel Ring Specimen (Ketos Ring) on Left. In-Use AS5282 Ring shown on Right.

3.4.3.3.2 For the inspection of newly manufactured parts, such as the machined and ground shafts and gears, direct current is frequently used. Although AC is excellent for the location of fine cracks that actually break the surface, DC is better for locating the very fine non-metallic stringers that can lie just under the surface.

3.4.3.3.3 Half-Wave Current provides the greatest sensitivity for detecting discontinuities that lie below the surface, particularly when using dry powder and the continuous technique. The pulsation of the half-wave current vibrates the magnetic particles, thereby aiding their migration across a surface to form indications at discontinuities. This particle mobility, which is very pronounced when dry magnetic powder is used, contrasts with the relative immobility of the powder when pure direct current is used. Due to the pulsating magnetic fields produced by half-wave current, there will be some skin effect present; however, the effect on field penetration is small at the usual frequencies of 50 and 60 Hertz.

3.4.4 Magnetic Field.

3.4.4.1 Field Direction. The proper orientation of the magnetic field in the part in relation to the direction of the defect, is a more important factor than the strength of the magnetizing current. For greatest sensitivity, the magnetic lines of force should be close to right angles to the defect to be detected. If the magnetic lines of force are parallel to the defect there will be little magnetic leakage at the defect, and therefore, if any indication is formed it is likely to be extremely small.

3.4.4.2 Right-Hand Rule. To best understand field direction and current flow, use the "right-hand-rule." The easiest way to demonstrate this rule is to grasp a straight bar in your right hand so your right thumb points in the direction the electrons would flow from negative to positive. Notice the direction your fingers curl around the bar while doing this. The direction your fingers point indicate the direction of the magnetic field in the straight bar.

3.4.4.3 Field Strength. ASTM E 1444 suggests when using a Hall-Effect probe gauss meter, tangential-field strengths measured on the part surface in the range of 30 to 60 gauss (G) peak values are normally adequate magnetization levels for magnetic particle examination. A study using DC magnetizing current confirmed this field strength could produce good indications from small defects. Other studies have suggested while good to excellent indications of defects may be produced with a tangential field in the range of 30 to 60 Gauss, the background produced from acceptable surface roughness may reduce the visibility of such indications. In such cases, lower field intensity may be optimal. If the residual method is used, field strength in the range 20 to 50 gauss are normally acceptable.

3.4.4.4 Rule-of-Thumb Formulas. These are common formulas which may be identified within this manual, in ASTM E 1444, or any other reliable technical publication. The inspector SHOULD be cautioned, when following "rule-of-thumb" formulas, the part length used in the L/D ratio is the part dimension measured in the direction of the coil axis, and the diameter is the dimension measured in the plane of the coil. For example, a 2-inch diameter steel bar, 10-inches long, will have an L/D ratio of 5 when the bar is placed in the coil with its axis parallel with that of the coil. If the bar is placed in the coil so the bar and coil axis are at right angles to each other, the L/D ratio will be only 0.2, a figure which, if used, would indicate the need for impracticably high amperages.

NOTE

All studies agree "rule-of-thumb" formulas for estimating magnetizing currents, contained in ASTM E 1444, will usually produce field strengths well in excess of what is needed for adequate magnetization with the concurrent risk of producing a background that can hide defect indications. Always use a magnetizing force sufficient to minimize background and maximize the signal to noise ratio of the method.

3.4.4.5 Circular Magnetization. Circular magnetization is used for the detection of radial discontinuities around edges of holes or openings in parts. It is also used for the detection of longitudinal discontinuities, which lie in the same direction as the current flow, either in a part or in a part that requires the use of a central bar conductor.

3.4.4.5.1 A circular magnetic field is generated in a part whenever an electric current is passed through it or through a central bar conductor. In the case of a concentric cylinder, a circular field traveling around the inside of the part will be entirely contained within the part and thus no magnetic poles will be produced from the part. Magnetic poles will be produced if the part is not a concentric cylinder, is irregularly shaped, or the path of the current flow is not located on the part's geometric axis. In these cases, the magnetic poles are caused by a relatively small portion of the magnetic flux that passes out of the part and into the air that surrounds the part. The no pole condition in a concentric cylinder occurs both while the magnetizing current is flowing and after current flow ceases. The part is thus residually magnetized, but since no magnetic poles exist, the part appears to be in an unmagnetized state. However, if the part is cut (Figure 3-6), such as when a keyway is made, some of the field will pass out and over the cut, producing opposite magnetic poles on each side of the cut. Such poles can hold chips or metal that can interfere with subsequent machining operations or damage bearing surfaces. Care SHALL be used in the case of circular magnetization, which may not be detectable, and appropriate means to ensure demagnetization SHALL be taken. This is usually accomplished by magnetizing the part with a longitudinal field AFTER inspection with a circular field.

3.4.4.5.2 Circular Magnetization Techniques.

CAUTION

Wet the contact pads with the suspension vehicle prior to current application to help prevent overheating of the part. Ensure the contact surfaces of the part are clean and free of paint or similar coatings and have adequate pressure applied to achieve good mechanical and electrical contact over a sufficient area of the part's surface.

There are two techniques used to induce circular magnetization: the "direct contact" technique and the "central conductor" technique.

3.4.4.5.2.1 Direct Contact Technique. This technique produces circular magnetization by passing electric current through the part itself (Figure 3-10). Direct contact is applied to parts by placing them directly between the headstocks. Lead faceplates and/or copper braid pads SHALL be used to prevent arcing, overheating, and splatter. On large parts, clamping lug-terminated cables to the part using ordinary C-clamps sometimes makes current contact. Regardless of how it is made, the electrical contact SHALL be as good as practicable to minimize any over heating or arcing at the juncture. Any excessive heating at the contact points may do a number of things (e.g., burn the part, affect its temper, finish, etc.).

3.4.4.5.2.2 Central Conductor Technique. Central conductors are any conductive material, such as a copper bar or cable, placed in the center of the part to be magnetized. This technique produces circular magnetization by passing electric current through a conductor that has been placed coaxially in an opening, frequently in the center of a part (Figure 3-11) and (Figure 3-12). A magnetizing field exists outside a central conductor carrying current, so the walls surrounding a central conductor become magnetized. Since the circular field produced around a central conductor is at a right angle to the axis of the conductor, the central conductor technique is very useful for the detection of discontinuities that lie in a direction generally parallel with the conductor.

3.4.4.5.2.2.1 Both the central conductor and the direct contact technique can be used to detect discontinuities on the outside surfaces of tubular or cylindrically shaped parts. The central conductor technique SHALL be used if longitudinal discontinuities must be detected on the inside of tubular or cylindrically shaped parts. The direct contact technique may not produce reliable results in this case, particularly if the part is a concentric tube or cylinder with good current contact at each end.

3.4.4.5.2.2.2 The central conductor technique is also very useful for detecting discontinuities, usually cracks, which emanate in a radial pattern from holes. A part, with a hole or opening to be inspected for inside and outside discontinuities, is usually positioned with the central conductor centered coaxially in the hole or opening.

3.4.4.5.2.2.3 On very large parts with large openings, the central conductor may be located close to the inside surface and several inspections made around the inside periphery of the opening. Placing the conductor close to the inside surface reduces the current requirement since the strength of the circular field increases with decreased distance from the conductor.

3.4.4.5.3 Selection of Current Amperage for Circular Magnetization. A number of factors SHALL be considered when determining what current amperage to use for circular magnetization. Some of these factors are:

- The type of discontinuity being sought and the expected ease or difficulty of finding it.
- The part’s size, shape, and cross-sectional area through which the current will flow.
- The amount of heating that can be tolerated in the part and at the current contact areas.
- The relationship between the current and the leakage fields at the surface of the part.

The magnetizing force at any point on the outside surface of a part through which electric current is flowing will vary with the current. The greater the current, the greater this magnetizing force. Inside the part, just under the point on the surface, the magnetic flux density will be the product of this magnetizing force and the magnetic permeability of the part at that point. It is this magnetic flux density that determines the leakage field strength at discontinuities. Thus, current is directly related to the strength of leakage fields at discontinuities, and it is these leakage fields that capture and hold magnetic particles. The more difficult the discontinuities are to detect, the weaker the leakage fields will be for a given current level. A higher current will be required to form discernible magnetic particle indications. At the same time, leakage fields from minor surface variations can attract and hold the magnetic particles, forming a background that makes indications of true discontinuities less distinct. Increasing the magnetizing force or current will also increase the intensity of this background. The correct magnetizing force or current is one strong enough to produce indications of the discontinuities which must be detected, but not too strong so the background masks the indications sought.

3.4.4.5.3.1 Current Amperage for the Direct Contact Technique. A problem arises when deciding what current to use for a given part, particularly when the part has a complicated shape. A "rule-of-thumb" from ASTM E 1444 suggests currents from 300 to 800 amperes per inch of part diameter when the part is reasonably uniform and cylindrical in shape may be used. Except for some special alloys the use of current values in the upper half of this range will result in excessively high field strength, thus impeding the detection of discontinuities. Generally, the diameter of the part SHALL be taken as the largest distance between any two points on the outside circumference of the part. However, as a starting point, the lower limit of such "rules-of-thumb" SHALL be used as the initial magnetization current level. From this point, either use a gauss meter or shim indicators to find the correct current level.

NOTE

> The use of the "rule-of-thumb" for excitation currents is fairly straightforward in the case of uniform cylindrically shaped parts. On parts having complicated shapes, such as irregular forgings, machinery parts, weldments, or castings, the use of any "rule-of-thumb" is often not practical. In these cases the inspector must rely on judgment and past experience and aids such as the shims or gauss meter previously discussed, to help in the selection of the optimum current level. Experience with similar parts, which do have discontinuities, is especially helpful in this respect.

3.4.4.5.3.2 Current Amperage for the Central Conductor Technique. Induction current requirements using a central conductor will depend upon the part’s size and the diameter of the opening through which the conductor is to be located. In the case of a centrally-located conductor, suggested currents from an old "rule of thumb" may range from 100 amperes per inch of the hole diameter, to as much as 1000 amperes per inch of the hole diameter, depending upon part material and the nature of the suspected discontinuities. Keep in mind the magnetizing field strength around a central conductor decreases with distance away from the conductor. The strongest flux field is present at the inner surface of the hole through which the central conductor passes as shown (Figure 3-25). Not only discontinuities parallel with the central conductor are detectable using the central conductor technique, but radial discontinuities at the ends of holes and openings can be detected, since some portion of the magnetic lines of force will intercept these discontinuities.

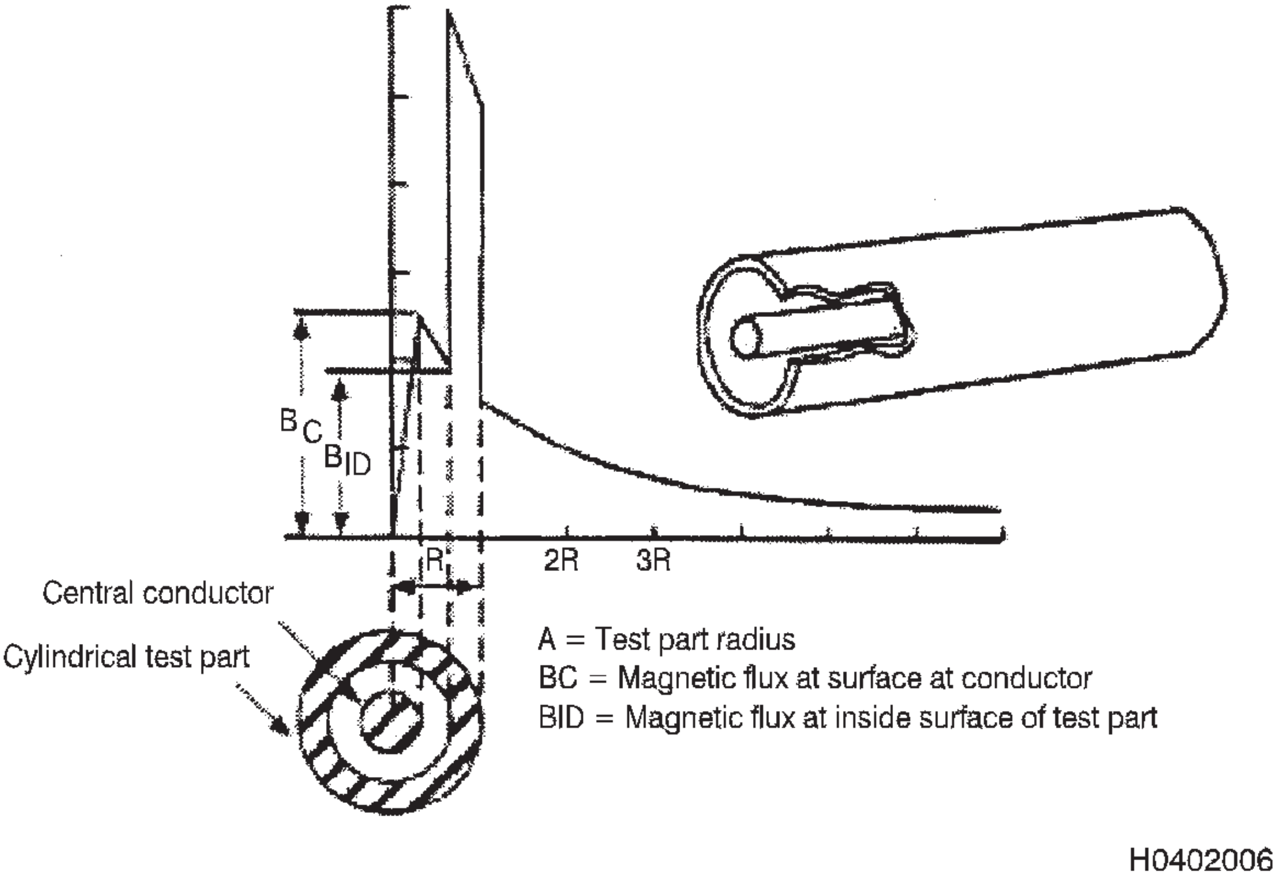


Figure 3-25. Magnetic Flux Distribution in a Central Conductor and a Cylindrical Test Part

3.4.4.5.3.2.1 When using a central conductor, alternating current SHALL only be used when inspecting for surface discontinuities on the inside circumference of the part, unless effectiveness on the outside surface has been demonstrated using QQIs. Because the skin effect with AC current decreases the field reaching the outside surface, much higher current will be required than for the inside, and on some parts, the inspection may not be possible. If only the inside surface is to be inspected, the diameter SHALL be the largest distance between two points, 180-degrees apart, on the inside circumference. Otherwise the diameter SHALL be determined as indicated (paragraph 3.4.4.5.3.1). The central conductor SHOULD have an outside diameter as close as practical to the inside diameter of the hole of the part being inspected and still permit access to apply solution.

3.4.4.6 Longitudinal Magnetization. A part is longitudinally magnetized when the field is approximately parallel with a major axis. A part magnetized in a coil, for example, will be longitudinally magnetized in a direction approximately parallel with the coil axis. A characteristic of a part magnetized longitudinally will be the appearance of opposite magnetic poles, north and south, at the extreme ends of the part. The existence of the poles is a disadvantage when magnetizing and inspecting, because much of the leakage flux from the pole-ends is not parallel with the part surface. This reduces the magnitude of flux that is parallel, thereby weakening the leakage fields at discontinuities in the end regions. The use of pole pieces as described (paragraph 3.4.4.6.4.1), overcomes this weakening effect in many cases. The poles are an advantage in demagnetizing since they make it easy to detect magnetized parts and to confirm removal of the residual fields after demagnetizing procedures.

3.4.4.6.1 Longitudinal magnetization is used for the detection of circumferential discontinuities that lie at approximately right angles to a part's 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 will cross the discontinuities creating leakage fields that can capture and hold magnetic particles to form indications at the discontinuities.

3.4.4.6.2 Applications. Like all other forms of magnetization, longitudinal magnetization is used to inspect ferromagnetic components having material permeability's of about 500 or greater. This includes most steel alloys (Table 3-3). A simple test to determine whether or not a part is sufficiently magnetic is to place a permanent magnet against a part to be tested. If the attraction of the magnet can be felt, the part is sufficiently magnetic for magnetic particle inspection.

Table 3-3. Relative Permeabilities for Some Ferromagnetic Materials

Ferromagnetic Materials	Relative Permeability [1]
Iron (99% annealed in H)	200,000
Iron (99.8% annealed)	6,000
Iron (98.5% cold rolled)	2,000
Nickel (99% annealed)	600
Cobalt (99% annealed)	250
Steel (0.9% Carbon)	100
Excerpt from Nondestructive Testing Handbook, Vol. 6, American Society for Nondestructive Testing, 2^d Ed., 1988	
[1] Relative to air, which has a permeability of 1.0	

3.4.4.6.2.1 Discontinuities detected by the longitudinal method are those, which lie generally in a direction transverse or crosswise to the direction of the applied field. The depth at which a discontinuity can be detected depends upon the size and shape of the discontinuity relative to:

- The size of the cross section in which it is located.
- The length to diameter ratio (L/D) of the part.
- The strength of the applied magnetizing field.

3.4.4.6.2.2 The smaller the L/D ratio, for any given coil and coil current amperage, the lower will be the magnetic flux density in the part, and the weaker will be the leakage fields over discontinuities. In other words, the smaller the L/D ratio, the greater the coil current amperage must be to produce the same flux density or field strength in the part. Coil amperages become impracticably large for L/D ratios of 2 or less. If L/D is less than 2, pole piece(s) (ferromagnetic material with the same diameter as the part being examined) may be placed on one or both ends to effectively increase the L/D to 2 or greater. Long parts, with L/D ratios greater than 15, SHOULD receive multiple inspections along the length of a part. The most effective field in a part extends about 6 to 9-inches on each side of a coil. For multiple inspections, a coil SHALL be repositioned at intervals of from 15 to 18 or less inches along the part.

3.4.4.6.2.3 Longitudinal magnetization of coated parts may be accomplished depending upon the type and thickness of the coating. Metallic plating generally SHOULD NOT exceed 0.003-inch in thickness, unless it is known that the discontinuities being sought can be detected through greater thickness. Nonmetallic coatings, such as paint or other protective coatings, require removal only if they are excessively thick or damaged to the extent particles can be trapped mechanically. Any oil or grease SHALL be removed since such materials contaminate the liquid media. Any loose scale or rust SHALL also be removed from parts before inspection since they also can interfere with formation of indications and are a contaminant in a liquid bath.

3.4.4.6.2.4 Inherent with longitudinal magnetization when using a coil is the difficulty in producing good indications near the ends of the part. The leakage field that emanates from the magnetic poles generated at the part ends causes this difficulty.

Longitudinal magnetization of a cylindrical part in a coil will produce free magnetic poles at the end of the part. The direction of the magnetic field in the part will be in the same direction as the magnetization force generated by the coil. However, since the flux lines are continuous, the flux lines that traverse from one pole to the other within the part will return outside the part, and in doing so travel in a direction opposite to the applied magnetizing force. This results in a reduction in field strength at the surface of the part and is called "free-pole" demagnetization. The inspection of areas near the ends of such parts is improved when the quick break in the magnetizing current is used. The resulting rapid decay of the field generates a pulse of induced current in the same direction as the original magnetizing current, which in turn produces a strong surface residual field over most of the length of a part. Parts must be moderately retentive for this type of residual inspection, and their shape must be generally cylindrical and have no long slots or cuts that would interrupt an induced current path around in the part near its outer surface. It must be mentioned the use of yokes or electromagnet magnetization will also assure an adequate inspection of the ends of generally cylindrical objects.

3.4.4.6.3 Longitudinal Magnetization Techniques.

3.4.4.6.3.1 Coil Technique. The most common way to longitudinally magnetize a part is by placing the part in a rigid coil on a stationary magnetic particle inspection unit. The part may be laid on the bottom inside 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 inspection. Coils are usually mounted on rails permitting movement along a long part for multiple inspections (multiple coil shots). Because the effective field extends only 6 to 9-inches on either side of a coil, multiple inspections are required along the part. The magnetizing field strength in the center of the magnetizing coil increases with the current passing through the coil and is proportional to the number of turns. The field strength decreases if the coil radius is made larger.

3.4.4.6.3.2 Cable Wrap Technique. Cable wrapping a coil around large or heavy parts is another method of producing longitudinal magnetization. Flexible, insulated copper cable is used. A cable-wrapped coil is connected to a magnetic particle mobile or portable power pack or it can be connected to the contact heads of a stationary inspection unit. The type of power source to be used will depend upon the type and level of current needed to accomplish the particular desired inspection, both magnetizing and demagnetizing.

3.4.4.6.3.2.1 Cable lengths used to connect cable-wrapped coils SHALL be kept as short as practical to minimize resistance losses in the cable and obtain higher magnetizing currents. In the case of AC, and to some extent half-wave DC, in addition to cable resistance, there is the inductance of the coil circuit which further reduces current flow. Twisting or taping the coil cable leads together aids in reducing the inductance of the coil circuit. Coil inductance increases directly with the coil opening area and increases as the square of the turns in the coil. Keeping each of these factors as small as practical, particularly when using AC, assures the maximum current will be obtainable from the power supply. To help keep coil current losses low, cable coils should be wrapped directly on a part or on some insulating material only a little larger than the part. Multiple inspections along a part, using a coil of only a few turns (3 to 5) is preferable to using a coil of many turns over the length of the part. The latter is occasionally done in some cases where performing multiple inspections is not possible or when a power pack having the required output voltage and current capacity is available. Finally, any cables and cable leads used with and for cable-wrapped coils SHALL have good quality electrical connections. Poor connections result in overheating and reduced coil amperage.

3.4.4.6.3.3 Cable Wrap Coil. Cables used are commonly 2/0 or 4/0 AWG (American Wire Gage), flexible stranded, insulated copper cable. The number of turns used is kept low, from 3 to 5 turns to minimize cable resistance in the case of DC and coil impedance when AC is used.

3.4.4.6.3.3.1 Multiple inspections, spaced approximately 15 to 18-inches along the length of a long part, are preferable to one inspection using one long coil of many turns. Cable lead lengths between the power source and coil wraps SHALL be kept as short as practical so maximum amperages are produced in the coil. When AC or HWDC is being used, twisting or taping together the cable lengths between the coil and the power supply can increase amperage. This reduces the coil-circuit impedance the same way that reducing turns on the coil does and makes it possible for more AC current to flow in the coil circuit. The total length of the cable, together with the resistance of its connections, determines the DC amperage obtainable in the coil. The longer the cable and the poorer the electrical connections, the less will be the DC and the half-wave DC amperages that can be obtained. Increased cable resistance also lowers available AC current, but in the case of AC, the impedance of the coil and coil length circuit has a much greater effect than does resistance in lowering and limiting available AC current.

3.4.4.6.3.4 Electromagnet Technique. Parts can be magnetized longitudinally by placing them between the pole pieces of a pair of electromagnets with the fields of the two electromagnets being directed in the same direction through the part.

3.4.4.6.3.5 Yoke Technique. Still another method is the magnetizing of parts between the feet of yoke or probe.

3.4.4.6.4 Selection of Current Amperage for Longitudinal Magnetization. A number of factors must be considered when determining current levels for longitudinal magnetization of parts. Some of the more important factors are:

- The coil diameter and the number of turns.
- Cross-sectional area of the part and the coil.
- The length to diameter (L/D) ratio of the part.
- The size, shape, and composition of the part.
- The orientation of the part within the coil.
- The kind of discontinuities being sought and their ease of detection.

3.4.4.6.4.1 If the need arises to inspect parts having L/D ratios of 2or less, the effective L/D ratio SHALL be increased by placing the part with one pole piece at end or between two pole pieces while it is being magnetized. The length dimension for the L/D ratio then becomes the length of the pole pieces plus the part length. These pole pieces SHALL make good contact on each side of the part and SHALL be made of ferromagnetic material. Solid steel pole pieces may be used when direct current is used in the coil and the continuous method of inspection is used. If the continuous method is used with either AC or half-wave DC current in the coil, the pole pieces SHALL be made from laminated magnetic material similar to the silicon steel legs of a hand probe with articulated legs. This is also true for residual inspection. Pole pieces SHALL be made from the proper ferromagnetic material if residual inspection, or the wet continuous method of inspection with AC or half-wave DC, is to be used.

3.4.5 Field Strength Measurement Techniques. The measurement of magnetic flux or field strength, either within a part or at the part's surface, is extremely difficult. There are several practical methods or devices for measurement all having limitations. The most direct way of determining the magnetic field strength required is to use a specimen representative of the part to be inspected, with a defect or defects representative of those to be found. This specimen would be magnetized at sequentially higher field strengths until a good indication of the defect is formed, without an excess of background from surface conditions. This magnetic field strength could then be measured and used for parts similar to the specimen utilized (e.g. creating a "rule-of-thumb" formula). Since suitable specimens are seldom available, an alternative is to use the techniques discussed in the following paragraphs to simulate a defect and measure the necessary magnetic field strengths.

3.4.5.1 Measuring Residual Leakage Field Intensities. Leakage field intensities can be measured by quantitative or comparative methods. Quantitative measurements usually involve the use of instruments in conjunction with search coils, probes, or Hall Effect probes. Such instruments are classified as laboratory equipment and are not generally found in field locations. For purposes of determining the effectiveness of demagnetization efforts, residual field intensities are measured by comparative methods. A list of other leakage field intensity equipment (e.g. field indicator and field compass) is located in (paragraph 3.3.5).

3.4.5.1.1 Another method of testing for demagnetization is to use a piece of steel feeler stock in a few thousandths of an inch thick and test if the feeler stock is attracted by the part. A small piece of iron or steel, such as a ferromagnetic paper clip, can be suspended on a string near the test part to determine if it is attracted to the part.

3.4.5.2 Field Strength Indicators.

3.4.5.2.1 Quantitative Quality Indicator (QQI). The QQI is a small, thin, metal shim, made of low carbon steel that contains artificial defects for establishing or verifying MPI techniques. Examples of QQIs are illustrated (Figure 3-26). By using an etching process that can produce very narrow (0.005 inch) flaws with tightly controlled depths, typically 15-percent, 30-percent and 60-percent of a QQIs thickness, artificial defects may be formed. The thickness of the shim is either 0.002 or 0.004-inch. The basic QQI shim satisfies most needs because its circular and crossed-bar flaw configuration is suitable for longitudinal and circular fields. The bars in the cross are 0.25 inch long, while the circular slot is 0.5 inch in diameter. The circular flaw is especially useful in balancing multi-directional fields. The miniature shim is designed for small areas on a test part; each circle is 0.25-inch in diameter. The QQI with three concentric circular flaws with different depths (typically 20-percent, 30-percent and 40-percent of shim thickness) may be used for more quantitative assessment of a magnetic field; the diameters of the circles are 0.25, 0.375 and 0.5-inch in diameter. The linear shim is 2-inches long by 0.4-inch wide; it may useful in covering a curved area of a part, such as a radius.

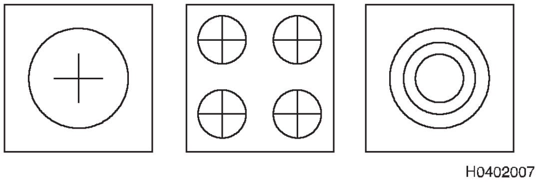


Figure 3-26. Shim-Type Magnetic Flux Indicators

3.4.5.2.1.1 QQIs are intended for use with the continuous method only. If a Gauss/Tesla meter is available, readings for both circular and longitudinal fields can be made at the point of QQI attachment. Once the readings are recorded for a part, it may be quicker to use the meter instead of a QQI to ensure sufficient field strength when the same type of part is inspected later.

3.4.5.2.2 Advantages of the QQI.

- It is the only device able to demonstrate adequacy and balance of multidirectional magnetization.
- It is quantitative to some extent.
- It has ultra-high permeability and virtually no retentivity.
- It can bend in one direction to conform to tightly curved surfaces. The 0.002-inch thick QQIs can conform to radii down to about 1/8-inch.
- Can be re-used with careful application and removal practice.

3.4.5.2.3 Disadvantages of the QQI.

- Its usefulness is readily destroyed with careless handling.
- It is not well adapted to dry powder applications.
- Physical size limits application to some areas.

3.4.5.2.4 Application of the QQI. To be effective, the QQI SHALL be placed flaw side down and in intimate contact with the part surface. Also, it SHALL be emphasized since the QQI responds to the field in its immediate vicinity, indications can be produced in the QQI when no other ferromagnetic material is present. Obviously, the primary rule of assuring the part is ferromagnetic before attempting an inspection applies with the use of QQIs. Additional information on QQIs is located in (paragraph 3.6.6.3.1).

3.4.5.3 Field Strength Measurement Devices.

3.4.5.3.1 Hall-Effect Gauss/Tesla Meter. This is a portable, hand-held digital instrument that can be used to measure magnetic-field strength. It applies a current to a Hall-effect probe or sensor and amplifies the output voltage proportional to the magnetic flux density present at the sensor and is at right angles to the applied current. It can be used in establishing MPI procedures to indicate magnetic-field direction and to measure both applied and residual fields. One limitation is it measures only the flux passing through the probe or sensor (See Figure 3-27) and does not measure the field at or below the part surface.

a. Tangential.

b. Normal.

(The arrow represents an external magnetic leakage field "B_L" at the point of measurement.)

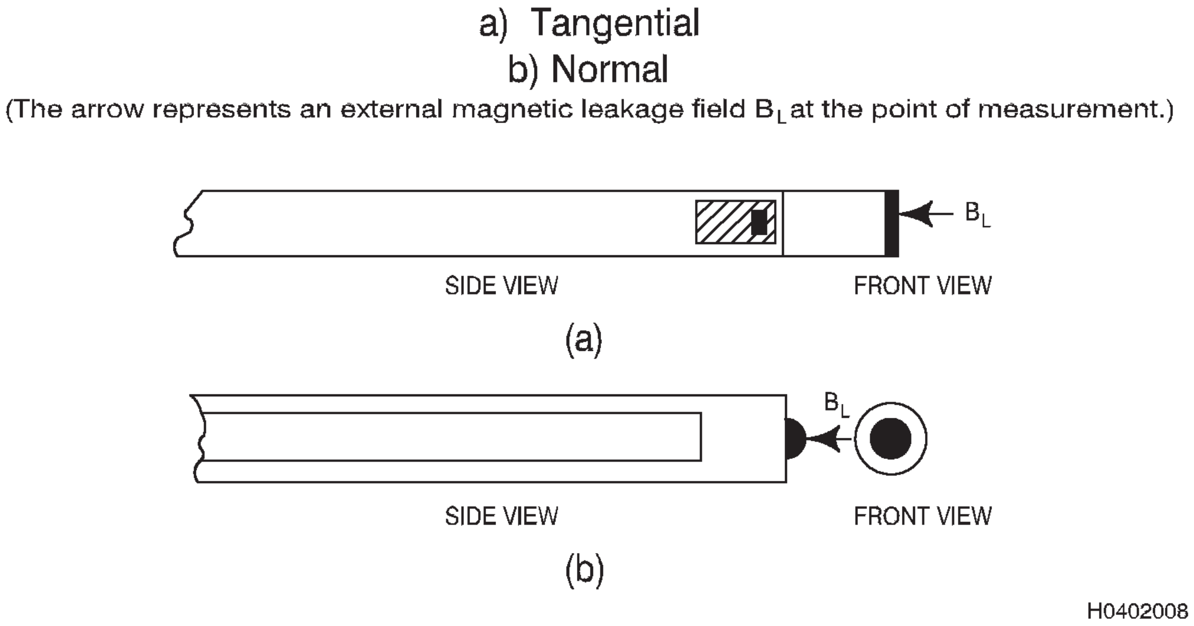


Figure 3-27. Hall-Effect Sensors

3.4.6 Methods of Particle Application.

3.4.6.1 Dry Versus Wet Application. Either the dry or the wet method for particle application can be used in the residual method. With the wet method, the magnetized parts may be immersed in an agitated bath of suspended magnetic particles, or they may be flooded with bath by a spray. In these circumstances a favorable factor occurs that affects the strength of indications. This factor is the time of immersion of the part in the bath. By leaving the magnetized part in the bath or under the spray for a considerable time, the leakage fields have time to attract and hold a maximum number of particles even at fine discontinuities. This produces an increase in sensitivity over the mere flowing of the bath over the surface of the part as it is being magnetized by the continuous method. It should be noted the location of the discontinuity on the part as it is immersed affects particle buildup. Build-up will be greatest on horizontal upper surfaces, and less on vertical surfaces or lower horizontal surfaces. Also, rapid withdrawal from the bath or spray may wash off indications held by extremely weak leakage fields. Care SHALL be exercised during this part of the process. The residual method, either wet or dry, has many attractive features and finds many applications, even though the continuous method has the inherent advantage of greater sensitivity.

3.4.6.2 Particle Description. The particles used in magnetic particle testing are made of ferromagnetic materials, usually combinations of iron and iron oxides, having a high permeability and low retentivity. Particles having high permeability are easily attracted to and magnetized by the low-level leakage fields at discontinuities. Low retentivity is required to prevent the particles from being permanently magnetized. Strongly retentive particles will cling together and to any magnetic surface, resulting in reduced particle mobility and increased background accumulation.

3.4.6.2.1 Magnetic particles may be applied as a dry powder or wet suspension. Dry powders are available in various colors so the user can select the color that contrasts best against the surface color of the part. Colors for use with ordinary visible light are red, gray, black, or yellow. Red and black colored particles are also available for use in visible light as wet suspensions. Wet suspensions use fluorescent yellow-green particles.

3.4.6.3 Dry Powder Magnetic Particles.

CAUTION

Dry powder method SHALL NOT be used on aerospace vehicles or aerospace parts without specific approval of the appropriate engineering authority for the individual inspection requirements.

3.4.6.3.1 The usual ways to apply magnetic particles in dry form are with: rubber squeeze bulbs, plastic squeeze bottles equipped with perforated caps having smaller holes than the normal saltshaker, or simply by hand. The objective is to lay down a light cloud of powder on the part being inspected. This is usually accomplished by using a combination of squeezing the bulb and/or tossing the powder toward the area being inspected.

3.4.6.3.1.1 The dry powder method is used for the inspection of welds and castings where the detection of defects lying wholly below the surface is considered important. The particles used in the dry method are provided in the form of a powder. 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 inspected and the degree of sensitivity desired.

3.4.6.3.2 Advantages and Limitations of Dry Powder. The dry powder method has good and bad features. The advantages and disadvantages, which may influence its use for a specific application, are summarized in the following list.

3.4.6.3.2.1 Good Features.

- Excellent for locating defects entirely below the surface and deeper than a few thousandths of an inch.
- Easy to use for large objects with portable equipment.
- Easy to use for field inspection with portable equipment.
- Good mobility when used with AC or half-wave (HW).
- Not as messy as the wet method.
- Equipment may be less expensive.

3.4.6.3.2.2 Bad Features.

- 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 method for large numbers of small parts.
- Not readily usable for the short, timed shot technique of the continuous method.
- Difficult to adapt to a mechanized test system.

3.4.6.3.3 Dry Powder Selection for Visibility and Contrast. Selection of the particle color to use is essentially a matter of obtaining the best possible contrast against the background of the surface of the part being inspected. The differences in visibility among the black, gray, yellow, and red particles are considerable on backgrounds which may be dark or bright, and which may be viewed under various light conditions. If difficulty is experienced in seeing indications, the inspector SHOULD try a different colored powder. Available colors for the dry powder method are:

3.4.6.3.3.1 Gray Powder. This is a general-purpose high contrast powder and by far the most widely used of the dry powders. It is effective on dark surfaces, whether black, gray, or rust colored.

3.4.6.3.3.2 Black Powder. This is especially designed for use on light colored surfaces. It is dust-free as well as the most sensitive of the dry powders. Its higher sensitivity is because it contains the highest proportion of magnetic material of all the dry powders.

3.4.6.3.3.3 Red Powder. This is a dark reddish powder used on light colored surfaces, as is the black powder. However, since the black powder on a silvery or polished surface is sometimes hard to see, the red color may offer a better contrast, particularly under incandescent lighting where the red color stands out.

3.4.6.3.3.4 Yellow Powder. This pale yellow powder features fair sensitivity and good contrast on dark colored surfaces.

3.4.6.3.4 Applying the Dry Powder. A few rules for the application of dry powder will make the process of testing easier and more effective. Dry particles are heavier and individually have a much greater mass than the very fine particles used in the wet method. If they are applied to the surface of a part with any appreciable velocity, the fields at the discontinuities may not be able to stop and retain them; this is especially true when vertical or overhead surfaces are being examined. The powder SHOULD reach the surface of part as a thin cloud, with practically zero velocity, drifting to the surface, so the leakage field has only to hold it in place. The fields of vertical and overhead surfaces must overcome the pull of gravity, which tends to cause the particles to fall from the part. Since dry particles have a wide range of sizes, the finer particles will be held under these conditions, unless the leakage fields are extremely weak. This problem is minimized on horizontal surfaces. The usual mistake is to apply too much powder. If too much powder is applied to a horizontal surface, the powder will have no mobility (unless AC or HWDC is being used) and this too heavy of an application will tend to obscure indications. If the part can be lifted and tapped, the excess powder will fall away and indications will be more readily visible. The excess powder can also be gently blown away with an air stream, which is not strong enough to blow off magnetically held particles forming an indication.

3.4.6.3.4.1 Dry Powder Applicators. Various devices have been used to make proper powder application easy. The squeeze bottle is light and easy to use. With some practice, by a combination of shaking, as with a saltshaker, and a squeeze of the bottle, powder can be ejected with minimum velocity. Practicing with the bottle on a sheet of white paper will assist in training the inspector to produce an even, gentle overall coverage. A powder gun or blower improves application, especially on vertical and overhead surfaces. The powder gun throws a cloud of powder at low velocity, much like a very thin paint spray. When held about one-foot from the surface being inspected, a very light dusting of powder permits easy observation of the formation of indications. On horizontal surfaces the excess of powder is blown away with a gentle air stream from the blower. Two push-button valves on the blower gun control the flow of powder or clean air. Less powder is used with the gun, which helps to assure a better inspection. A more elaborate gun-type powder blower has a motor-driven compressor integral with a powder container and air-powder mixer. The gun is connected to a multi-channel rubber hose and a work light is contained in the gun tip to illuminate the inspection area. A trigger on the gun controls the discharge of the powder-air mixture and blow-off air. More elaborate production systems have been built using this same principle of operation. In these cases, the discharge nozzles are mechanically controlled, as is the movement of parts through the machine. Spent powder is automatically retrieved and reused.

3.4.6.3.5 Effects of Part Surface Condition/Orientation. When the surface is horizontal, clean, smooth surfaces are best for successful dry powder inspection. If the surface is rough, powder tends to gather and be held mechanically in depressions on the rough surface. A stronger stream of air than normal may be required to blow off this loose powder. Care SHALL be taken during the inspection of rough areas (for example, a rough weld bead), so weakly held indications are not also blown away. By watching the area very carefully during powder application and while blowing off the excess, you can often see the weak indications as the powder shifts. For very critical inspections, the weld bead is sometimes machined away. Indications of discontinuities, which are below the surface, are more readily formed on the smooth machined surface of the weld. If the surface being tested is vertical or even at an angle to the horizontal, an extremely smooth surface becomes a disadvantage, since the dry powder tends to slide off easily, and weak leakage fields may not be able to hold it in place. Under these circumstances, a slightly roughened surface gives better results.

3.4.6.3.6 Inspection Technique Variables. The two basic inspection variables to be considered are the type of current to use, and the current/particle application technique. The type of current is dictated by the location of the defects, whether they are on the surface of the part, or located entirely below the surface. The choice of current is between AC and some form of DC. If the defect is on the surface, either AC or DC may be used, and the choice is determined by other considerations. AC SHALL NOT be used if the defect lies below the surface.

3.4.6.3.7 Current Selection for the Dry Powder Method. AC versus DC is the first basic choice to be made, since the skin effect of AC at 50 or 60 hertz limits its use to the detection of defects on the surface, or only a few thousandths of an inch below it. However, the skin effect of AC is less at lower frequencies, resulting in deeper penetration of the lines of force. At 25 hertz the penetration is deeper, and at frequencies of 10 hertz and less, the skin effect is almost nonexistent.

3.4.6.3.7.1 If the defects sought are on the surface, AC has several advantages. The rapid reversal of the field imparts mobility to the particles. The dancing of the powder helps it to move to the area of leakage fields and to form stronger indications. Alternating current has another advantage. The magnetizing effect is 1.41 times that of the current read on the meter. To get equivalent magnetizing effect from DC more power and heavier equipment is required.

3.4.6.3.7.2 DC on the other hand, magnetizes the entire cross section uniformly in the case of longitudinal magnetization. Direct contact (circular) magnetization produces a field that varies linearly from a maximum at the surface to zero at the center of the bar. The types of DC are; straight DC from batteries, full wave rectified three phase AC, and full wave and half-wave rectified single phase AC.

3.4.6.3.7.3 For the inspection of finished parts, such as the machined and ground shafts and gears of precision machinery, DC is frequently used. Although AC is excellent for the location of fine cracks that actually break the surface, DC is better for locating very fine nonmetallic stringers lying just below the surface. It is usually important to locate such stringers in parts of this type, since they can initiate fatigue failures. These comparisons point out the importance of choosing the right current type to give the best indications possible, and show how the choice will vary, depending upon the nature and location of the defects sought.

3.4.6.3.8 Current/Particle Application Technique. The use of dry powder with the residual inspection has several disadvantages:

- It is more difficult to apply to interior regions of a part than is wet media.
- It is more difficult to completely cover a part in a short time.
- Removal of powder from a part can be a problem.

3.4.6.3.9 Dry Powder Inspection Guidelines. Proper illumination and good eyesight are the principal requirements for observing the presence of indications on the surface of parts. Selection of the best color powder for contrast against the surface is an aid to visibility. Last, but certainly not least, magnetization SHALL be sufficient to generate a useable leakage field at the location of discontinuities, but not excessive to where the background degrades the contrast of any indications formed. On large discontinuities, dry powder build-up is often very heavy, making indications stand out clearly from the surface. Finer cracks produce less build-up, since the leakage field holds fewer particles. Extremely fine cracks require some form of the wet method, which is more sensitive to very fine discontinuities and SHOULD be used.

3.4.6.3.9.1 The same requirements for proper inspection of surfaces apply for the detection of subsurface discontinuities. The depth below the surface and the size and shape of the discontinuity determine the strength and spread of the leakage field. A proficient inspector will observe the surface as the powder is allowed to drift onto it, and will see faint but significant tendencies of the powder to gather. Often indications are seen under these conditions, but are no longer visible when more powder has been applied, the excess blown off, and the surface then examined for indications. Standardized techniques for careful and proper application of the powder can help assure the required sensitivity is achieved where similar assemblies are repetitively tested.

3.4.6.3.9.2 Indications are held at the defect by the residual field for highly retentive steels. In low carbon steels, the retentivity is very low. On these steels it is important to perform the inspection while the magnetizing current is on and the powder is being applied, since indications may not remain in place after the current is turned off. This is particularly true on vertical and overhead surfaces, where gravity plays a part in causing particles to fall away if lightly held. However, inspection requirements for the higher retentive steels often require the detection of very small defects. Even though the residual field may be high in such steel, the leakage fields for small defects will also be small, and therefore the indications are not held at the surface very well.

3.4.6.4 Wet Suspension. Either water or a high flash point petroleum distillate is used as a wet suspension vehicle.

3.4.6.4.1 Water Suspensions.

CAUTION

> The use of water suspensions SHALL be carefully controlled to prevent corrosion and provide wetting of ferromagnetic aerospace components. Wetting agents and corrosion inhibitors SHALL be used with water suspensions. Weekly monitoring of corrosion inhibitor and wetting agent concentrations SHALL be conducted per the process control section in TO 33B-1-2 WP 103 00.

Usually, the magnetic particle concentrates provide the correct amount of wetting agent and corrosion inhibitor for initial use. However, these materials are also available separately so the concentrations can be maintained or adjusted to suit the particular conditions. If no corrosion can be tolerated, a higher concentration of corrosion inhibitor will be used. Acidity SHALL be checked weekly and the pH of the water bath SHALL be between 6 to 10. If the part being inspected has a residual solvent film, more wetting agent is required so the part surface will be completely wetted. Breaking of the bath into rivulets as it is applied over a part is an indication additional wetting agent is required or the part requires further cleaning. A water break test SHALL be conducted daily using a clean specimen or part having the smoothest surface finish to be inspected. The specimen SHALL be flooded with bath and examined once flooding is stopped. If a smooth continuous film of bath forms over the entire surface, sufficient wetting agent is present. Reference SHALL be made to the manufacturer's recommendations for the correct quantity of wetting agent to be added.

3.4.6.4.2 Petroleum Distillate Suspensions. No additives other than the magnetic particles themselves are used with petroleum distillate suspensions. Petroleum distillate recommendations are included in manufacturer publications or specifications.

3.4.6.4.3 Advantages and Disadvantages of Wet Suspension. As is true of every process, the wet method has both good points as well as less favorable characteristics. The more important good points of the wet method, which constitute the reason for its extensive use, as well as the less attractive characteristics, are tabulated as follows:

3.4.6.4.3.1 Advantages.

- It is the more sensitive method for very shallow fine surface cracks.
- It quickly and thoroughly covers all surfaces of irregularly shaped parts, large or small, with magnetic particles.
- It is the faster and more thorough method for testing 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 bath, which makes for uniformity and accurate reproducibility of results.
- It is easy to recover and reuse the bath.
- It is well adapted to the short, timed shot technique of magnetization for the continuous method. It is readily adaptable to automatic unit operation.

3.4.6.4.3.2 Disadvantages.

- It is not usually capable of finding smaller defects lying entirely below the surface, if more than a few thousandths of an inch deep.
- It is messy to work with, especially when used for the expendable technique, and in field-testing. A recirculation system is required to keep the particles in suspension.
- It sometimes presents a post-inspection cleaning problem to remove magnetic particles clinging to the surface.

3.4.6.4.4 Wet Suspension Characteristics. Wet method particles may be suspended either in water or in a petroleum distillate. Water is initially cheaper, but it requires additives to make it a suitable medium for suspending the wet magnetic particles. Wetting agents, anti-foaming materials, corrosion inhibitors, suspending and dispersing agents are necessary and SHALL be carefully controlled. In order to assure proper control of the various conditioners, water SHALL NOT be used as a suspending liquid unless adequate process control capabilities are present.

3.4.6.4.4.1 Particle Characteristics. Dry material concentrates to be used in water suspension SHALL contain all of the extra ingredients necessary to make the finished suspension. Cost of the concentrate is comparable for water or oil suspension.

3.4.6.4.4.1.1 The need to incorporate all of the special ingredients for water or oil suspension into the concentrate necessitates two separate and distinct products. Water-suspendible concentrates cannot be used in oil. The various additives for water-suspendible concentrates are insoluble in oil and will not disperse the particles in an oil bath. Alternatively, the additions made to the concentrates intended for oil suspension are not soluble in water. However, with suitable water conditioners, some of the oil-suspendible concentrates can be used in water.

3.4.6.4.4.1.2 One outstanding characteristic of the wet visible method particles is their extremely small size. These very fine particles do not act as individuals but agglomerate into groups. Dry concentrates are almost always formulated to include all required constituents.

3.4.6.4.4.1.3 Oil-/Water-Suspension Power Concentrate. The requirement to meet a variety of conditions for successful magnetic particle testing has resulted in the development of different materials to obtain this result. The most commonly used materials, black and red oil/water suspensions, are listed below with the special characters of each:

- Black Power Concentrate. This is available as an oil- or water-suspension powder. It is especially suited for finding fine cracks on polished surfaces, such as bearings or crankshafts. It is the most sensitive of the non-fluorescent wet method powders for such applications.
- Red Power Concentrate. This is available as a reddish brown oil- or water-suspension powder. The red color provides improved contrast and visibility in situations where the contrast of the black powder is poor. The color tends to be more visible than the black under incandescent light.

3.4.6.4.4.2 Vehicle Characteristics. The bath liquid or vehicle may be either a petroleum distillate or water. Both require conditioners to maintain proper dispersion of the particles and to permit the particles mobility to form indications on the surfaces of parts. These conditioners are usually incorporated with the powders.

3.4.6.4.4.2.1 Petroleum Distillates Characteristics.

WARNING

> Lighter distillates have even lower viscosities than those used, but they have other properties undesirable in a magnetic particle bath. For example, lower initial boiling points accompany the lower viscosities, and results in faster evaporation losses. In addition, a lower flash point also accompanies the lower viscosity with the resulting increase in fire hazard. Inhalation of fumes from a light distillate can impair an inspector’s health. The odor of distillate can be a distraction for the inspector and is associated with color and sulfur content.

Petroleum distillates were the first choice as a suspension liquid. Significant characteristics for a suspension vehicle are low viscosity, odorless, low sulfur content, and a high flash point. The specifications for a suitable vehicle are given in (Table 3-1). Of these properties, viscosity is probably the most important from a functional standpoint. High viscosity will retard the movement of particles under the influence of leakage fields, thus slowing the build-up of particles to form indications.

3.4.6.4.4.2.2 Water Suspension Characteristics.

WARNING

Equipment SHALL be thoroughly and positively grounded.

Since water is a conductor of electricity, equipment using water is designed to isolate all high voltage circuits to avoid all possibility of an inspector receiving a shock. Corrosion of equipment can occur if proper provision is not made to avoid this. However, equipment designed for use with water suspension liquid is safe for the inspector, and minimizes the corrosion problem. There is no restriction on the water to be used for the bath, as there is with oil. Ordinary tap water is suitable, and hardness is not a problem, since the mineral content of the water does not interfere with the conditioning chemicals necessary to prepare the bath.

3.4.6.4.4.2.2.1 The advantages of water versus oil for magnetic particle wet method baths are lower initial costs, lower viscosity (about 1-centistoke), not flammable, and readily availability. The disadvantages of water include potential corrosion, electrical conductivity, freezing, and the requirement for more conditioners to assure adequate particle function.

3.4.6.4.4.2.2.2 Water baths, without auxiliary heating, can be used only in shop areas where the temperature stays above freezing. Anti-freeze liquids SHALL NOT be used because the viscosity of the bath will then exceed the maximum allowable standards. Because detergents that assure wetting of surfaces can cause foaming of the bath, circulation systems SHALL be designed to avoid air entrapment or other conditions that produce foam. Anti-foaming agents help minimize this tendency, but are not 100-percent effective.

NOTE

The use of water bath suspension is not recommended for field NDI laboratories unless adequate base laboratory facilities exist to test the serviceability of the wetting agents, dispersing agents, corrosion inhibitors, anti-foam agents, and other additives required in the water suspension. Where water is used, baths SHALL be carefully controlled to prevent corrosion and ensure adequate wetting of parts to be inspected, procedures are published in TO 33B-1-2 WP 103 00.

3.4.6.4.4.2.3 Wetting agents and rust inhibitors SHALL be used with water-type wet baths. Usually, the magnetic particle concentrates provided include the correct amounts of wetting agent and corrosion inhibitor for initial use. However, these materials are available separately so concentrations can be maintained or adjusted to suit the particular conditions. Reference SHALL be made to the manufacturer's recommendations for the correct quantity of wetting agent to be added.

3.4.6.4.5 Wet Suspension Particles. Many techniques are used to apply liquid suspension magnetic particles. These range from simple hand pouring of the suspension onto a part, to large industrial systems in which the suspension is applied automatically by dumping or spraying. The most common technique for application is through the use of a hand-held nozzle and recirculating pump on the stationary units. Other forms of application are hand-held, lever-operated sprayers or aerosol-type cans similar to those used for spray paint.

3.4.6.4.5.1 Wet Particle Visibility.

CAUTION

The wet visible method SHALL NOT be used on aerospace vehicles or aerospace vehicle parts without specific approval of the appropriate engineering authority for the individual inspection requirements.

Once wet method magnetic particles are dispersed in the suspending liquid, they are fundamentally similar to each other. In past years, the most common form of the material concentrate was a paste. Today, however, the pastes have been almost exclusively reformulated and produced as dry powder concentrates. These powders incorporate the needed materials for dispersion, wetting, corrosion inhibition, 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 will pick up the powder and quickly disperse it in the bath.

3.4.6.4.6 Suspension Agitation. The magnetic particles are considerably heavier than the vehicle in which they are suspended. When the agitation system is turned off, the particles will rapidly settle out. All particles SHALL be agitated into suspension before conducting any inspections or concentration tests. This agitation time varies with downtime due to compacting of the particles from their own weight. The following schedule SHALL be followed to ensure particles are agitated into the suspension. When the agitation system has been off for:

- One or more weeks a 60-minute agitation SHALL be performed.
- Four or more hours a 30-minute agitation SHALL be performed.
- Thirty minutes to 4-hours a 10-minute agitation SHALL be performed.
- Less than 30-minutes does not require a pre-agitation

3.4.6.4.7 Wet Suspension Particle/Field Application Techniques. There are two techniques used to apply the particles: the residual technique or the continuous technique. The method to use in a given case depends upon the magnetic retentivity of the part being inspected, and the desired sensitivity of the inspection to be made. Highly retentive parts may be inspected using what is called the residual technique. The part may be magnetized first, and particles applied after the magnetizing force has been turned off (the residual technique). The other technique, continuous, SHALL be used on parts having low retentivity. The part may be covered with particles while the magnetizing force is still present (the continuous technique). For a given magnetizing current or applied magnetizing field, the continuous approach offers the greatest sensitivity for revealing discontinuities. With parts having high retentivity, a combination of these techniques is sometimes used.

3.4.6.4.7.1 Application of Suspension. There are many techniques to apply magnetic particles. The techniques range from a simple pouring of a bath onto a part, to large industrial systems in which the bath is applied automatically, either by immersion or flooding, and then recirculated for reuse. Occasionally small hand-held, lever-operated sprayers are used. Various sizes of ordinary pressurized paint spray tanks equipped with special guns are used, particularly with water-type baths.

3.4.6.4.7.1.1 Aerosol Cans. Prepared bath is widely available in aerosol cans. Such cans, usually containing oil-based baths, are very convenient to use for spot-checking, or small area tests in the field. They are often furnished in kits, including a permanent magnet or electromagnetic yoke, which makes a portable package for small field-testing jobs or for maintenance testing around the shop.

NOTE

- Aerosol containers SHALL be demagnetized to less than two increments on the magnetic field indicator, or three gauss on the gauss meter prior to performing an inspection. If inspection fluid does not spray freely, replace spray nozzle or can.

- Shelf life dates on aerosol containers of magnetic particle materials are the final date the manufacturer will warranty its product. These products SHALL only be used after this date provided there is sufficient propellant remaining in the container and they pass the system effectiveness check (TO 33B-1-2 WP 103 00). Only aerosol containers being used to perform inspections require testing.

- Aerosols require a system effectiveness check prior to initial use. Aerosols older than two years from the manufactured date, or are undated, require a system effectiveness check prior to daily use.

3.4.6.4.7.2 Wet Suspension Application Precautions. There are many techniques used to apply magnetic particles in vehicle. The techniques range from simply pouring bath onto a part, to large industrial systems where the bath is applied automatically, either by immersion/flooding where it is then recirculated. Occasionally, small hand-held, lever-operated sprayers are used to apply bath. Prepared bath is also widely available in prepackaged aerosol cans.

3.4.6.4.7.2.1 A technique practiced, mostly on small parts, is where the parts are magnetized one at a time, and then placed in a tray and immersed into a tank containing an agitated bath of magnetic particles. Sometimes, a similar situation occurs when closely laying parts in the coil prior to flooding and magnetizing them. Precaution SHALL be taken to place these parts in the tray so they do not touch each other; or else non-relevant indications from magnetic writing may be produced at the points of contact. Haphazard loading into a basket for immersion application SHALL NOT be permitted.

3.4.6.4.7.2.2 Additional Precautions. Bath concentration and immersion time also affect the production of indications. In addition, if the leakage field at the discontinuity is weak, prolonged immersion may permit more particles to come into the influence of the field and makes the indication more visible.

3.4.6.4.7.3 Method of Current Application. The residual method requires two steps: magnetization and application of particles, plus the added time for indications to build-up if the immersion method is used. It is frequently used with AC on highly retentive materials because the alternating current field produces excellent mobility of the particles. The continuous method is preferred unless special circumstances make the residual method more desirable.

3.4.6.4.7.3.1 Residual Application Technique. The residual inspection technique for applying magnetic particles, either dry powder or a liquid suspension, is applied after magnetization. This technique is used only when parts are magnetized with DC and when parts have sufficient retentivity to form and retain adequate magnetic particle indications at discontinuities. This technique can be used with both longitudinal and circular magnetization with either direct contact or central conductor application. Usually, it is limited to the search for discontinuities open to the surface such as fatigue cracks. Residual inspection permits the magnetizing of parts followed by the application of the magnetic particle media after the current is removed. When a central bar conductor is used, inspection of holes or bores is facilitated since inspection takes place after removal of the central bar conductor.

3.4.6.4.7.3.1.1 Currents used with the residual technique only need be great enough to magnetize the part sufficiently to show the type of discontinuity being sought. Some gross discontinuities may require only weak magnetization, and others, may require the maximum residual field obtainable. The residual magnetic field retained in a part is always less than the applied magnetic field strength that produced it. A maximum residual field strength results when the magnetization level within the part reaches magnetic saturation. Magnetizing currents greater than those needed to produce the maximum saturation field strength are of no value with the residual technique.

3.4.6.4.7.3.1.2 The residual method, in general, is reliable only for the detection of surface discontinuities. Since hard materials that have high retentivity are usually low in permeability, higher than usual magnetizing currents may be necessary to obtain a sufficiently high level of residual magnetism. The difference in the behavior between hard steels and soft steels is usually not very serious if only surface discontinuities are sought.

3.4.6.4.7.3.1.3 Inspector experience with typical discontinuities is very helpful to determine what current levels should be used to inspect a part using residual magnetism. In the absence of such experience, an inspector should first determine whether or not a part could be inspected using the residual approach. The part must be retentive enough so magnetic particle indications will be formed at any discontinuities in the part. Magnetizing the part in a coil with the maximum DC current available can make a rough determination of a part’s retentivity. If after magnetization, the part will lift and hold an ordinary steel paper clip chances are good the part is retentive enough for residual inspection. If the part will not hold a paper clip, residual techniques may still be possible depending upon the nature of the discontinuities you expect to find. In this case, the inspector must test the part using the continuous technique, inspect for indications at possible weak areas, and then remove these indications and reapply the magnetic particle media to see if residual indications are produced. The current used to form the indications found with the continuous technique will give an inspector some indication of the current level needed for residual inspection.

3.4.6.4.7.3.1.4 The application of magnetic particle media for residual inspection is simply a matter of covering the area to be inspected. Care SHALL be taken with a liquid suspension to ensure the parts are adequately covered using low velocity streams or sprays, and the parts are positioned to take advantage of any particle flow resulting from drainage on the part surface. Some parts may need a longer drain time than others, since on smooth surfaces indications may be slower in forming. In some cases a formation of fine indications may be enhanced by immersing the magnetized part in liquid media for a considerable time. This permits time for the leakage fields to attract and hold the maximum number of particles resulting in an increase in sensitivity.

3.4.6.4.7.3.1.5 Care SHALL be taken when applying dry magnetic powders to magnetized parts to avoid getting too much powder on a part’s surface and masking a discontinuity. A combination of a light blowing and tossing action is needed, either from a hand-held container or a pressurized powder blower. Additional care is also required when removing any excess powder from a surface so you will not hinder formation of indications or remove indications already formed. The use of dry powder with the residual technique has several disadvantages. It is more difficult to apply to interior surfaces of a part than is a liquid suspension and is more difficult to completely cover a part in a short time.

3.4.6.4.7.3.1.6 Spraying, flowing, or immersing the part into a tank may be used to apply liquid suspensions. Care is required on parts with smooth surfaces to avoid removing any indications by the rapid removal of a part from the bath when using the immersion technique. To ensure uniform concentration, the suspension SHALL be continuously agitated. The bath concentration SHALL be maintained within the manufacturer's specified limits, too weak a particle concentration will produce weak indications, and in borderline cases may cause fine discontinuities to go undetected. Also, too heavy a concentration produces heavy background accumulations that reduce contrast.

3.4.6.4.7.3.1.7 Most magnetic particle indications produced using the residual technique appear quickly on a part. Longer times are required when discontinuities are extremely fine. Holding the part in a position that will allow residual suspension drainage to flow across the suspected areas can sometimes speed up formation of the indications. In the case of a cylindrical part, hold it in a near vertical position allowing the drainage flow across circumferential (transverse) cracks.

3.4.6.4.7.3.1.8 One application method practiced, mostly on small parts, the parts are magnetized one at a time, and then placed in a tray and immersed in a tank containing an agitated bath of magnetic particles. These parts SHALL be placed in the tray so they do not touch each other or else non-relevant indications, known as magnetic writing (paragraph 3.5.5.2.1), may be produced at the points of contact. Parts SHALL NOT be carelessly loaded into the basket for the immersion application. Both the concentration of the bath and the immersion time affect the production of indications. If the leakage field at the discontinuity is weak, prolonged immersion permits more particles to come into the influence of the field and makes the indication more visible.

3.4.6.4.7.3.1.9 Although the residual technique is not as widely used today as the continuous technique, it does have some advantages that make it attractive in some circumstances. The residual approach is capable of close control and provides uniform results to a greater degree than the continuous technique.

3.4.6.4.7.3.2 Continuous Application Technique. The continuous technique is used primarily with liquid suspensions, although occasionally dry powder is more appropriate. This technique requires the magnetizing force be present while the liquid suspension is being applied to the part in sufficient quantity for the particles to be highly mobile. When the current is on, the maximum flux density will be created in the part and the maximum flux leakage will be present at a discontinuity to attract the magnetic particles to form an indication. Leaving the current on for long periods of time is not practical or necessary in most instances. However, when using dry particles and either AC or HWDC as the magnetizing current, the current is sometimes kept on for minutes at a time. If allowed to flow for any appreciable time, the heavy current required for proper magnetization can cause overheating of parts and contact burning or damage to the equipment. In practice, the magnetizing current is normally on for only a fraction of a second at a time since the real requirement is a sufficient number of magnetic particles have been applied to the area of interest. These particles SHALL be free to move while the magnetizing current flows. The bath ingredients are selected and formulated to enable particles to move through the film of liquid on the surface of the part and form strong, readable indications. This is one of the reasons why the viscosity and concentration of the bath are so important.

3.4.6.4.7.3.2.1 The reason for the greater sensitivity of the continuous method is simple. When the magnetizing force is applied to a ferromagnetic part, the flux density rises. Its intensity is derived from the strength of the magnetizing force and the material permeability. When the magnetizing force is removed, the residual magnetism in the part is always less than the field present while the magnetizing force was active. The key difference depends on the retentivity of the material being magnetized. Consequently, the continuous technique, for a given value of magnetizing current, will always be more sensitive than the residual technique. Procedures have been developed for the continuous technique which make it faster than the residual technique because the indication is being formed at the time the current is being applied, plus the added time for indications to build-up allowing particles to build-up while being immersed. The indication is produced during current application and the sixty-second migration of the magnetic particles as the excess vehicle drains from the part. Parts made of low retentivity materials, such as low carbon steel, SHALL be inspected using the continuous technique; since residual leakage fields at discontinuities in these materials are too weak to produce good magnetic particle indications.

3.4.6.4.7.3.2.2 The continuous technique is the only effective technique to use on low carbon steels or on iron having little retentivity. It is frequently used with AC on such materials because the alternating current field produces excellent mobility of the particles. With the wet technique, the usual practice is to flood the surface of the part with the bath, then simultaneously terminate bath application and momentarily apply the magnetizing current. Thus the magnetizing force acts on the particles in the film of the bath as they are draining over the surface. Strength of the particle bath has been standardized to supply a sufficient number of particles in the film to produce good indications with this technique.

NOTE

> The continuous technique requires more attention and alertness on the part of the inspector than does the residual method. Careless handling of the bath/current application sequence can seriously interfere with reliable results.

3.4.6.4.7.3.2.3 Probably the highest possible sensitivity obtainable for very fine defects is achieved by immersing the part in the wet bath, magnetizing the part for a short time while immersed, and continuing to magnetize while the part is removed from the bath and while the bath drains from the surface.

3.4.6.4.7.3.2.4 Wet suspensions are primarily used with the continuous technique, with the exception being when small, subsurface defects must be found. Under some conditions, a dry particle continuous technique can produce slightly greater sensitivity. Timing of the liquid suspension application and the magnetizing current is critical to form good indications. The area of the part to be inspected SHALL be completely flooded with suspension and then the current SHALL be applied at least twice in rapid succession. Turning off or diverting the suspension flow before the final application of current ensures the force of the flow will not interfere with the formation of indications. Extra care SHALL be taken with parts having low retentivity to minimize the risk of washing away an indication. On larger parts where the entire area of interest cannot all be flooded simultaneously, additional "shots" of current SHALL be applied immediately after the suspension application hose is moved away from each point of application. If the equipment duty cycle permits, one or two additional current applications may be applied just before stopping the bath to help form small indications.

3.4.6.4.7.3.2.5 It should be noted, the continuous technique requires more attention and alertness on the part of the inspector than does the residual. Careless handling of the suspension or applying the current application sequence may seriously interfere with the results. Normally, the duration of the magnetizing shots will vary from one-half-second to 2-seconds, depending on the difficulty involved in showing the condition of interest. In some instances, when large forgings or steel castings are to be inspected with manual suspension application, the magnetizing current may be left on from 5 to 10-seconds, during which time the part may be repeatedly swept with the suspension spray. The magnetizing field is maintained for a second or two after the final spray has ceased or been diverted.

3.4.7 Wet Fluorescent Inspection Technique.

3.4.7.1 General. When exposed to near ultraviolet light (UV-A), fluorescent magnetic particles emit a highly visible yellow-green color. Indications produced are easily seen, and the fluorescent particles give much stronger indications of very small discontinuities than do the non-fluorescent magnetic particles. The differences between the wet visible technique and the wet fluorescent technique are comparatively minor regarding suspension characteristics, maintenance, and application, as well as the inspection variables and demagnetization techniques. The following applies only to the wet fluorescent technique.

3.4.7.2 Advantages and Limitations. Fluorescent particles have one major advantage over the untreated or visible particles. That is their ability to give off a brilliant glow under UV-A illumination. This brilliant glow serves three principal purposes:

- In semi- or complete darkness, 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 uncolored particles.
- Even on discontinuities large enough to give good visible indications, fluorescent indications are easier to see and the chance of the inspector missing an indication is reduced; even when the speed of inspecting parts is increased.
- Concurrent with the greater visibility of indications formed by fluorescent particles, the background caused by excessive magnetization is also more severe. Consequently, greater care SHALL be exercised in selection of the particle concentrations and magnetization levels for the inspection with fluorescent particles.

3.4.7.2.1 In most applications, the fluorescent particle technique is faster, more reliable, and more sensitive to very fine defects than the visible colored particle technique. Indications are easier to detect, especially in high volume testing. In addition, the fluorescent technique has all the other advantages possessed by the wet visible suspension technique.

3.4.7.2.2 The wet fluorescent technique also shares the disadvantages found with the wet visible technique. In addition, there is a requirement for both a source of UV-A and an inspection area from which the white light can be excluded. Experience has shown these added requirements are more than justified by the gains in reliability and sensitivity.

3.4.7.3 Inspection Materials. There is no difference in vehicle requirements between the fluorescent and non-fluorescent materials. Petroleum distillates SHALL meet the same specifications as listed in (Table 3-1), with one additional requirement, the vehicle itself SHALL NOT strongly fluoresce.

3.4.7.3.1 The particles used in the wet fluorescent technique are magnetically the same as the visible type, but they carry a fluorescent dye and the binding material that holds the dye and particle together as a unit. This coating could make the particles less effective in producing indications. However, fluorescent particle indications require only a small fraction of the particles to be easily visible as compared to the non-fluorescent type. Thus, the overall effect is a significant increase in sensitivity.

3.4.7.3.2 Fluorescent particles are supplied primarily as a dry concentrate, incorporating all the ingredients necessary for use in oil or water, as appropriate.

3.4.7.3.3 It is important the bond between the fluorescent dye or pigment and the magnetic particle is able to resist the vigorous agitation received in the circulation pump and the solvent attack from the suspension fluid. If the dye separates from the magnetic particle, the dye tends to cling to the surfaces of the part, independent of any magnetic attraction, thus increasing the background against which indications must be viewed. At the same time, the magnetic particles held magnetically at indications have lost some or all of their fluorescing ability, reducing their visibility.

3.4.7.3.4 The need to provide successful magnetic particle testing under varying conditions has resulted in the development of different materials. These fluorescent materials are readily available in a dry concentrate powder form suitable for use in water and/or oil suspensions. Prepared oil-based baths are also available in aerosol-type cans and bulk quantities.

3.4.8 Portable Magnetic Particle Inspection.

3.4.8.1 Capabilities and Limitations of Portable Inspection. Sometimes, it may not be feasible to bring a part to the laboratory for inspection, thus the inspector must travel to the part. In these cases, mobile (paragraph 3.3.2.2) and portable equipment (paragraph 3.3.2.3) SHALL be used to conduct the inspection.

3.4.8.1.1 Portable induced field inspection equipment generally refers to a power pack or a probe (yoke). Magnetic power packs, probes, and yokes are small and easily portable. The terms probe and yoke are synonymous, and differ only due to manufacturer’s nomenclature. This category of inspection equipment is described here in conjunction with the techniques for their use and application.

3.4.8.1.2 This equipment is easy to use and adequate when testing small castings or machine parts for surface cracks and weld inspection. They induce a strong magnetic field into that portion of a part that lies between the poles or legs of the yoke. The induced field flows from one leg of the yoke to the other regardless of the style or leg configuration. Yokes or probes are available with either fixed or articulated legs.

3.4.8.1.3 Either dry powder or wet magnetic particles may be used in conjunction with a yoke for the detection of discontinuities. Yokes are available for operation from a 115-volt, 60-hertz AC outlet, or from a 12-volt DC battery. A permanent magnet yoke is also available, permitting inspections to be performed without the use of electric current.

3.4.8.1.4 The units are designed for simplicity, ease of handling, and one-person operation. They may be used on machine-finished surfaces, as well as castings and weldments fabricated in a variety of configurations. The units induce a strong magnetic field at the surface of the part being inspected. Since no current is flowing through the part being subjected to inspection it is impossible to overheat or burn the part. The flexibility of a yoke with articulating legs is greatly increased permitting inspections to be performed on parts of varied configurations.

3.4.8.1.5 Yokes or probes are limited to the detection of surface and near surface discontinuities only. They SHOULD NOT be used for deep-seated, subsurface discontinuities due to the limited penetration of the induced magnetic field. Because of their size, they cannot be used with a 100-percent duty cycle. Rather, they are limited essentially to spot-checking and occasional sample testing rather than continuous production testing. Under optimum operating conditions, the fixed leg yoke has a limited inspection area governed by the distance between and immediately surrounding the legs. The moveable or articulated leg yoke can inspect either a larger area (legs apart) or detect finer discontinuities by concentrating the magnetic field in a smaller area (legs closer together).

3.4.8.2 Portable Equipment Current Capabilities. Both AC and DC current can be used for electromagnetic yokes. Under certain circumstances, it is even possible to use a strong magnet to produce a field. The design of a yoke will help determine the type current it is capable of producing.

3.4.8.2.1 Alternating Current (AC). An alternating current magnetizing field induced in a part concentrates at the surface layers of the material and produces a surface longitudinal field. AC provides a very desirable and useful field. Polarity reversal at the 60-hertz rate produces a noticeable surge peak reflected in the magnetic field. Eddy currents are a by-product of AC, which tend to guide the field basically between the poles. The vibratory action of AC adds significantly to the magnetic particle mobility enhancing the formation and build-up of larger and sharper indications at discontinuities. Yokes magnetizing with AC can be readily used for demagnetizing. Because of the reversing nature of AC, the residual method of inspection cannot be used when AC is used for magnetism.

3.4.8.2.2 Direct Current (DC). Direct current provides a constant, strong magnetic field. Magnetic particle mobility is minimal and the gathering of magnetic particles at a discontinuity is quite difficult because the vibratory action of an AC field is missing. Direct current induced fields can be successfully applied to small parts. Surface and near subsurface defects can be revealed. The residual method of inspection may be used with direct current, but alternating current SHALL be used for demagnetizing.

3.4.8.2.3 Pulsed Direct Current. Pulsed direct current combines the strong magnetic field of direct current; with the particle mobility of alternating current. Pulsed direct current is produced by rectifying single-phase alternating current. This pulsating direct current pulses at a rate and level to produce a noticeable surge peak in addition to providing the necessary vibratory action for magnetic particle mobility. Though pulsed, the direct current aspect permits the residual method of inspection to be used.

3.4.8.2.4 Permanent Magnet. When permanent magnets are placed on a ferromagnetic surface, the magnetic field travels through the surface from one pole to the other. The flux field will be relatively straight along a line between the poles and strongest near the poles. Field strength will vary and be weakest at a point midway between the poles. The actual field strength at any point will depend upon the strength of the magnet and the distance between the poles.

3.4.8.3 Field Direction. Regardless of the current selected (AC or DC), or the position of the legs, the magnetic flux field induced in a test surface always traverses a path in the same direction from one pole or leg to the other. The yoke is therefore oriented in a transverse direction to the discontinuities being sought to obtain optimum results.

3.4.8.4 Selection of Application Method and Particles. The type of magnetic particles to be used boils down to two choices: application with the dry or wet method, and choose from the various colors available, including fluorescent colors.

3.4.8.4.1 Dry Powder or Wet Suspension Selection. As in all other cases of magnetic inspection, it is possible to use both dry and wet application methods during portable inspection. Portable inspection is commonly accomplished with aerosol cans containing wet/fluorescent particles, but small shakers are available to apply the dry powder. The decision for selecting an application technique is influenced principally by the following considerations:

3.4.8.4.1.1 Size/Location of the discontinuity. Dry powder is excellent for surface defects of moderate size. The wet method is usually best for very fine and shallow defects.

3.4.8.4.1.2 Convenience. The wet technique offers the advantage of easy, complete coverage of the part surface of all sizes and shapes. Dry powder is more often used for localized inspections.

3.4.8.4.2 Color Selection. Selection of the color of particles to use is essentially a matter of securing the best possible contrast with the background of the part surface being inspected. The differences in visibility among the black, gray, red, and yellow particles are considerable on backgrounds that may be dark or bright, and when viewed in various kinds of light may be difficult to see. If some difficulty is experienced in seeing indications, the inspector should try a different color of powder. For the wet technique, the best visibility and contrast is obtained by the use of fluorescent particles. The wet/fluorescent technique supplied with an aerosol can has been used in constantly increasing numbers of inspection applications for many years, principally because of the ease of seeing even the faintest indications.

3.4.8.5 Application of Current and Particles during Portable Inspection. Magnetic particles may be applied either dry or in a liquid suspension. The part may be magnetized first and the particles applied after the magnetizing force is removed (residual method, applicable to DC or specially designed AC units only), or the particles may be applied while the magnetizing force is being applied (continuous method of inspection). In order to select the proper variations to obtain optimum results, the inspector must understand the variations and how each affects the desired end result.

3.4.8.6 Portable Inspection Applications. Hand-held yokes are versatile, general-purpose magnetic particle test equipment because of their compact size, low voltage requirements, and minimal weight. They may be used at an inspection facility where parts are brought for inspection, or they may be taken to the inspection site. They are used to test large castings and weldments, assembled and welded structures, or component parts of assemblies without the necessity of disassembly. Yokes are used on parts subject to arc burns, to detect surface cracks in welds and castings, and to locate fatigue cracks of large assemblies that may not be conveniently inspected with either mobile or stationary equipment. Where no source of electric current is available, or because of fire or explosive hazard, the use of electric current is not permitted; a permanent magnet yoke can be used for inspection. One typical application of a probe/yoke is shown (Figure 3-28). The yokes SHALL be able to pass the dead weight checks in TO 33B-1-2 WP 103 00.

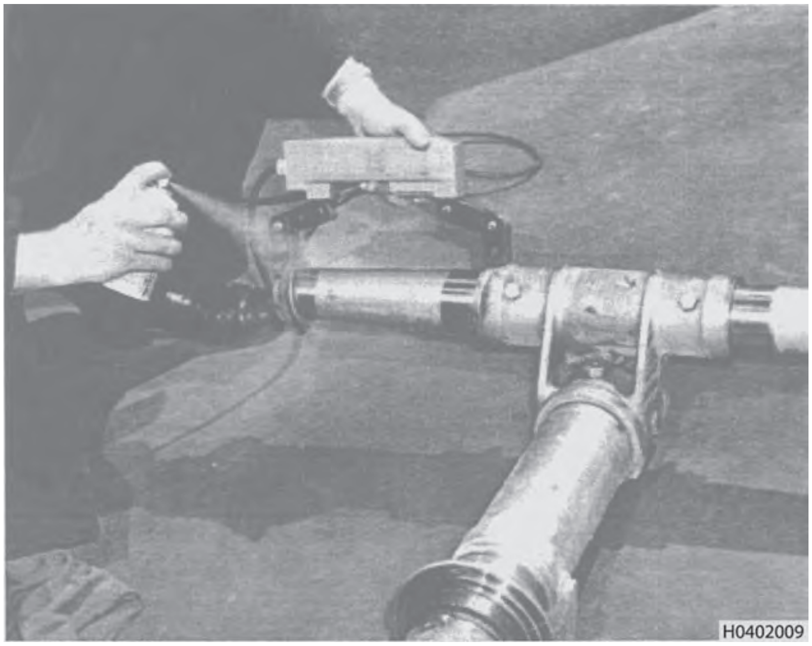


Figure 3-28. Field Inspection of Nose Wheel Strut

3.4.9 Special Magnetization Techniques. Many parts require specialized techniques to obtain a good magnetic particle inspection, because of their small L/D ratio, shape, complicated geometry, or the location and kind of discontinuities. Some of these techniques are: "Induced Current," "Slurry," "Mag Rubber" and Multi-directional techniques.

3.4.9.1 Induced Current Magnetization. This technique uses the fields generated by induced currents in a part, which are produced by rapidly varying longitudinal fields. Induced current magnetization is used for the detection of circumferential defects in rings, discs, and cylinders. A varying magnetic field in any conducting metal generates electrical current in that metal. Increasing the length of the current path can reduce the amplitude of the current. Therefore, a cut, an insulated joint, or a deep surface indentation causes the current path to increase around the discontinuity. The amplitude will also depend on:

- The size and shape of the cross section through which the magnetic field varies.
- The rate of variation in flux lines per second.
- The electrical conductivity of the metal.

3.4.9.1.1 When the magnetic field strength is changing, the induced current will flow through in the part, at right angles to the magnetic field. When the magnetic field varies continuously, as it does in the case of alternating or half-wave DC fields, a succession of induced current pulses are produced. These induced current pulses are often referred to as eddy currents. The process of inducing high amplitude eddy currents in a part to be inspected can also introduce stray eddy currents in adjacent metallic components. The effect of stray eddy currents in a metal is twofold. First, heat is generated whenever an electric current flows in a conductor because of resistance. The generation of such heat is of little consequence in magnetic particle inspection because of the relatively short duration of the current flows. The second effect of stray eddy currents is important in magnetic inspection. The magnetic fields resulting from the stray eddy currents is in opposition to the magnetic fields which produce them, resulting in either a reduction of the amplitude of inducing alternating magnetic fields or a decrease in decay rate for an inducing field generated by a collapsing DC current. Either condition results in a reduction in amplitude of the induced current in the part to be inspected. Precautions SHALL be taken to minimize the generation of any induced stray eddy currents within metals in contact with, or in the immediate vicinity of the part to be inspected. Any pole pieces should be made of laminated silicon transformer steel or low carbon steel with a low magnetic retentivity. Any part, supports, or contact plates should be split or cut partially through in such a manner as to produce as long a current path as practical. In addition to being split, some part supports are made of nonmagnetic metals such as brass or stainless steel, which are also poor electrical conductors. This also reduces the stray eddy currents generated in them.

3.4.9.2 Advantages of Induced Current Magnetization. The advantages of using the induced current method are:

- No current contact need be made on a part.
- Strong fields are generated in a part by the induced currents.
- Parts with L/D ratios of less than one can be inspected without the need for extremely high coil currents.

3.4.9.3 Induced Current Magnetization Technique. Induced current techniques require the part be circular in shape and have no deep radial cuts or slits which would prevent the generation of an induced current through the part. It is the circular field produced by such an induced current that generates the leakage fields at circumferential discontinuities. Circumferential discontinuities, in order to be detected using the induced current method, must be at or very near the surface of a part. The circular magnetic fields generated by induced currents tend to be crowded toward an outer surface. Circular, disc, or cylindrically-shaped parts, which are retentive, may be inspected residually using a single pulse of induced current; such as obtained when DC current in a coil is suddenly interrupted allowing the coil field to rapidly collapse to zero. Parts having a low retentivity SHALL be inspected using the continuous method and AC or half-wave DC current in the coil. The repetitively induced current pulses generated by each cycle of these currents is responsible for the formation of the indications at discontinuities. For parts with smooth surfaces, care is required when handling the parts after inspection to prevent mechanical loss of the indications. Washing action is much less of a problem with parts having rougher surfaces, as both mechanical and magnetic bonds hold indications.

3.4.9.3.1 Parts to be inspected using the induced current method must be positioned with their axis parallel to the coil, or coils. Two coils, one on each side of a part, may be used when the part’s diameter is larger than the coils. The coils in this case must be connected electrically; assuring that the coil fields will be in the same direction through the central region of the part. If the part is retentive and is to be inspected residually, DC current is used in the coil. The power pack supplying the DC to the coil must have quick-break electrical circuitry to obtain a rapid collapse of the coil field. Alternating or half-wave DC current must be used in the coil with the continuous technique when a steel part has a low retentivity.

3.4.9.3.2 The longitudinal flux density in a part and the rate of decay or collapse of this flux determines the magnitude of the induced current generated in the part. The higher the coil amperage, the higher the coil field strength and the flux density in a part, up to a coil amperage that produces magnetic saturation in the part. The flux density, and thus the induced currents in short cylinders having an L/D ratio of less than 3 or 4, can be increased by placing the part between two laminated pole pieces while being magnetized. Placing a laminated core or pole piece in the ring while it is being magnetized can increase induced currents in ring-shaped parts, such as bearing races. The laminated core in this case increases the total flux threading the ring. Remember when using the induced current technique, any means used to increase the flux in the direction of the coil field through the part will increase the magnitude of the induced currents, up to the point of magnetic saturation.

3.4.9.3.3 Placing a laminated core centered against each side of a disc can increase magnetic flux through the center region of disc-shaped parts. Another variation for the use of a laminated core is in the inspection of holes in large parts suspected of having circumferential discontinuities. In this case, the magnetizing coil is placed around one end of the core and the other end is used as a probe for placement in the hole. Alternating current is used to energize the coil. In operation the core is placed in a hole, liquid magnetic particle media is sprayed around the inside surfaces of the hole, and while the coil is energized. Before withdrawing the core from the hole, the coil is de-energized so as not to demagnetize the area around the hole. When demagnetization of the area is required, the core is simply removed from the hole while the AC current is flowing.

3.4.9.4 Selection of Induced Current Level. No "rule-of-thumb" formulas have been developed for the induced current method of magnetization. Lacking any other information upon which to select a current level, the "rule-of-thumb" formulas given in (paragraph 3.7.1) may be used to obtain trial amperages for parts having L/D ratios up to 15. Part diameters, which approach or are greater than the coil and are very short in length (e.g., disc-shaped parts), will usually require laminated cores to be used, so the rule-of-thumb coil formulas are not applicable. The formulas were developed for the determination of coil amperages, which will produce a longitudinal flux density in a part of 70,000 lines per square inch. The rate of change or rate of collapse of this longitudinal flux produces an induced current in the part, which in turn results in leakage fields at the discontinuities.

3.4.9.4.1 Magnetic Slurry. This specialized technique uses magnetic flakes in viscous slurry, taking advantage of the difference in light reflection from flakes reoriented by leakage fields at discontinuities. The slurry, being a viscous liquid applied by brush, has the advantage over dry powder of eliminating any hazard to adjacent equipment by airborne magnetic particles. Another advantage is the slurry can be applied and used successfully on vertical or overhead surfaces, on wet (even underwater) or dry surfaces, and over scaly, plated, or painted surfaces if the coatings are not too thick.

3.4.9.4.1.1 A magnetic particle testing material is available that supplements both wet and dry magnetic particle testing materials. This material formulation uses selected magnetic particles dispersed in a viscous, oily vehicle which results in slurry having the consistency of paint. The material is brushed on a surface to be inspected until the magnetic particles are evenly and thoroughly distributed. A magnetic field is generated in the test part through conventional AC or half-wave DC magnetizing techniques. Any discontinuities show up as contrasting black indications on a gray background. Alternating current fields using a yoke or probe are capable of revealing very fine surface discontinuities using this slurry technique.

3.4.9.4.1.2 The slurry concentration can be varied to suit particular inspection requirements. The material is brushed evenly on a part, much as paint would be, prior to magnetization of the part. If required, the material can be brushed repeatedly permitting magnetization in various directions. The oily vehicle used in the slurry mixture is nondrying, and the slurry can be removed using dry rags, paper towels, or prepared cleaning solvents.

3.4.9.5 Magnetic Rubber. This technique uses a diluted silicone rubber containing black magnetic particles for the inspection of the interior or otherwise difficult to view surfaces. Additionally, it is the most sensitive of all magnetic particle techniques for detecting the smallest possible surface cracks on any surface. Its use is limited by the high labor requirement. The liquid rubber is catalyzed, placed against the surface to be inspected, and held in place with the appropriate dams and fixtures. Applied magnetic fields cause the particles to migrate to defect locations while the rubber cures. After curing, the rubber material which has formed a replica of the surface against which it was placed, is viewed under low power magnification for the indications formed during the inspection.

3.4.9.5.1 Magnetic rubber formulations using finely divided magnetic particles in a silicone rubber base are used for the inspection of holes and other surfaces not easily accessible. The liquid silicone rubber mixture is poured into holes or against the surface of the magnetic parts to be inspected. Curing time for silicone rubbers varies from about 10 to 30-minutes, depending upon the particular silicone rubber, the catalyst, and the amount of catalyst used to produce the curing reaction.

3.4.9.5.2 While the rubber cures, the surface inspected must stay in the required magnetized state. This can be accomplished using a permanent magnet, a direct current yoke, an electromagnet, or some other suitable means. Whatever method of magnetization is used, the leakage fields at any discontinuities on the surfaces inspected must be maintained long enough to attract and hold in position the magnetic particles until a partial cure takes place. A two-step magnetizing procedure has been developed: 1) The first magnetization is accomplished for a short time in one direction, 2) followed by a second at 90-degrees to the first for the same length of time. This procedure SHALL be repeated for whatever period of time is needed until the cure prevents particle mobility. Magnetization in two directions 90-degrees apart assures formation of indications at discontinuities in all directions.

3.4.9.5.3 After curing, the rubber plugs which are exact replicas of the surfaces, are removed and visually examined for indications, which will appear as black lines against the gray or yellow background of the silicone rubber. Examination of the replicas is usually done with magnification, and often with a microscope when the goal of the inspection is to detect the smallest possible cracks. Location of any discontinuities or other surface imperfections can be determined from the location of the indications on the plugs.

3.4.10 Multidirectional Magnetization. Multidirectional magnetization can be very effective in detecting randomly oriented discontinuities quickly. The technique energizes two or more magnetizing circuits in different directions very rapidly (almost simultaneously) resulting in a reduction of testing time and part handling.

3.4.11 Demagnetization. Any ferromagnetic material subjected to magnetic particle inspection requires demagnetization. When performing magnetic particle inspection of aircraft parts, it is essential to demagnetize them. The inspector SHALL understand the reasons for this step, as well as the problems involved and the available means for solving them.

3.4.11.1 Purpose of Demagnetization. Ferromagnetic materials retain a certain amount of residual magnetism (or remnant field) after application of a magnetizing force. This does not affect the mechanical properties of the part. However, a residual field can impede the operation of some parts, as well as, affect the operation of adjacent equipment sensitive to low level stray magnetic fields.

3.4.11.2 Principles of Demagnetization. Demagnetization may be accomplished in a number of different ways. The technique used depends upon the electrical power and equipment available, the degree of demagnetization required, and the skill of the inspector.

3.4.11.2.1 One of the simpler techniques subjects the magnetized part to a magnetizing force that continually reverses its direction. At the same time, this force is gradually decreased in strength. As the decreasing magnetizing force is applied, first in one direction and then the opposite direction, the magnetization of the part is decreased. This decreasing magnetization is accomplished by smaller and smaller hysteresis loops created by the application of decreasing current as shown (Figure 3-29). The smaller the hysteresis loop produced the more demagnetization accomplished.

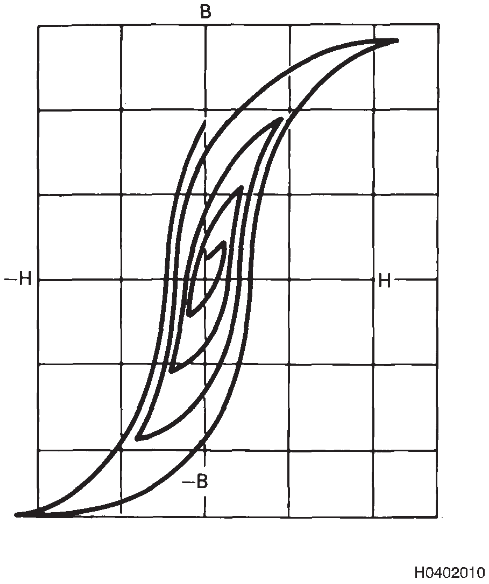


Figure 3-29. Hysteresis Loops Produced During Demagnetization

3.4.11.2.2 For all practical purposes, the only way to completely demagnetize a part is by heating it to its Curie point (paragraph 3.4.11.6.1) or above. This SHALL NOT be attempted without engineering direction due to the risk of damaging the part.

3.4.11.2.3 Under normal conditions, a part is considered satisfactorily demagnetized if the magnetic field is at or below 3 units on a gauss meter or 2 units on a field indicator.

3.4.11.3 Requirements for Demagnetization. Ferromagnetic aircraft parts require demagnetization principally to prevent magnetic flux from affecting instrumentation. There are several additional reasons supporting the requirement for demagnetization.

3.4.11.4 Situations Requiring Demagnetization. Demagnetization is required when the residual field in a part:

- Aircraft components are required to be demagnetized after inspection unless specified otherwise.
- May interfere with subsequent machining operations by causing chips to adhere to the part surface, or the tip of a tool to become magnetized from contact with the magnetized part. Such chips can interfere with smooth cutting by the tool, adversely affecting both part surface finish and tool life.
- May interfere with electric arc or electron beam welding operations. Residual magnetic fields may deflect the arc or electron beam 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 (e.g., milling cutters, hobs, etc.) will hold chips and cause rough surfaces, and may even be broken by chips adhering to the cutting edge.
- Might cause trouble on moving parts, especially those running in oil, by holding particles of metal or magnetic testing particles - for instance, on balls or races of ball bearings, or on gear teeth.
- May prevent proper cleaning of the part after inspection by magnetically holding particles to the part surface.
- May interfere with subsequent magnetization requirements.
- May hold particles that interfere with later applications of coatings such as plating or paint.

3.4.11.5 Situations Not Requiring Demagnetization. Demagnetization is not usually required when:

- The parts are not aircraft parts and have low retentivity. In this case, the residual field is low or disappears after the magnetizing force is no longer acting. An example is low-carbon plate such as used for low strength weldments, tanks, etc.
- The material in question consists of non-aircraft structural parts such as weldments, large castings, boilers, etc., where the presence of a residual field would have no effect on other components or the proper service performance of the part.
- If the part is to be subsequently processed or heat-treated, and in the process will become heated above the Curie point, or about 770°C (about 1418°F). Above this temperature, steels become nonmagnetic, and completely demagnetized on cooling when they pass through the reverse transformation.
- The part will become magnetized anyway during a subsequent process, for example, when held in a magnetic chuck.
- A part is to be subsequently magnetized in another direction to the same or higher level at which it was originally magnetized, for example, between circular and longitudinal magnetization for magnetic particle inspection.
- The magnetic field contained in a non-aircraft finished part is such there are no external leakage fields measurable by ordinary means (e.g., the field produced during magnetic particle inspection with circular magnetization).

3.4.11.5.1 A residual magnetic field in a ferromagnetic material exists because there is a preferred orientation of the magnetic domains caused by a previously applied magnetic field. A residual magnetic field perpendicular to a previously established residual field can only be produced by application of a magnetic field in the perpendicular direction strong enough to rotate the domain 90-degrees. Because the preferred orientation of the domains has been rotated 90-degrees, the previous residual field no longer exists. For this reason, longitudinal magnetization, strong enough to produce indications of discontinuities in a part that previously had a residual circular magnetic field, reduces the circular residual field to zero. If the magnetizing force is not of sufficient strength to establish the longitudinal field, the strength SHALL be increased or other steps taken to ensure a residual longitudinal field actually has been established. For example, a large part having a large L/D ratio may require multiple longitudinal shots along its length to eliminate the circular field. Rotation of the preferred orientation of the magnetic domains also occurs when a circular residual field is produced in a part with an existing residual longitudinal field.

3.4.11.5.2 If the two fields, longitudinal and circular, are applied simultaneously, an applied field results that is a vector combination of the two in both strength and direction. If the magnitude of the resultant applied field is large enough, then a residual field will be produced in this same direction. If, however, the fields are induced sequentially the last field applied, if strong enough to produce a residual field, will eliminate the residual field from the previous magnetization. A convenient method of assuring reduction of a residual magnetic field in one direction and establishing a field in a perpendicular direction is to slightly increase the magnetizing force of the second shot.

3.4.11.6 Demagnetization Limitations.

NOTE

Complete demagnetization is not possible even though it is often specified.

3.4.11.6.1 Curie Point. When steel is heated, it passes through its Curie point, approximately 770°C (or about 1418°F) for soft steels. Above the Curie point it is no longer ferromagnetic. When the steel cools to room temperature in the absence of a magnetic field, it will contain no residual magnetism. Other means of demagnetization always leave some residual field.

3.4.11.6.2 Earth's Magnetic Field. The earth's magnetic field can contribute to the difficulty of demagnetizing parts. A long part to be demagnetized SHOULD be placed so its principal axis is in an east-west direction. A long part lying in a north-south direction can never be demagnetized 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 not lying east-west. Vibration of the structure during the demagnetization process is also helpful under these circumstances. Complete removal of all magnetic fields is virtually impossible.

3.4.11.6.2.1 The earth's field will always affect the residual magnetism in a ferromagnetic part and will often determine the lower limit of practical demagnetization. Long parts or assemblies of long parts, such as welded tubular structures, are especially likely to remain magnetized at a level determined by the earth's field, in spite of the most careful demagnetizing technique.

3.4.11.6.2.2 Many articles and parts become quite strongly magnetized from the earth's field alone. Transporting parts from one location to another may produce this effect. Long bars, demagnetized at the point of testing, have been found magnetized when delivered to the point of use. It is not unusual to find parts of aircraft, automotive engines, railroad locomotives, or any parts made from steel of fair retentivity are quite strongly magnetized after having been in service for some time, even though they may never have been near any artificially produced magnetic field. Parts also become magnetized by being near electric lines carrying heavy currents, or some form of magnetic equipment.

3.4.11.7 Demagnetization Methods.

3.4.11.7.1 General. Alternating and direct currents are used in demagnetizing aircraft parts after magnetic particle inspection. Although direct current can be used for demagnetization, alternating current demagnetization has been found to be more convenient. Since alternating current does not penetrate very deeply below the surface of magnetic materials, some parts may be difficult to demagnetize completely using alternating current. This is particularly true with large heavy parts, and may also be the case with parts of unusual shape. Direct current can be used to demagnetize if there is provision for current decay or reduction and a means for reversing the direction of the current. Demagnetization accomplished in this manner with direct current is the most complete and effective possible.

3.4.11.7.1.1 To demagnetize with direct current, the part is placed in a coil connected to a source of direct current. The current is adjusted to a value at least as great as that used to magnetize the part and a shot of current is given at this initial value. The direction of the current is then reversed, the value reduced, and a shot of current given at the new value. This process of reversing and reducing the current is continued until a very low value is reached. The part is now effectively demagnetized.

3.4.11.7.1.2 Parts with a circular field do not have magnetic poles. This lack of measurable poles, providing there are no discontinuities present, makes it impossible to check the magnitude of residual circular magnetization with the conventional residual field indicator. A common and recommended practice on aircraft parts is to magnetize the part longitudinally after it has been circularly magnetized. The difficult to measure circular field is then replaced by an easy to measure longitudinal field.

3.4.11.7.2 AC Demagnetization.

3.4.11.7.2.1 AC Tunnel Coil. The most common and convenient method of demagnetizing small to moderate sized parts is by passing them through an open tunnel-type coil through which alternating current at line frequency (usually 50 to 60-hertz) is passing. Another practice is to pass the 50 or 60-hertz AC through a coil with the part inside the coil, and gradually reduce the current to zero. In the first case, the reduction of the strength of the reversing field is obtained by withdrawal of the part axially from the coil (or the coil from the part) and for some distance beyond the end of the coil (or part) along that axial line. In the second case, the gradual decay of the current in the coil accomplishes the same results. This method of demagnetization is particularly suitable for large numbers of relatively small parts.

3.4.11.7.2.2 Stationary MPI Bench. Stationary magnetic particle testing equipment often has demagnetization capabilities. If so equipped, AC current may be passed directly through the part or through the coil on the magnetizing unit. For demagnetization of parts, the alternating current is reduced to zero automatically by built-in means of step-down switches or variable transformers for older equipment, or solid-state devices for newer equipment. The step-down feature permits the demagnetization of parts without removal from the magnetizing equipment. This procedure is more effective on long, circularly magnetized parts than the separate coil method, but does not overcome the lack of penetration due to skin effect unless frequencies much lower than 60-hertz are used.

3.4.11.7.3 DC Demagnetization.

3.4.11.7.3.1 Stationary MPI Bench. Demagnetizing by the direct current reversing step-down feature is essentially identical in principle to the AC method, but is more effective on parts with heavy cross sections. Modern stationary DC magnetizing equipment usually incorporates this capability. The use of DC current permits a more even and complete penetration of even large cross sections. The DC current flows in one direction for a short time, it then is slightly reduced in magnitude and completely reversed in direction. The process of automatically reversing and reducing the current is continued until the current reaches zero and the part is effectively demagnetized. This method of demagnetizing is especially effective in removing circular fields when the current can be passed through the part and works well with a central conductor, when applicable. Small parts can be placed in a standard coil and larger parts can be cable-wrapped for their full-length, as induction loss is not present with DC.

3.4.11.8 Demagnetization Procedures.

NOTE

It is important to remember the part SHALL be completely withdrawn from the magnetic field of the coil before the current is shut off.

3.4.11.8.1 Demagnetizing Coil. The most common type of stationary demagnetizing equipment consists of an open coil through which alternating current at line frequency, usually 50 to 60-hertz is used. The demagnetizing coil may be equipped with a stand or may be constructed and placed on a bench. Larger coil sizes have a track or carriage on which parts can be placed to facilitate handling.

3.4.11.8.1.1 To use a demagnetizing coil such as illustrated (Figure 3-30), the part is placed in the coil and the current turned on. While the current remains on, the part SHALL be slowly withdrawn from the yoke a distance of 4 to 5-feet before the current is shut off. The axis of the part SHOULD be parallel to the axis of the yoke for regularly shaped parts. On complex parts, more complete demagnetization is sometimes possible if the part is rotated and turned end for end. For best results, the diameter of the demagnetizer yoke SHOULD be just large enough to accommodate the part. However, for practical purposes one or two yoke sizes will satisfactorily serve an inspection facility. To demagnetize small parts in a large coil, place the parts close to the inside wall or corner of the yoke since the demagnetizing forces are strongest in that area.

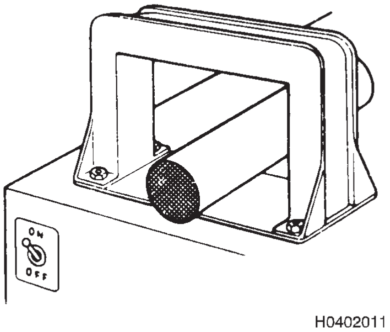


Figure 3-30. Part in Demagnetizing Coil

3.4.11.8.2 Demagnetizing with Stationary Equipment. Magnetic particle inspection equipment that magnetizes with AC or DC is used to demagnetize parts after inspection, depending upon the demagnetization features included in the equipment and the size and shape of the part.

3.4.11.8.2.1 Step-Down Demagnetization.

CAUTION

Care SHALL be used when demagnetizing small parts using machines equipped with “step-down” demagnetizers, which do not have adjustable current tap switches. A small part such as a bolt being circularly demagnetized with this equipment may be overheated by the initial high current steps.

3.4.11.8.2.1.1 Some stationary AC equipment has a coil on rails and a toggle switch, which enables the inspector to turn the current on in the coil, and leave it on. This coil then becomes a demagnetization coil when a part is drawn through it while the current is flowing.

3.4.11.8.2.1.2 This same equipment may also have a rheostat or current control switch enabling the inspector to select different magnetizing current levels as well as initial demagnetizing current levels. These switches may be motor driven. When equipment with a motor driven switch is used for demagnetization, the inspector places the part in the equipment and presses the demagnetization switch, this causes the motor to drive the switch contactor from maximum to minimum current positions, giving a shot at each successively lower current value. This effectively demagnetizes the part and can be used either by passing the current through the coil on the equipment (longitudinal demagnetization), or by passing the current through the part itself (circular demagnetization). This process is referred to as "step-down" demagnetization.

3.4.11.8.2.1.3 A step-down reversing DC demagnetization is usually completed in about 30-seconds; one-second per step. The one-second at each step allows time for the field in the part to reach a steady state, at which time induced currents become zero, permitting maximum penetration of the field into the part. This can easily be done using a continuously variable autotransformer or electronic decay circuitry to reduce the AC current to zero.

3.4.11.8.2.2 Circular Demagnetization.

NOTE

> Circular demagnetization is particularly effective on parts of complicated shape, such as multiple throw cranks or coil springs.

Two techniques are used to circularly demagnetize parts: 1) the direct contact and 2) central conductor methods. The technique used depends upon the part's size, shape, and the technique used to magnetize it. Generally, the same technique used to magnetize is used to demagnetize a part. Though the techniques used may be the same, the type of current required to demagnetize a part may differ from that used to magnetize it. For example, parts having large cross sections which have been magnetized using AC may require step-down reversing DC to demagnetize them. The use of reversing DC overcomes the lack of field penetration, which occurs with AC.

3.4.11.8.2.3 Direct Contact Demagnetization. Alternately reversing and reducing the current in a part accomplishes demagnetization using the direct contact method. The part may be clamped between contact heads on a stationary unit having provision for demagnetization; or the part may be connected to cables and to a suitable demagnetizing current power supply. Starting with a current amperage greater than or equal to that used for magnetizing, the current is reduced to either zero or a very low amperage. Either AC or reversing DC may be used depending on the size, shape, and retentivity of the part. The AC demagnetization is usually less time consuming and is satisfactory for many small to medium-sized parts. However, for large parts or parts having thick cross sections, step-down reversing DC is required.

3.4.11.8.2.3.1 Parts having a complicated geometry or that have been magnetized using more than one current path through the part may not be completely demagnetized in one demagnetizing cycle. The same number of demagnetizing cycles may be needed, and through the same current paths, as were used for magnetization. Quite often with small, low retentivity parts, instead of repeat demagnetization on the part, a satisfactory and quicker demagnetization can be obtained using coil demagnetization with AC or reversing DC.

3.4.11.8.2.3.2 To circularly demagnetize a part by direct contact, clamp the part between the contact heads. Demagnetization is accomplished by automatically passing shots of decreasing current through the part. Care SHALL be taken not to demagnetize very small parts between the heads because the high initial current can overheat the parts. If longitudinal demagnetization is desired, the coil is then placed in position with the part still clamped in the heads. The same general procedure is followed, except the demagnetizing current passes through the coil instead of the part.

3.4.11.8.2.4 Central Conductor Demagnetization. The method used for direct contact demagnetization also applies to central conductor demagnetization. Demagnetizing currents SHOULD start from the same or slightly higher amperages than were used for magnetizing. Placement of the central conductor or threaded-cable configuration should be the same used for magnetization. Sometimes different central conductor locations or configurations must be used and be determined by experiment.

3.4.11.8.3 Demagnetizing With Mobile Equipment. Mobile equipment used for magnetization can also be used for demagnetization. Selecting a current output equal to or greater than the one used when magnetizing the part performs demagnetization. Cables are either formed into a coil of three or four turns, or wrapped around the part three or four times. The cables are then connected to the output terminals. On units without a demagnetization cycle, initiate the magnetizing cycle and pass the part through the coil or pass the coil over the part, leaving the current on until the coil and part are well separated (approximately 4 to 5-feet). On units incorporating a demagnetization capability, place the part in the coil, and initiate the demagnetization cycle that starts the automatic step-down of the applied current.

3.4.11.8.4 Demagnetizing With Portable Equipment. Portable equipment, other than hand probes or yokes will usually supply both alternating current and half-wave direct current. Demagnetization with this equipment and cables is done using alternating current through one of two methods, as follows:

a. Make a coil with three or four loops of cable.

b. Adjust the alternating current output to a higher level than used in magnetizing the part.

c. Place the coil around the part and turn on the current.

d. Then withdraw the coil four or five feet from the part and turn off the current; OR withdraw the part from the coil for four or five feet along the centerline of the coil and turn off the current.

3.4.11.8.4.1 Demagnetizing With Hand Probe or Yoke. Hand probes or yokes (AC or DC) provide a portable means for demagnetizing when other methods are impractical. In some cases, they are more effective than coil-type demagnetizers because the field of the probe or yoke can be concentrated into a relatively small area. For probes with adjustable legs, the space between the poles should be such that parts to be demagnetized will pass between them as close as possible. With AC flowing in the coil of the probe, parts are passed between the poles and withdrawn (Figure 3-31). On large parts, the probe is placed on the part and is moved around as it is slowly withdrawn. This method of demagnetizing is very effective. When the probe incorporates a DC magnetization capability, it can be used for DC demagnetization as well.

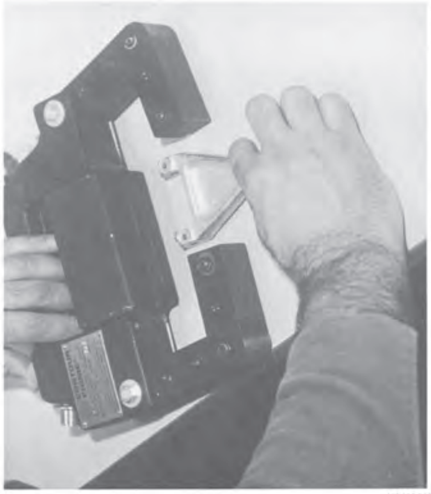


Figure 3-31. Non-Contact Demagnetization

3.4.11.9 Special Demagnetization Techniques. Where the size, shape, or techniques of part magnetization make demagnetization difficult, there are several techniques which may be used effectively. Most difficult parts can be demagnetized to the extent required for service by using the following techniques:

3.4.11.9.1 Rubber Mallet. Sometimes, striking the part with a rubber mallet during the demagnetizing operation can effectively demagnetize parts difficult to demagnetize. To use this technique, the part is placed in the demagnetizing coil and the current is turned on. The part is then hammered with a rubber mallet and withdrawn from the coil field while the hammering is continued. Care SHALL be taken so the hammering does not damage the part.

3.4.11.9.2 Positioning. Demagnetizing coils sometimes work better if they are positioned so the path of the part, as it is drawn through the coil, is in an east-west direction rather than north-south. This is particularly true for long parts that may be influenced by the earth’s magnetic field.

3.4.11.9.3 Transient Demagnetization. Sometimes the residual field from heavy parts can best be removed by a technique known as the transient method of demagnetization. To perform this technique, the part is placed in the demagnetizing coil and the current turned on and off five to ten times. The current is then turned on and left on while the part is withdrawn from the magnetic field of the coil.

3.4.11.9.4 Demagnetization of Short Hollow and Cylindrical Parts. When a short, hollow, or cylindrical part is being demagnetized in an AC coil, by the method of withdrawing the part along the line of the axis of the coil, it is helpful to rotate the part both around the axis parallel to and transverse to the coil’s axis. This should be accomplished while the part is in the coil as well as during the entire time of withdrawal. A part with an L/D ratio of one or less can sometimes be better demagnetized by placing it between two soft iron pole pieces of similar diameter, but longer than the part. This combination is then passed through the coil as a unit. It has the effect of increasing the L/D ratio and facilitates the removal of the field in the part.

3.4.11.9.5 Demagnetization of Ring-Shaped Parts. For the demagnetization of ring-shaped parts an effective method is to pass a central conductor through the ring. The central conductor is energized with AC and the current reduced to zero by means of either a step-down switch or a step less current control. The latter method can be quicker (down to a few seconds) than the step-down switch. This method can also be used with reversing, decaying, or step-down DC as well.

3.4.11.9.6 Demagnetization of Long Parts. Long parts, such as rods, bars, and tubes may retain an objectionable amount of residual magnetism from the earth's magnetic field. As the earth's field extends from the north to the south pole, it is desirable to demagnetize these types of parts by withdrawing from an AC coil in an east-west direction. This will minimize the effect of the earth's field on the residual magnetism in the parts.

3.4.11.9.7 Demagnetization of Large Structures. Frequently, large structures such as engine mounts may require demagnetization, and demagnetizing coils of suitable size may not be available. In such case, each individual extension from the structure, such as the legs of a mount, should be placed within the coil as close to the wall as possible and withdrawn. The structure should then be reversed. The other end is then brought close to the face of the coil and rotated, so all parts of the structure are passed across the open face of the coil. The entire structure is finally withdrawn four to five feet from the coil before it is shut off. In handling such tubular structures, it is important they be moved to and from the coil in an east-west direction.

3.4.11.9.8 Removal of Longitudinal and Circular Fields. In considering the problem of demagnetization, it is important to remember a part may retain a strong residual field after having been circularly magnetized, and yet exhibit little or no external evidence of such a condition. Such a field is difficult to remove and there is no easy way to check the success of demagnetization. There may be local poles on a circularly magnetized piece at projecting irregularities, changes or sections, that can be checked with a field indicator. However, to demagnetize a circularly magnetized part, it is often better to first convert the circular field to a longitudinal field. The longitudinal field does possess external poles, is more easily removed, and the extent of removal can be easily checked with a field indicator.

3.4.12 Post Inspection Cleaning.

CAUTION

All plugs and masks SHALL be removed after post-inspection cleaning and the part SHALL be demagnetized to the maximum extent possible.

3.4.12.1 Particle Removal. The magnetic particle inspection process leaves behind at least a scattering of magnetic particles that are abrasive. This may or may not be harmful to the part when it is subjected to further use. Where this slight residue cannot be tolerated, it SHALL be removed. When its presence makes no difference, post-inspection cleaning can be eliminated. Dry magnetic particle inspection leaves only the particles behind. These particles are fairly coarse, quite abrasive, and probably magnetically bonded to the test surface. The wet method magnetic particles are much finer than the dry method magnetic particles (0.0002-inch instead of 0.002-inch to 0.006-inch in diameter) and are softer, though still somewhat abrasive. On highly polished surfaces, residual powder from the bath can contribute to rapid corrosion.

3.4.12.2 Inspection Vehicle Removal. The wet method inspection process will normally leave the carrier liquid or vehicle on the test surface. If the vehicle is oil, it can be removed by vapor degreasing or solvent cleaning. If the vehicle is water, the residue will consist of wetting agents and water-soluble corrosion inhibitors, which may be removed with a plain water rinse or spray. Regardless of the type of vehicle used, the part SHOULD be cleaned as soon as possible after inspection and demagnetization.

3.4.12.3 Post-Cleaning Methods.

CAUTION

> Post-cleaning methods that use water can cause corrosion of the test surfaces if the water is not promptly removed. The surfaces SHALL be thoroughly dried off by wiping, heating, or blowing with properly regulated compressed air.

Regardless of whether the wet or dry, visible or fluorescent, magnetic particle inspection process is used, once the carrier liquid or vehicle is removed, the requirement for removal of the magnetic particles is the same. Thoroughly demagnetize the part, and then remove the magnetic particles by wiping or scrubbing. Cleaners or detergents cannot break the magnetic attraction of a magnetized part. The particles cannot be dissolved from the part surface, as they are a ferrous oxide, so mechanical scrubbing or detergent washing may be necessary. Solvents may be used to remove the residue, and in some cases, the use of ultrasonic cleaning has been successful.

3.4.12.4 Requirements Following Post Inspection Cleaning. After inspection by the wet method using a petroleum distillate as the bath liquid, the surfaces of parts are left vulnerable to corrosion. The bath vehicle is, by specification, free of any residual non-volatile material and when it dries it leaves no protective film. Every effort SHALL be taken to clean a part and apply a protective finish as soon as possible after the inspection. When water is the bath vehicle, the dried film on the surface of a part consists of the various conditioners used in the bath formulation in addition to the residual magnetic particles. One of the conditioners is a corrosion inhibitor, so this inhibitor affords some corrosion protection after testing. However, this is by no means permanent and a protective finish should be applied as soon as possible.

NOTE

> In the event a functional material, such as oil, grease, or anti-seize compound is removed from the part to facilitate inspection, the same material SHALL be reapplied after the part has been inspected.

3.4.13 Magnetic Rubber Inspection.

3.4.13.1 Introduction. Magnetic rubber inspection (MRI) is a nondestructive inspection technique used for detecting cracks or other flaws on or near the surface of ferromagnetic materials. Its principal applications are in certain problem areas, such as (1) areas having limited visual accessibility (e.g., inside holes, tubes, etc.), (2) coated surfaces, (3) complex shapes or poor surface conditions, and (4) inspections for defects that require magnification for detection and interpretation. Magnetic rubber inspection involves the use of a material consisting of magnetic particles dispersed in a room temperature curing silicon rubber. The material is catalyzed, applied to the test surface, and the area to be inspected is magnetized, causing the particles to migrate through the rubber and accumulate at discontinuities on the surface. Following cure, the solid replica casting is removed from the part and examined for indications. The magnetic principles discussed in Section 2 (paragraph 3.2) of this chapter apply equally to Magnetic Rubber Inspection.

3.4.13.1.1 Currently, there is only one manufacturer known to produce magnetic rubber materials. The example data presented in this section applies to that manufacturer’s three material formulations; MR-502, MR-502K, & MR-502Y. However, the principles and instructions presented will apply to any material complying with SAE Specification AMS 83387.

3.4.13.1.2 MR-502 is the more viscous and slow curing of the three formulations, and provides medium sensitivity. It is usually not the best choice when highest crack detection sensitivity is required. MR-502K has the lowest viscosity and is the most sensitive. MR-502Y is MR-502K with a yellow coloring agent added. It is slightly more viscous and very slightly less sensitive than MR-502K. The yellow color makes the indications more noticeable to the inspector reading the replica, thereby improving the probability of detection for very small cracks. MR-502Y has a greater tendency to stick to the part surface after it is cured, so the use of a release agent will be required for more applications.

3.4.13.1.3 Some specifications refer only to MR-502 because this was the first material available. It is recommended cognizant engineering activities specify or authorize substitution of MR-502K or MR-502Y unless long gel time and lower sensitivity are desirable for the specific application.

NOTE

Technical directives, requiring a magnetic rubber inspection SHALL specify the formulation to be used, including any alternatives, in the procedure.

3.4.13.2 Safety Precautions. General safety precautions are applicable to magnetic rubber inspection (paragraph 3.8). The silicon rubber, dibutyltin dilaurate, stannous octoate, cure stabilizers, cleaners, and release agents are, or can be, skin and eye irritants, skin sensitizers (e.g., causing allergic reactions), inhalant, and ingestion hazards. For specific information concerning any of the materials used as magnetic rubber, magnetic rubber catalysts, release agents, or cleaners, consult the Material Safety Data Sheets, or contact the appropriate Safety Officer. Silicon oil is an ingredient in the material and can result in very slippery surfaces, especially floors, if not well controlled.

3.4.13.2.1 When performing magnetic rubber inspection on aircraft using electromagnets to magnetize, the aircraft SHALL be grounded.

3.4.13.3 Gel Time (Cure Time). Gel time (also called cure time or pot life) refers to the time from the addition of the catalyst to when the viscosity starts to noticeably increase and magnetization must be completed. Cure time is the time to completely cure to a tack-free state.

3.4.13.4 Magnetic Rubber Inspection Procedure (Typical).

CAUTION

Areas to be magnetic rubber inspected must be free of grease, oil, dirt, and other foreign matter that could cause false or confusing indications or prevent the base material from curing.

NOTE

This procedure is provided as an example and is not authorized for use unless specified and/or approved for a specific application by a cognizant MT Level III. Directive originators SHALL obtain Level III concurrence prior to issuing a directive requiring a magnetic rubber procedure.

A general list of the required materials and equipment to obtain is contained in (Table 3-4) and (Table 3-5). Materials and equipment required for a specific inspection SHOULD be identified in the task specific directive.

Table 3-4. Magnetic Rubber Equipment

Electromagnetic yoke, fixed or articulated legs (same as used for magnetic particle inspection)
Permanent bar magnets
Soft iron pole pieces
Stereo zoom microscope (7-10X or higher) with high intensity light (mandatory)
Electronic gauss meter
Mechanical shaker (e.g., paint shaker)
Vacuum chamber

Table 3-5. **Magnetic Rubber Inspection Materials**

Base material
Dibutyltin Dilaurate and Stannous Octoate catalysts
Sealing compound (putty for forming dams)
Aluminum or plastic sheet material for forming dams
Release agent to aid in the removal of replicas from holes (not silicone based)
Paper or plastic cups in which to mix magnetic rubber material
Tongue depressors for mixing the material
Isopropyl alcohol for cleaning replicas
Disposable syringe for applying the rubber mixture to the inspection area

3.4.13.4.1 Part Preparation. Prepare the part for magnetic rubber inspection as follows:

CAUTION

If a delay is expected that would leave any area of steel in a bare metal state for over 1-hour, protect the area from corrosion per NAVAIR 01-1A-509 (TO 1-1-691/TM 1-1500-344-23), Chapter 3. Volatile corrosion inhibitor (VCI) film MIL-PRF-22019 held on and sealed at the edges with AMS-T-22085 Type II preservation tape is effective and convenient where the part geometry allows its use. Upon removal of VCI film the area is not required to be cleaned again.

a. Using cheesecloth or equivalent moistened with cleaning solvent; remove grease, oil, dirt, lint, and similar contaminants from the area to be inspected. Refer to NAVAIR 01-1A-509 (TO 1-1-691/TM 1-1500-344-23), Chapter 3 for specific instructions and approved materials.

b. Remove loose corrosion products, sealants, paint, plating, and other coatings, as required by the task specific directive. If removal requirements are not specified, remove all corrosion products and coatings except primer and plating which, may be left on the surface if they do not exceed 0.005 inch in total thickness. Normal primer and corrosion preventive plating MAY be assumed to not exceed 0.005 inch thick.

NOTE

- Using the procedures and materials as discussed above, virtually any area or configuration can be prepared for magnetic rubber inspection. Upside-down surfaces may be inspected by building a reservoir beneath the test area and pressure filling with magnetic rubber. A vent hole must be provided with this type of reservoir to prevent air entrapment.
- When building dams, make certain they are small enough to allow magnets or the legs of an electromagnet to span the reservoir. Magnets or the legs of an electromagnet SHOULD NOT be placed into the uncured magnetic rubber.

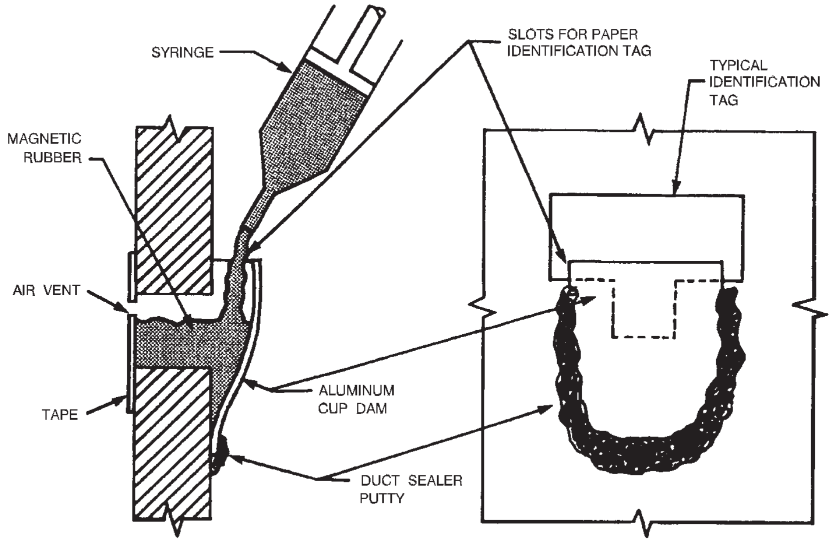
c. Prepare a dam around the surface or hole to be inspected. Examples are shown in (Figure 3-32). Use tape, aluminum foil, special sealing putty, and specially made dams (singly or in combination) to form a reservoir to hold the magnetic rubber.

NOTE

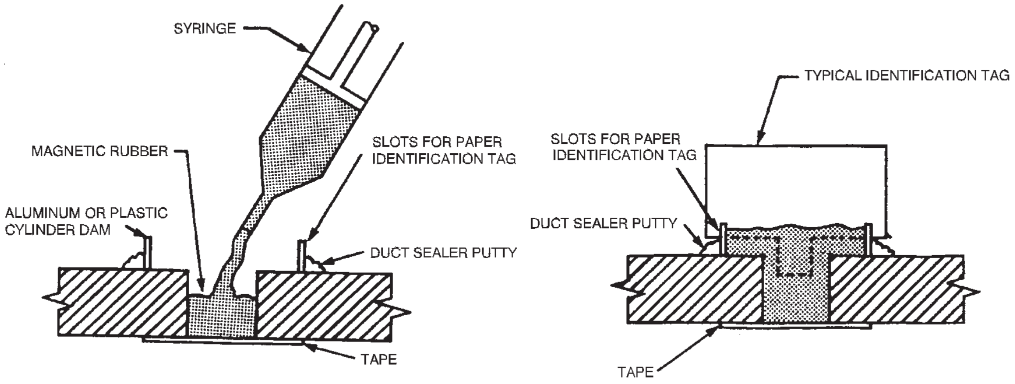
The steps in (paragraph 3.4.13.4.2) through (paragraph 3.4.13.4.7) are for pre-magnetization setup and adjustment. Magnetization will be conducted after addition of the magnetic rubber.

3.4.13.4.2 Select Method of Magnetization. Magnetism may be applied with portable electromagnets (yokes), permanent magnets, or conventional magnetic particle inspection equipment. DC or rectified AC current must be used to electrically generate the magnetic field. An AC generated field will not be effective with slow-moving particles. In areas of limited accessibility, soft iron, low alloy steel extensions, or pole pieces are used to transfer magnetism into the inspection area. Permanent magnets are useful in certain specialized applications, such as threaded bolts, gears, or other small parts whose shape makes magnetization difficult with an electromagnet. The magnetic fields produced in large parts by permanent magnets are often quite low and unpredictable; therefore, they SHOULD NOT be used on such parts unless a specific procedure has been developed and verified. Central conductors are effective for fastener and attachment holes; particularly when there are multiple layers of materials and the layer being inspected is not accessible to an electromagnetic yoke.

3.4.13.4.3 Select the Method of Magnetic Contact. Field strength is greatly reduced when there is poor contact between the magnet and the test piece. To improve contact, auxiliary pole pieces are useful as illustrated in (Figure 3-33). These may be machined from soft iron and attached to the poles of magnets. Pole pieces SHOULD be designed to have the least reduction in cross-section consistent with space requirements.



HORIZONTAL HOLE PREPARATION



VERTICAL HOLE PREPARATION

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Figure 3-32. Preparation for Magnetic Rubber Inspection

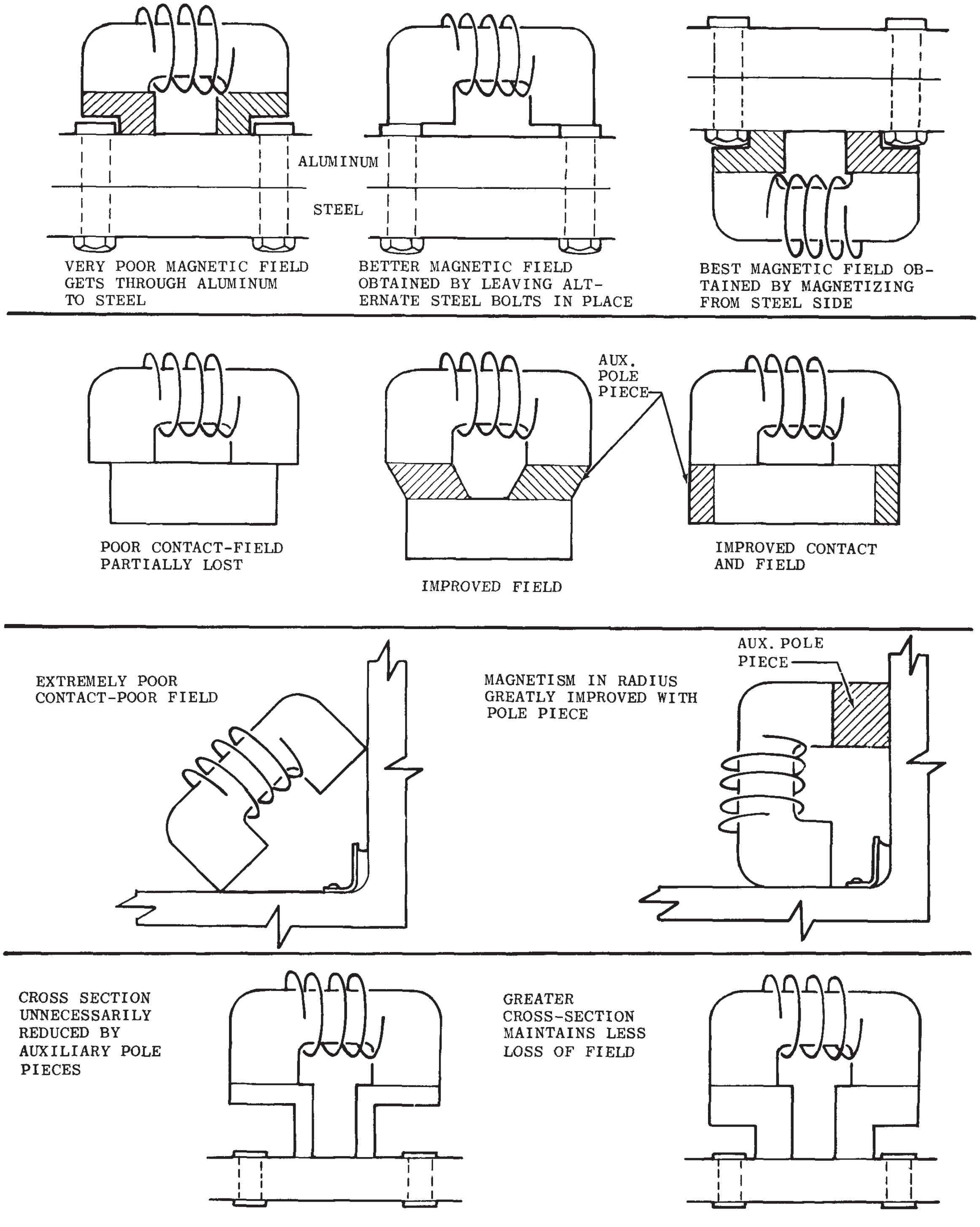

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Figure 3-33. Using Pole Pieces to Improve Magnetic Contact

3.4.13.4.4 Determine the Magnetic Field Requirements. Magnetic field recommendations (strength and duration) for inspection of holes and surfaces are shown in (Table 3-6). These are recommended starting points; actual requirements are those that produce inspection replicas with the needed defect detection sensitivity.

Table 3-6. Magnetic Field Strength and Duration Recommendations

(Variations may be required for specific applications.)			
Inspection Area	**Magnetic Rubber Base Material**	**Field Strength (Gauss)**	**Magnetization Duration, Each Direction**
Hole (bare)	MR-502 (NSN 6850-01-037-9015)	50 to 100	30 seconds
	MR-502K (NSN 6850-01-163-0276) MR-502Y (NSN 6850-01-163-0277)	30 to 50	30 seconds
Surface (bare)	MR-502 (NSN 6850-01-037-9015)	150	1 minute
		100	3 minutes
		50	10 minutes
	MR-502K (NSN 6850-01-163-0276) MR-502Y (NSN 6850-01-163-0277)	100	30 seconds
		50	1 minute
		30	2 minutes
Coated Holes and Surfaces	Extend magnetization duration from the times listed above depending on coating thickness.		

3.4.13.4.5 Determine Field Direction. Since cracks and other flaws are displayed more strongly when they lie perpendicular to the magnetic lines of force, the magnetism SHOULD be applied from two directions to increase reliability when the flaw direction is unknown or uncertain. Usually this is accomplished by magnetizing in one direction and then rotating the magnetization source 90-degrees and magnetizing again. When the direction of a suspected defect is known, only one magnetizing direction is required.

3.4.13.4.6 Measure the Magnetic Field Strength. Measure the magnetic field strength using a gauss meter by placing the probe in the hole or on the surface to be inspected. Most electronic gauss meters have interchangeable probes to permit measurement of the magnetic field either parallel or perpendicular (transverse) to the axis of the probe. The transverse probe, which can measure the field parallel to the part surface, will be used most often. Refer to the operating manual for the gauss meter for specific operating instructions.

3.4.13.4.7 Adjust the Magnetic Field Strength.

3.4.13.4.7.1 Electromagnets. The magnetic field strength is adjusted to the recommended value from Table 3-6) by adjusting the control knob of the magnetization power supply. The control knob reading and the position of magnet and pole pieces are noted so these settings can be repeated when final magnetization is performed after addition of the rubber formulation.

3.4.13.4.7.2 Permanent Magnets. Appropriate bar magnets are placed to obtain the needed field strength and direction.

3.4.13.4.8 Mix, Measure, and Deaerate. Mix, measure, and deaerate (only if bubbles in replica are a problem) magnetic rubber base material as follows:

3.4.13.4.8.1 Mixing. The magnetic rubber base material must be thoroughly mixed prior to use. Prior to measuring or weighing a quantity of magnetic rubber it SHOULD be thoroughly mixed with a wooden tongue depressor or a spatula. Mixing SHOULD continue until the material contains no streaks or color variations. Materials that have settled SHOULD be agitated on a mechanical shaker (paint shaker or equivalent). Steel balls may be placed in the container containing the magnetic rubber to facilitate thorough mixing.

3.4.13.4.8.2 Measuring. The magnetic rubber base material may be weighed or measured, volumetrically, into paper cups or other suitable containers. One gram of magnetic rubber base material is equal to one cubic centimeter (cc) of base material. The number and size of the batches measured must be based on the area to be inspected. Do not measure more material per batch than can be poured and magnetized within the gel time of the formula selected. To determine the gel time at the time of inspection, measure a small trial batch and time the gel time in the mixing cup before the inspection batch is mixed and poured.

3.4.13.4.8.3 Deaerating. Deaerate the base material for inspections of horizontal holes, upside-down surfaces and any time bubbles interfere with interpretation of the replica. The magnetic rubber base material is placed in a vacuum chamber and pumped down to 25 to 30-inches of mercury for one to two minutes. This will remove excess air and help prevent the formation of bubbles on the upper surfaces of the cured replicas.

Table 3-7. Cure Times for Different Amounts of Catalyst

Material	Gel Time	Cure Time
MR-502	8 min.	1 hr.
	15 min.	2 hrs.
	30 min.	4 hrs.
MR-502K and MR-502Y	2 min.	5 - 10 min.
	3 min.	10 - 15 min.
	5 min.	15 - 20 min.
	10 min.	1 hr. 15 min.

3.4.13.4.9 Add Magnetic Rubber.

NOTE

- The magnetic rubber will begin to thicken when curing agents are added. Therefore, magnetization must begin immediately and the entire batch must be magnetized before the gel time of the formula has expired.
- Magnetic rubber material, catalyst addition, and cure time are based on a room temperature of 76°F. The cure times are very unpredictable when the temperature is below 60°F or over 90°F.
- When inspecting deep holes with small diameters, with scored surfaces, or of unusual configuration, the inspection area may be coated with a thin film of release agent to aid in removal of the replica.

Add to the magnetic rubber base material the correct number of drops of catalysts, and cure stabilizer according to the instructions provided with the material by the manufacturer. Typical combinations of gel time and cure times attainable by varying the amount of catalyst added is shown in (Table 3-7). Higher humidity or higher temperature will increase the cure rate. When temperature or humidity change, or when material from a different batch is first used, mixing a small test batch to determine optimum ratios of catalyst to base material is recommended. If the cure is too fast and the rubber starts to gel before the magnetization is complete, the process will have to be repeated. If the cure is too slow, time is lost waiting for the replica to solidify enough for removal.

3.4.13.4.10 Mix. Using a tongue depressor or equivalent, thoroughly stir the mixture. Avoid whipping air into the mixture.

3.4.13.4.11 Fill. Using the mixing container or a syringe, fill only the number of holes or other test areas that can be magnetized within the gel time. Following fill, vent holes SHOULD be sealed with putty to prevent the continual flow of rubber.

NOTE

> Holes in steel having high retentivity may be magnetized by a “residual” method. Using this method, the hole is filled with magnetic rubber and is magnetized with an electromagnet at the maximum field obtainable for a period of about one second. This SHOULD establish a residual field of 25-100 gauss to be effective. This field must stay undisturbed for 30 to 60-seconds (depending on the level of residual magnetism). Do not magnetize the hole in a second direction or magnetize any other hole on the same test part until the 30 to 60-seconds have elapsed.

3.4.13.4.12 Magnetize. Magnetize each test area according to the pre-magnetization setup established in (paragraph 3.4.13.4.2) through (paragraph 3.4.13.4.7).

3.4.13.4.13 Identify. Replicas can be identified by inserting an identification tag into the rubber before it gels, or by individually bagging the completed replica along with the identification.

NOTE

> Care SHALL be exercised to avoid disturbing the magnetic rubber in the area of interest when inserting a tag.

3.4.13.4.14 Allow magnetic rubber to cure for the time specified. Avoid movement of the part and contamination of the magnetic rubber by foreign matter.

3.4.13.4.15 Determine if the magnetic rubber if is cured (tack-free) by lightly touching the replica or the material remaining in the mixing container.

3.4.13.4.16 Remove each replica as follows:

a. Remove the magnets if applicable.

b. Remove tape, aluminum dam, duct sealer putty, and/or central conductor and dam assembly.

c. Gently remove replica from test area.

NOTE

> The replicas tear easily.

3.4.13.4.17 Visually examine replicas for overall condition and proper identification. A stereomicroscope providing magnification of at least 10X magnification, and a high intensity illuminator SHALL be used for microscopic examination as follows:

a. Adjust the illuminator so the light does not produce a glare on the surface of the replica. A good stereomicroscope with excellent light gathering characteristics and a strong light projected at a shallow angle is generally best for this work. Experience has proven that using a mediocre microscope or inadequate lighting may result in small cracks going undetected. The inspector may check the adjustment of the illuminator periodically on a replica known to display a faint crack indication.

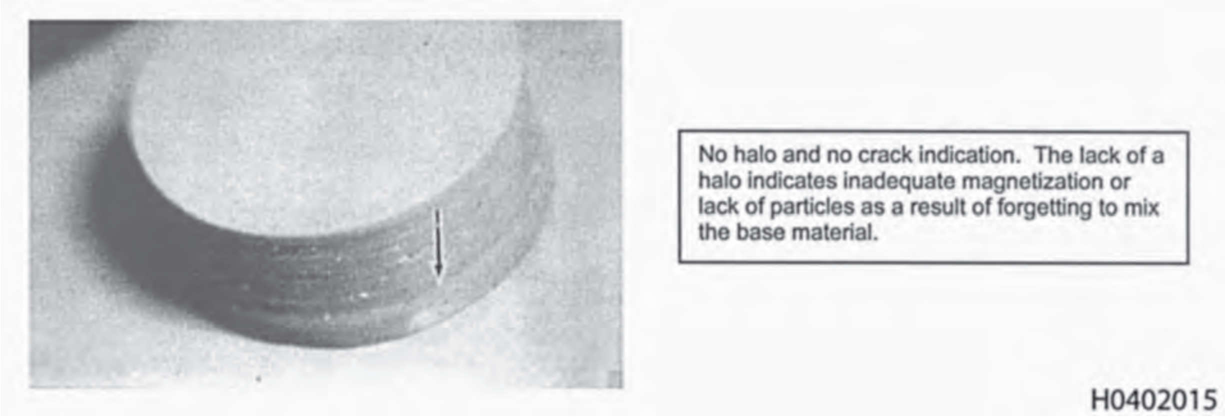
b. Hold the replica with finger tips and focus by lowering or raising the replica beneath the microscope lens (rather than raising or lowering the lens itself). This allows the inspector to view the replica at various angles and to scan the entire area of interest.

c. Evaluate the level of magnetism. Although magnetic rubber responds satisfactorily to a wide range of magnetism, the reliability is increased if the optimum level is used. Too little magnetism will result in faint indications easily missed. Too much magnetism darkens the background so indications might be hidden. The experienced inspector can determine if the magnetism level is satisfactory by the appearance of the replica. For a hole magnetized with a yoke or permanent magnet, adequate magnetism is indicated on the replica by a dark "halo" around the edge (Figure 3-35). Adequate magnetism on flat surfaces and areas of gentle contour is indicated by darkness in the rough areas of the replica. On very smooth surfaces, external "penetrameter type" indicators such as staples, nickel foil, or other magnetic material may be taped to the part to indicate magnetism.

d. Evaluate the replica quality. Replicas that contain excessive air bubbles, debris, or poorly mixed rubber are difficult to interpret and SHOULD be recast. Correct any technique or procedural errors. Clean the inspection area down to bare metal if necessary. Vary the inspection technique as appropriate.

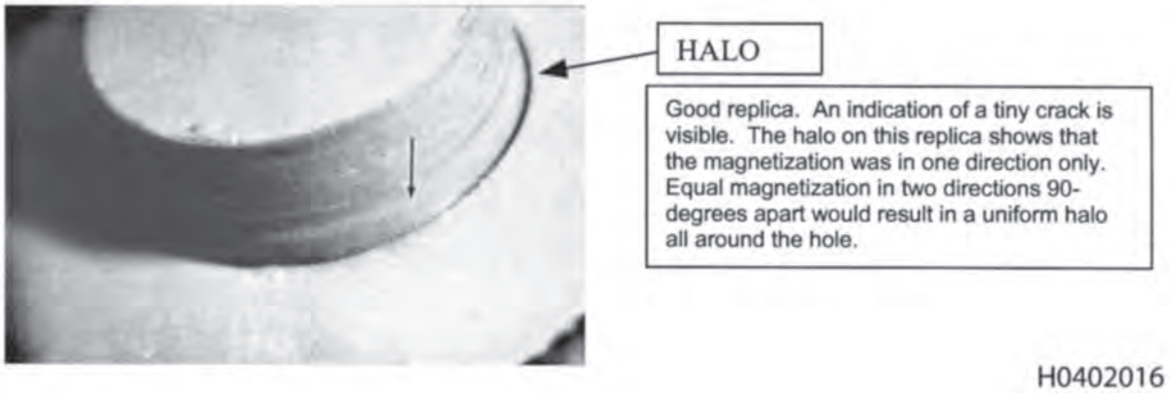
e. Evaluate indications of discontinuities and report relevant ones as required by the directive specifying the inspection.

f. A replica may show obvious surface defects (tool marks, corrosion pitting, etc.) not attracting magnetic particles. The inspector is not responsible for identifying this type of defect unless the procedure specifically requires such identification.



No halo and no crack indication. The lack of a halo indicates inadequate magnetization or lack of particles as a result of forgetting to mix the base material.

Figure 3-34. Magnetic Rubber Replica With No Indication



Good replica. An indication of a tiny crack is visible. The halo on this replica shows that the magnetization was in one direction only. Equal magnetization in two directions 90-degrees apart would result in a uniform halo all around the hole.

Figure 3-35. Magnetic Rubber Replica With Good Indication

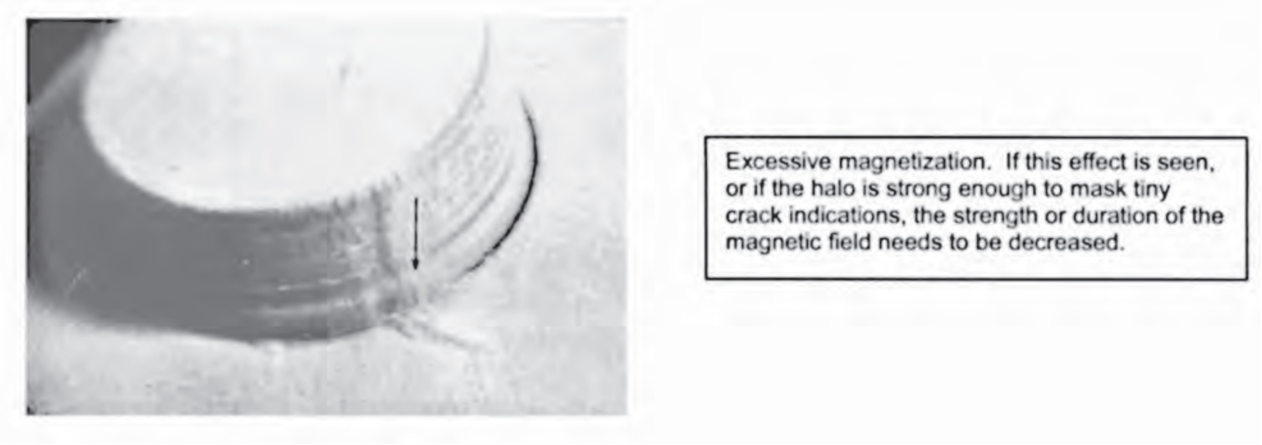


Figure 3-36. Magnetic Rubber Replica With Excessive Magnetization

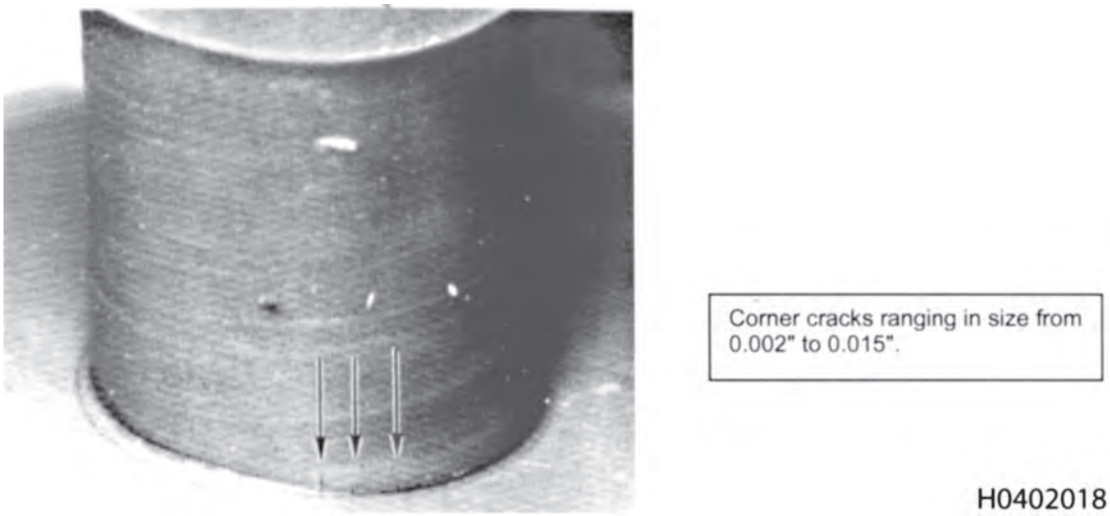


Figure 3-37. Magnetic Rubber Replica With Crack Indications

3.4.13.5 Post-Inspection Procedures.

a. Demagnetize parts until the residual magnetism is less than two gauss measured with the electronic gauss meter, or two divisions on the magnetic field indicator.

b. Clean parts with cleaning solvent. Refer to NAVAIR 01-1A-509 (TO 1-1-691/TM 1-1500-344-23), Chapter 3 for specific cleaning instructions and approved materials.

c. Restore finish or apply preservative promptly if corrosion preventive plating is not present or has been breached. High strength steels like 300M and Aermet 100 in current use on high performance military aircraft are extremely sensitive to stress-corrosion cracking. Harmful corrosion can start on these materials in a matter of hours. Refer to NAVAIR 01-1A-509 (TO 1-1-691/TM 1-1500-344-23), Chapter 3 for specific preservation instructions and approved materials.

SECTION V MAGNETIC PARTICLE INSPECTION INTERPRETATIONS

3.5 MAGNETIC PARTICLE INSPECTION INTERPRETATION.

3.5.1 Formation of Discontinuities and their Indications.

3.5.1.1 The Iron and Steel Manufacturing Processes. Knowledge of iron and steel manufacturing processes is necessary to enable an inspector to interpret and evaluate magnetic particle indications. It is not possible in this manual to explain all of the processes used in the manufacture of iron and steel parts, but a brief review will explain how some discontinuities are formed.

3.5.1.1.1 Purpose of Processing. Iron ore is converted into metal by heating it in a furnace. When it becomes liquid or molten, iron can be poured into molds and allowed to cool and solidify. In the molten state, it is possible to remove impurities and also to add other elements to form alloys. These additions, along with other appropriate metal processing steps, impart desirable properties to the finished metal that can make it:

- Harder
- Softer
- Tougher
- Stronger
- Easier to machine
- Resistant to heat
- Resistant to corrosion

3.5.1.2 Ingot Production. After melting, purifying, and alloying the iron or steel, the molten metal is poured into an ingot mold where it is allowed to solidify. Most impurities rise to the top of the ingot before the metal is completely solid. However, some of the foreign materials can become trapped within the ingot during solidification. Because such entrapment is usually concentrated near the top, the ingot is cropped to remove most of the impurities.

3.5.1.3 Primary and Secondary Processing. Ingots undergo primary processing to form the metal into basic shapes according to end-product requirements. Secondary processing is subsequently used to manufacture the final products. A pictorial story of steel processing (Figure 3-38) shows in sequence the principal stages or operations where defects may be created, and indicates the defects most likely to be found in the material as it leaves each stage. This illustration SHOULD be studied in conjunction with the text in this section.

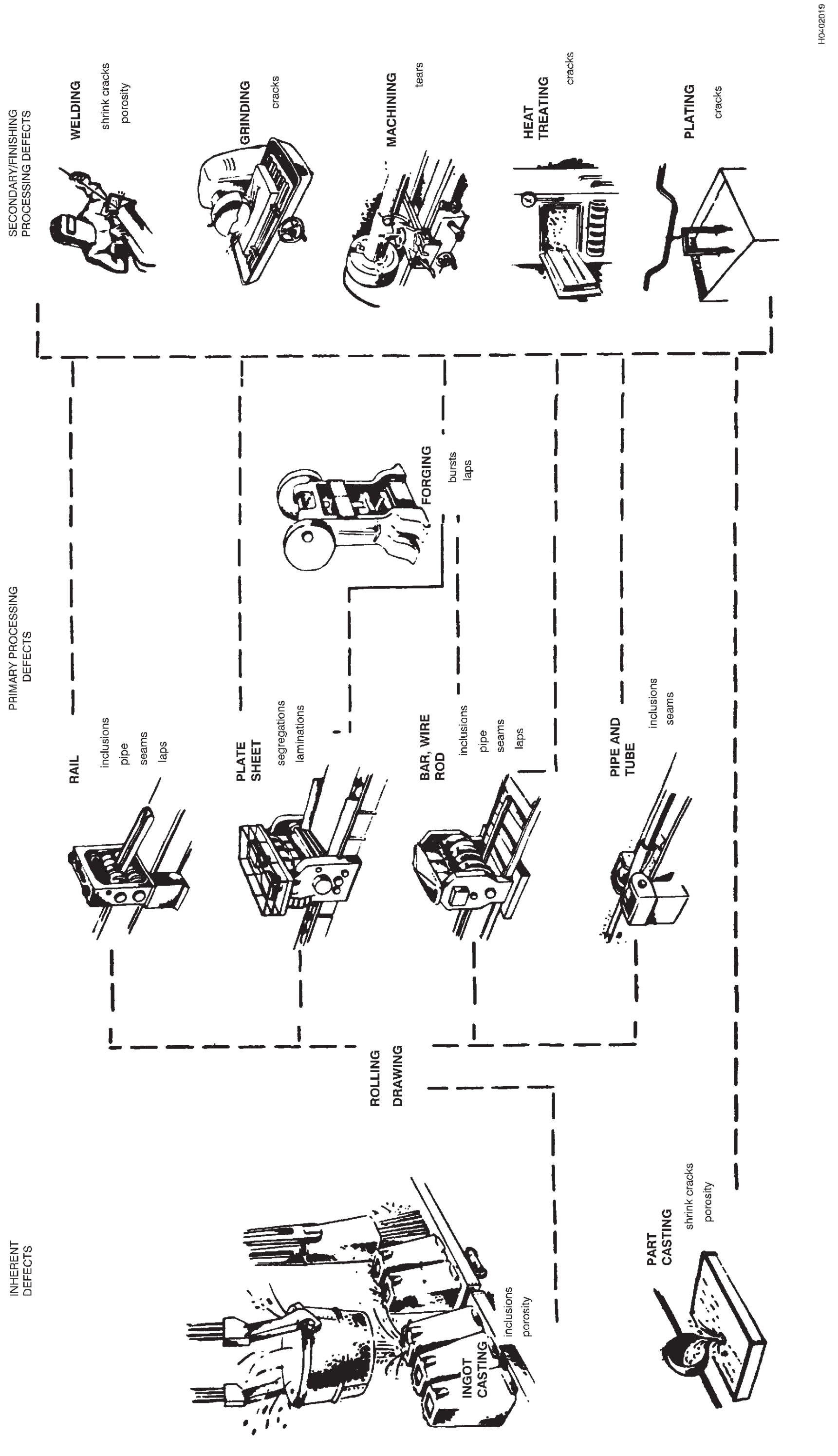


Figure 3-38. Sequence of Steel Processing Stages, Indicating the Principle Operations and the Defects Most Likely to be Found in the Material After Each Process

3.5.2 Definition of Terms. The magnetic particle inspector SHALL understand the distinctions between a discontinuity, an indication, and a defect.

3.5.2.1 Discontinuity. A discontinuity is an interruption in the normal physical structure or properties of a part. Discontinuities may be cracks, laps in the metal, folds, seams, inclusions, porosity, and similar conditions. A discontinuity may be very fine or it may be quite large. A discontinuity may or may not be a defect; that is, it may or may not affect the intended use of the product or part. A discontinuity, which would be a defect in one part, may be entirely harmless in another part designed for a different service.

3.5.2.2 Indication. An indication is an accumulation of magnetic particles being held by a magnetic leakage field to the surface of a part. The indication may be caused a discontinuity, by some other condition that produces a leakage field, or by mechanically held particle accumulation.

3.5.2.3 Defect. A defect is a discontinuity that interferes with the intended use of a part.

3.5.3 Basic Steps of Inspection. Magnetic particle inspection can be divided into three basic steps:

- Producing an indication on a part.
- Interpreting the indication.
- Evaluating the indication.

3.5.3.1 Producing an Indication. In order to produce a proper indication on a part, it is necessary to have some knowledge of the principles of magnetism, the materials used in inspection, and the technique employed. Since these subjects have been covered in previous sections of this manual, observance of the procedural steps therein should ensure a proper indication is produced.

3.5.3.2 Interpreting the Indication. After the indication is created, it is necessary to interpret that indication. Interpretation is the determination of what caused that indication. Knowledge of metal processing is often invaluable in identifying the cause of an indication.

3.5.3.2.1 Indications caused by a discontinuity at the part surface are characterized by particles tightly held to the surface by a relatively strong magnetic leakage field. The particle accumulation has well defined edges and there is a noticeable ‘‘build-up’’ of the particles. This build-up consists of a slight mound or pile of particles, on which deep surface cracks are sometimes high enough above the part surface to cast a shadow. If such an indication is wiped off, the discontinuity can usually be seen.

3.5.3.2.2 Indications caused by a discontinuity below the surface are characterized by a broad and fuzzy looking accumulation of particles. The particles in such an indication are less tightly held to the surface because the leakage field is weaker.

3.5.3.2.3 The difference in appearance between indications of surface and subsurface discontinuities is clearly shown (Figure 3-39 and Figure 3-40). Notice the sharpness and definition of the accumulation of magnetic particles in (Figure 3-39). The pattern in (Figure 3-39) is much broader than in (Figure 3-40) and is quite typical of the indications formed over subsurface discontinuities.

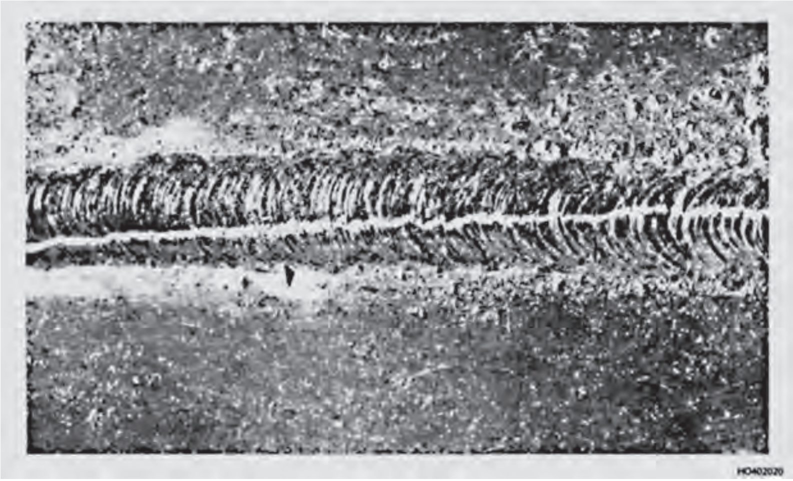


Figure 3-39. Sharp, Well Defined Indication of Surface Discontinuity in a Weld

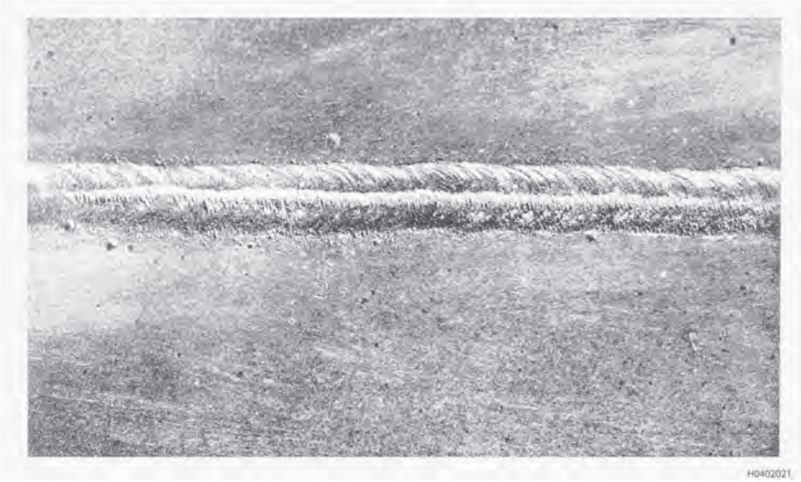


Figure 3-40. Broad Indication of Subsurface Discontinuity in a Weld

3.5.3.3 Evaluating the Indication. Finally, after the indication has been formed and interpreted, it must be evaluated. Evaluation helps determine the consequences of the discontinuity. This includes determining if the discontinuity is a defect and if so, can the part be reworked or repaired, or must the part be scrapped.

3.5.3.3.1 Generally, an inspector has fairly detailed guidance concerning the interpretation and evaluation of indications included with the procedure by which the inspection was done. In the event such guidance is not available, the following basic considerations may be used in conjunction with the inspector's knowledge and experience to help with indication evaluation.

3.5.3.3.1.1 A discontinuity of any kind lying at the surface is more likely to be harmful than a discontinuity of the same size and shape which lies below the surface.

3.5.3.3.1.2 Any discontinuity, whether surface or sub-surface, having a principal dimension, a principal plane which lies at right angles, or at a considerable angle to the direction of principal stress, is more likely to be harmful than a discontinuity of the same size, location, and shape lying parallel to the stress.

3.5.3.3.1.3 Any discontinuity that occurs in an area of high stress SHALL be more carefully considered than a discontinuity of the same size and shape in an area where the stress is low.

3.5.3.3.1.4 Discontinuities that are sharp, such as grinding cracks or fatigue cracks, are severe stress risers and are more harmful in any location than rounded discontinuities, such as scratches.

3.5.3.3.1.5 Any discontinuity that occurs in a location close to a keyway or fillet SHALL be considered more harmful than a discontinuity of the same size and shape occurring away from such a location.

3.5.3.3.2 Magnetic Particle Indications. Discontinuities in the part under examination will produce indications. These indications may not always be associated with physical discontinuities. Indications may be caused by:

3.5.3.3.2.1 An actual physical discontinuity at or near the surface of a part, which may have been present in the original metal or may have been produced by subsequent forming, heating, finishing processes, or service use (Figure 3-41).

Figure 3-41. Typical Magnetic Particle Indications of Cracks

3.5.3.3.2.2 Actual physical discontinuities which are present by design (e.g., an interference or close fit between two members of an assembly) (Figure 3-42).

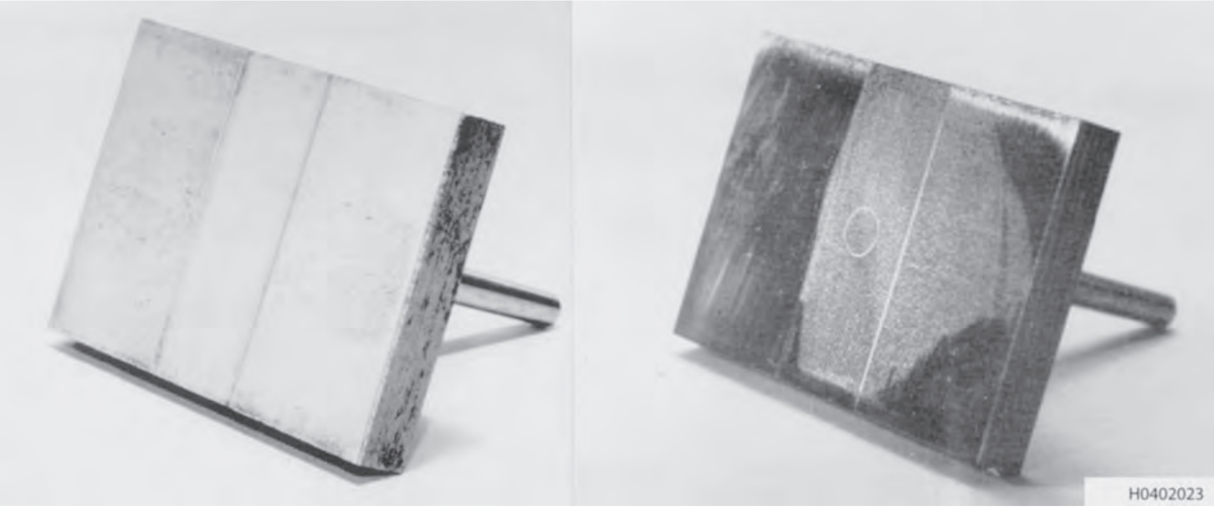


Figure 3-42. Magnetic Particle Indication of a Forced Fit

3.5.3.3.2.3 A weld between two dissimilar ferromagnetic metals having different permeabilities; or between a ferromagnetic metal and a nonmagnetic material. Indications may be produced at such a point even though the joint is perfectly sound. Such an indication may be produced in a friction or flash weld of two dissimilar metals (Figure 3-43).

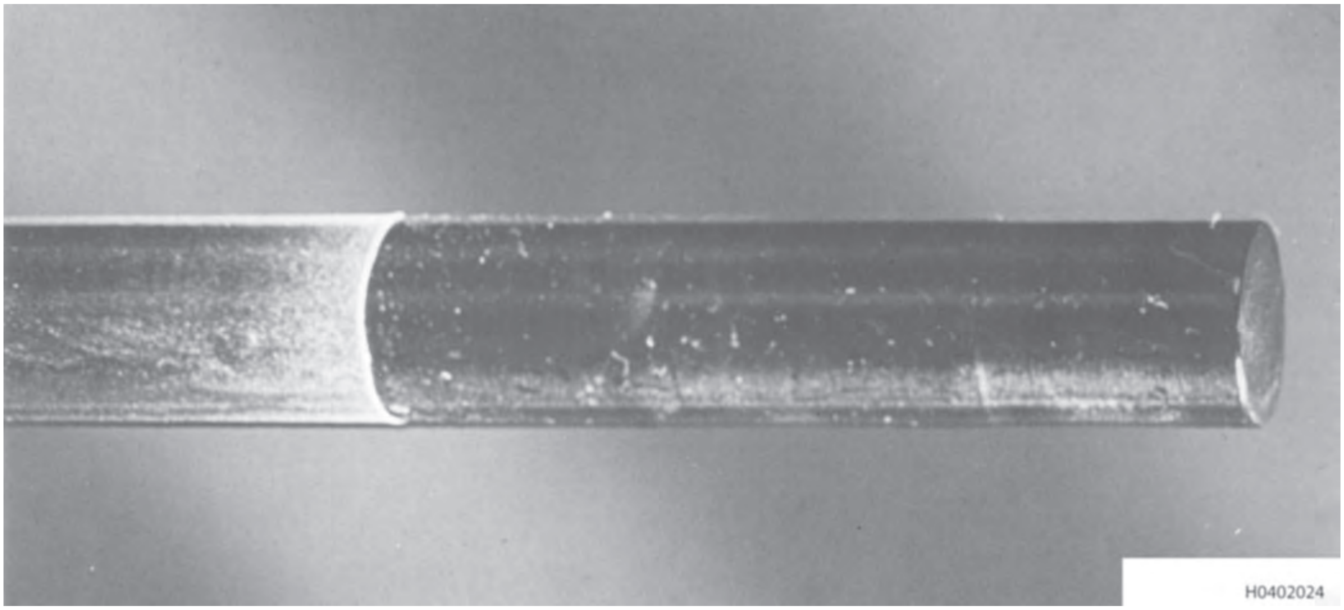


Figure 3-43. Particle Indication at the Weld Between a Soft and a Hard Steel Rod

3.5.3.3.2.4 The junction between two ferromagnetic metals by means of nonmagnetic bonding materials, as in a brazed joint. An indication will be produced though the joint itself may be perfectly sound (Figure 3-44).

Figure 3-44. Magnetic Particle Indication of the Braze Line of a Brazed Tool Bit

3.5.3.3.2.5 Segregation of the constituents of the metal, where these have different permeabilities (e.g., low carbon areas in a high carbon steel, or areas of ferrite, which is magnetic, in a matrix of stainless steel which is austenitic and therefore nonmagnetic). Another example would be in the weld zone and/or the heat-affected zone in welds between details of the same alloy (Figure 3-45).

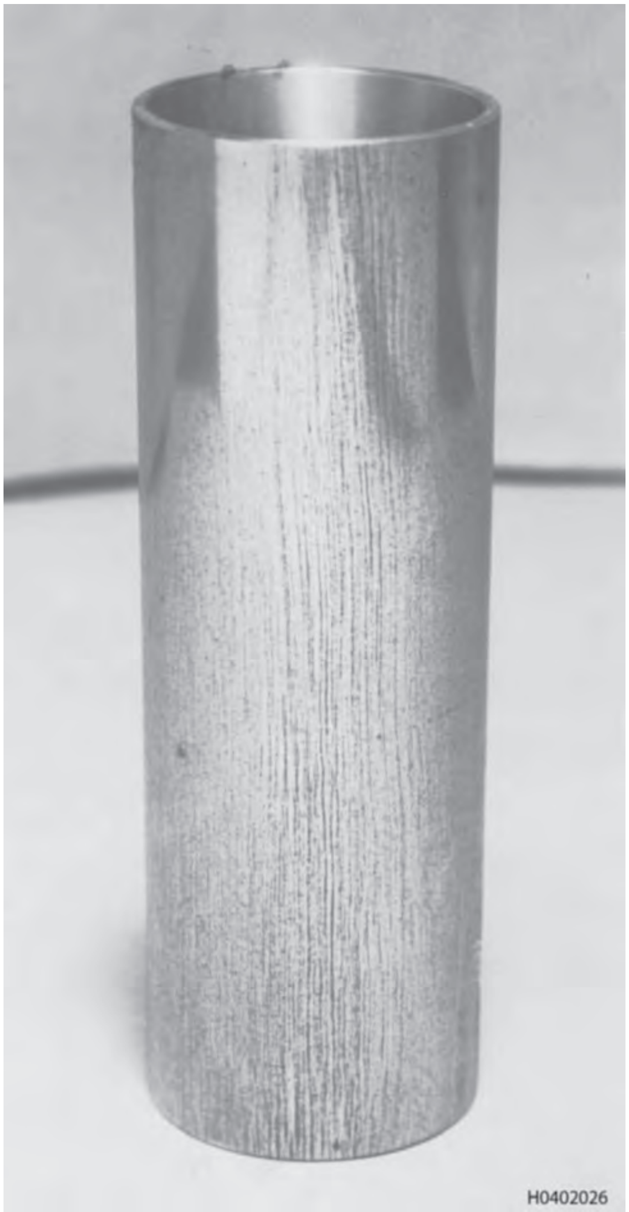


Figure 3-45. Magnetic Particle Indications of Segregations

3.5.4 Classes of Discontinuities. There are a number of ways to classify discontinuities that occur in ferromagnetic materials and parts.

- Class by Location. One broad grouping is based on location (surface discontinuity or subsurface discontinuity). The ability of magnetic particle inspection methods to locate members of these two groups varies sharply, but beyond this, the classification is too broad to be very useful.
- Class by Process. Another possible system is to classify discontinuities by the process that produced them. Although such a system is too specific to be suitable for all purposes, it is used extensively. When speaking of forming defects, welding defects, heat-treating cracks, grinding cracks, etc. Practically every process, from the original ore refinement to the last finishing operation, can and will introduce discontinuities which magnetic particle testing can find. Therefore, it is important that the nondestructive testing engineer or inspector to be aware of all of these potential defect sources.

3.5.4.1 Conventional Classification System. For many years, it has been customary to classify discontinuities according to their source or origin in the various stages of metal production, fabrication, and use:

- Inherent: Produced during solidification from the liquid state.
- Processing: Primary.
- Processing: Secondary, or finishing.
- Service.

A discussion of each class with detailed examples is given below.

3.5.4.1.1 Inherent Discontinuities. This group of discontinuities is present as the result of its initial metal solidification from the molten state, before any of the operations to forge or roll it into useful sizes and shapes have begun. The names of these inherent discontinuities are given and their sources described below.

3.5.4.1.1.1 Pipe. As the molten steel which has been poured into the ingot mold cools, solidifies first at the bottom and walls of the mold. Solidification progresses gradually upward and inward. The solidified metal occupies a somewhat smaller volume than the liquid, so there is a progressive shrinkage of volume as solidification continues. The last metal to solidify is at the top of the mold, but due to shrinkage there is not enough metal to fill the mold completely, and a depression or cavity is formed. This may extend quite deeply into the ingot (Figure 3-46). After early breakdown of the ingot into a bloom, this shrink cavity is cut away or cropped. If this is not done completely before final rolling or forging into shape, the unsound metal will show up as voids called "pipe" in the finished product. Such internal discontinuities, or pipe, are obviously undesirable for most uses and constitute a true defect. Special devices ("hot tops") and special handling of the ingot during pouring and solidification can control the formation of these shrink cavities.

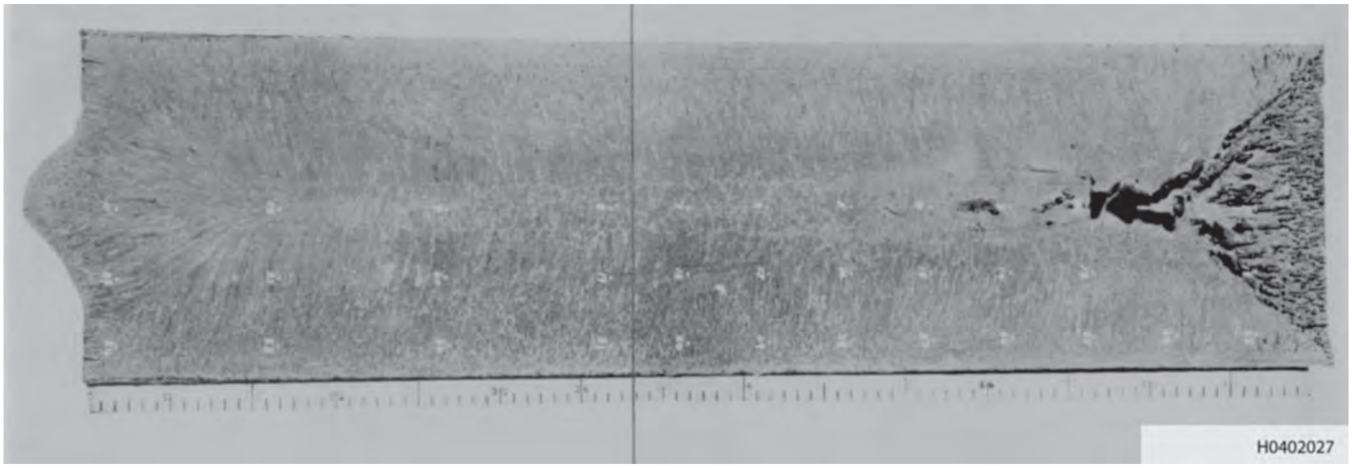


Figure 3-46. Cross-Section of Ingot Showing Shrink Cavity

3.5.4.1.1.2 Blowholes. As the molten metal in the ingot mold solidifies there is an evolution of various gases. These gas bubbles rise through the liquid and a small percentage escape. The remainder is trapped as the metal freezes. Most of these, usually small, will appear near the surface of the ingot; some often large, will be deeper in the metal, especially near the top of the ingot. Many of these blowholes are clean on the interior and are fused shut into sound metal during the first rolling or forging of the ingot, but some near the surface may have become oxidized and do not fuse. These may appear as seams in the rolled product. Those deeper in the interior, if not fused in the rolling, may appear as laminations.

3.5.4.1.1.3 Segregation. Another action that takes place during the solidification is the tendency for certain elements in the metal to concentrate in the last-to-solidify liquid, resulting in an uneven distribution of some of the chemical constituents in the ingot. Various means have been developed to minimize this tendency, but, if for any reason, severe segregation does occur, the difference in permeability of the segregated areas may produce magnetic particle indications. Segregation can adversely affect physical properties as well as contribute to the formation of defects later in the processing cycle.

3.5.4.1.1.4 Nonmetallic Inclusions. Nonmetallic inclusions are usually oxides, sulfides, or silicates. They can be introduced by the use of dirty raw materials, crucibles, or rods. Other contributing factors can be faulty linings and poor pouring practices. The inclusions can form stringers during subsequent rolling operations. These stringers can affect the physical properties of the materials and are usually considered defects. An example of an indication of nonmetallic inclusions is shown (Figure 3-47).

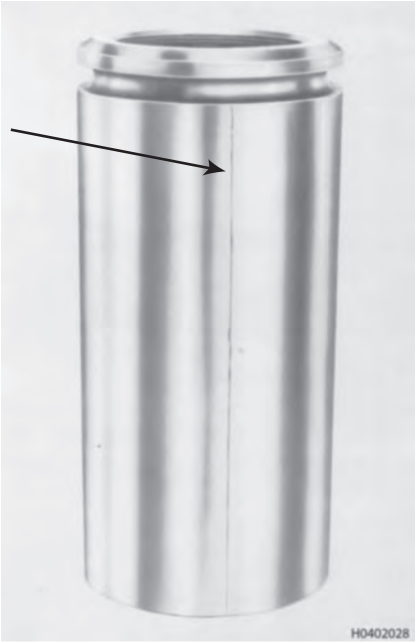


Figure 3-47. Magnetic Particle Indication of a Subsurface Stringer of Nonmetallic Inclusions

3.5.4.1.1.5 Internal Fissures. Because of the stresses setup in the ingot as the result of shrinkage during cooling, internal ruptures may occur, this may be quite large. Since air does not reach the surfaces of these internal bursts, they may be fused during rolling or other forming operations and leave no discontinuity. If there is an opening from the fissure to the surface, however, air will enter and oxidize the surfaces. In this case, fusion does not occur and they will remain in the finished product as discontinuities.

3.5.4.1.1.6 Scabs. When liquid steel is first poured into the ingot mold, there is considerable splashing or spattering up and against the cool walls of the mold. These splashes solidify at once and become oxidized. As the molten steel rises and the mold become filled, these splashes will be reabsorbed to a large extent into the metal. But in some cases they will remain as scabs of oxidized metal adhering to the surface of the ingot. These may remain and appear on the surface of the rolled product. If they do not go deeply into the surface, they may not constitute a defect, since they may be removed by machining. This condition is illustrated (Figure 3-48) on a rolled bloom.

Figure 3-48. Scabs on the Surface of a Rolled Bloom

3.5.4.1.1.7 Ingot Cracks. Surface cracking of ingots occurs due to surface stresses generated during cooling of the ingot. They may be either longitudinal, transverse, or both. As the ingot is formed into billets by rolling, these cracks form long seams. Inspection of billets for seams of this type with magnetic particles is now common practice in modern mills. Detection at this point permits removal of the seams by flame scarfing, chipping, or grinding without waste of good metal. If not removed before further rolling, these seams appear greatly elongated on finished bars and shapes, often making them unsuitable for many purposes.

3.5.4.1.2 Primary Processing Discontinuities. When steel ingots are worked down into usable sizes and shapes such as billets and forging blanks, some of the above described inherent defects may appear, but the rolling and forging processes may also introduce discontinuities that may constitute defects. Primary processes are those which work the metal down by either hot or cold deformation into useful forms such as bars, rod and wire, and forged shapes. Casting is another process usually included in this group. Even though it starts with molten metal it results in a semi-finished product. Welding is included for similar reasons. A description of the discontinuities that can be introduced by these primary processes follows:

3.5.4.1.2.1 Seams. Seams in rolled bars or drawn wire are usually highly objectionable. As previously described, seams may originate from ingot cracks. Conditioning of the billet surfaces by scarfing, grinding, or chipping can eliminate the cracks before final rolling is performed, but seams can be introduced by the rolling or drawing processes themselves. Laps can occur in the rolling of the ingot into billets as the result of overfilling the rolls. This produces projecting fins, which on subsequent passes are rolled into the surface of the billet or bar. In similar fashion, under-fills in the rolling process may on subsequent passes be squeezed to form a seam, which often runs the full length of the bar. Seams derived from laps will usually emerge to the surface of the bar at an acute angle. Seams derived from the folds produced by an under-filled pass are likely to be more nearly normal to the surface of the bar. Seams or die marks may also be introduced in the drawing process due to defective dies. Such seams may or may not make the product defective. For some purposes, such as springs or bars for heavy upsetting, the most minute surface imperfections (or discontinuities) are cause for rejection. For others, where machining operations are expected to remove the outer layers of metal, shallow seams will be machined off (Figure 3-49) and (Figure 3-50).

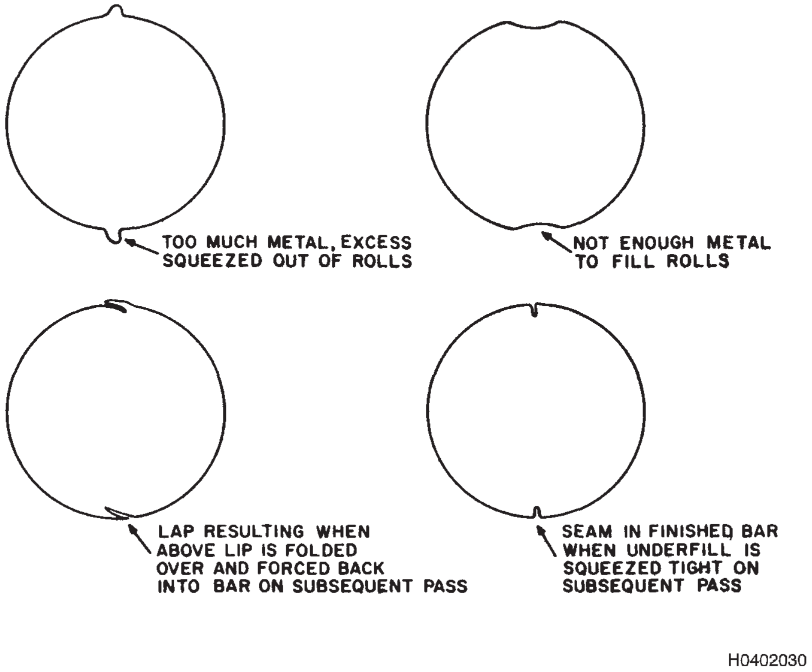


Figure 3-49. How Laps and Seams Are Produced from Overfills and Under-Fills

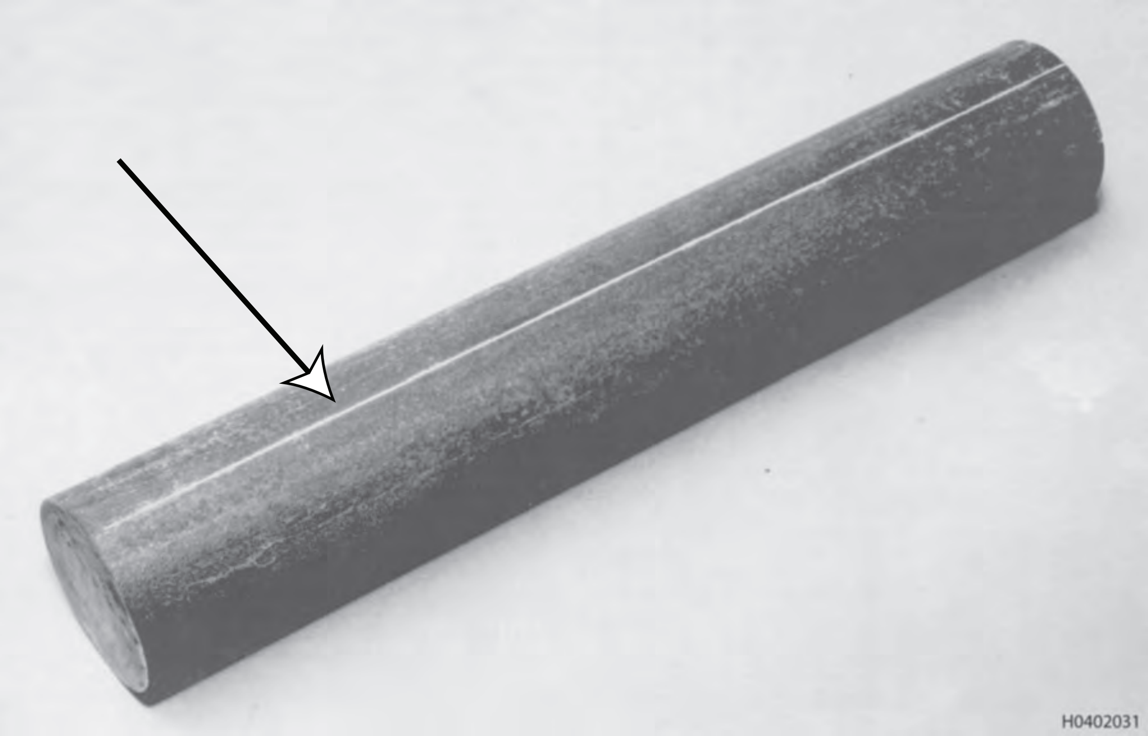


Figure 3-50. Magnetic Particle Indication of a Seam on a Bar

3.5.4.1.2.2 Laminations. Laminations in rolled plate or strip are formed when blowholes or internal fissures are not fused during rolling, but are enlarged and flattened into sometimes quite large areas of horizontal discontinuities (Figure 3-51). Laminations may be detected by magnetic particle testing on the cut edges of plate. The laminations do not give indications on plate or strip surfaces since they are internal and parallel to the surface. Ultrasonic mapping techniques are used to define them.

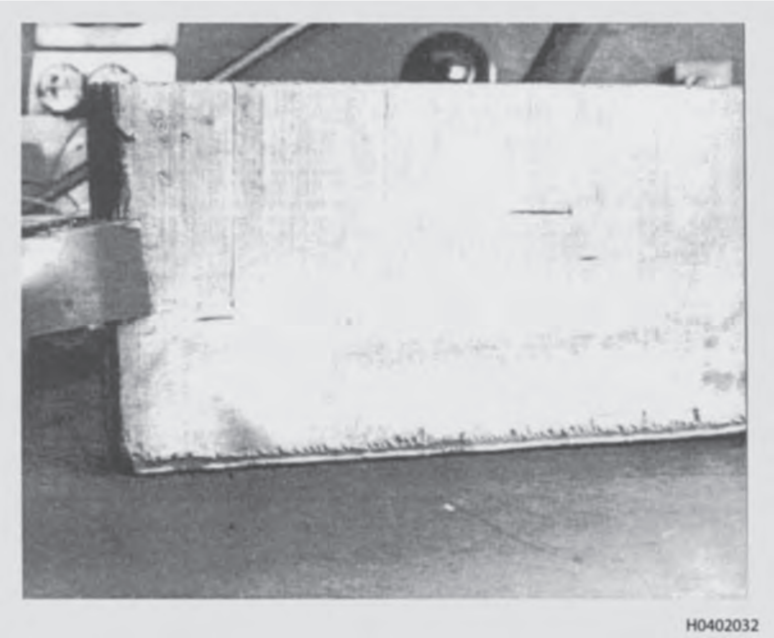


Figure 3-51. Magnetic Particle Indications of Laminations Shown on Flame-Cut Edge of Thick Steel Plate

3.5.4.1.2.3 Cupping. This is a condition created in drawing or extruding when the interior of the metal does not flow as rapidly as the surface. Segregation in the center of the metal usually contributes to this occurrence. The result is a series of internal ruptures that are severe defects whenever they occur. They may be indicated with magnetic particles if the ruptures are large and are near the surface of the part. The cupping problem can be minimized by changing die angles (Figure 3-52).

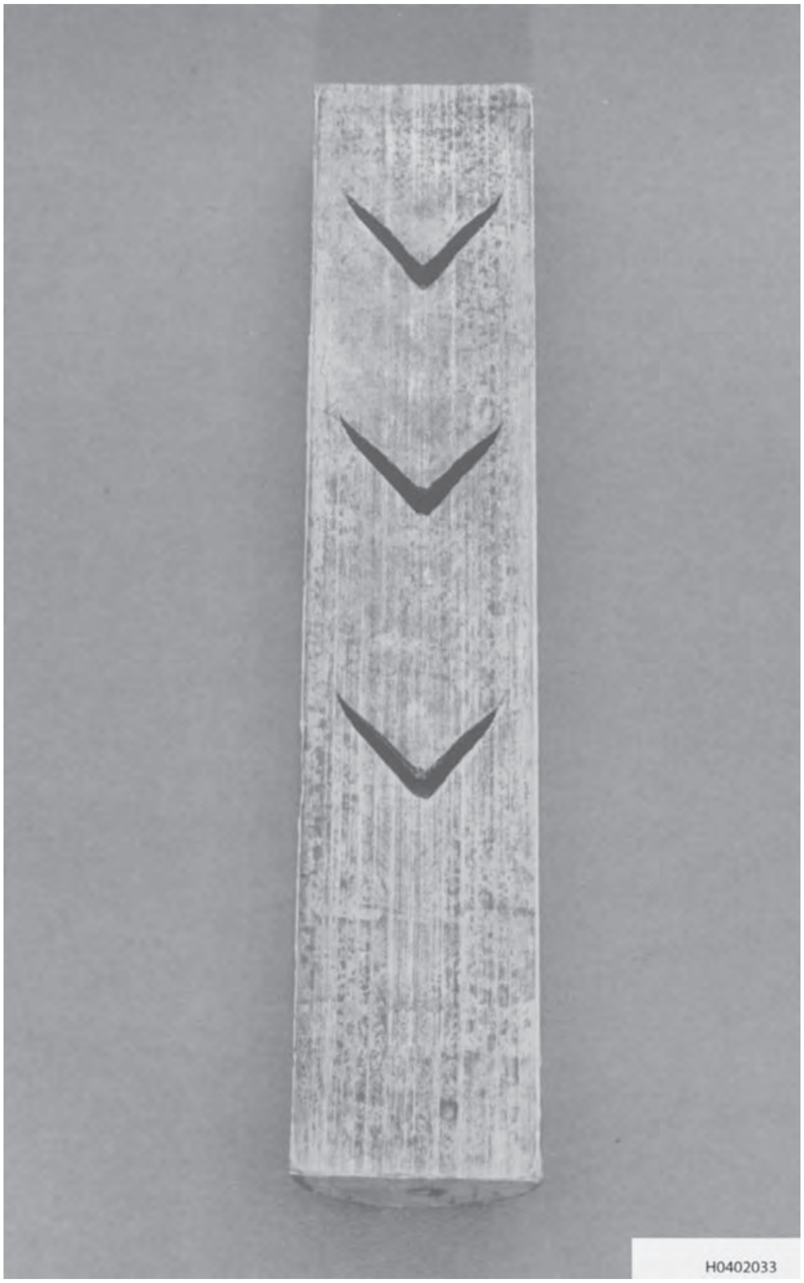
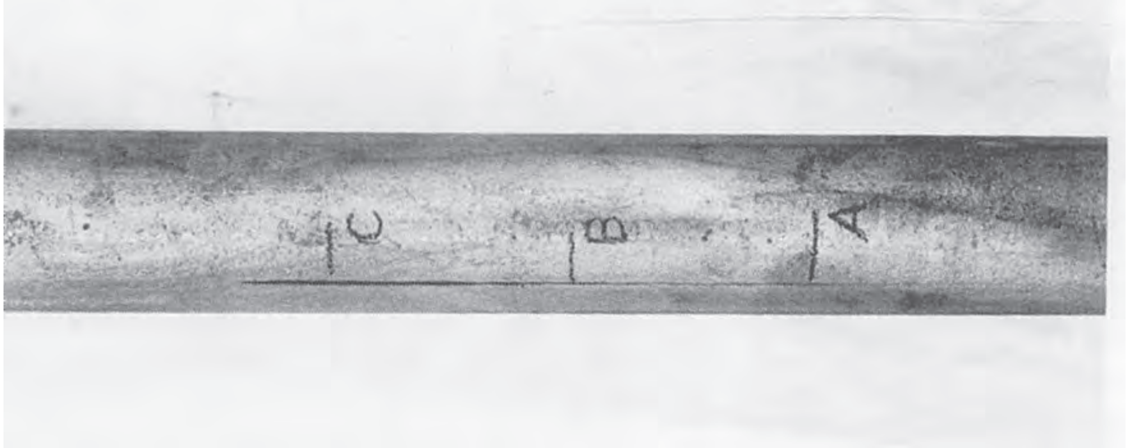


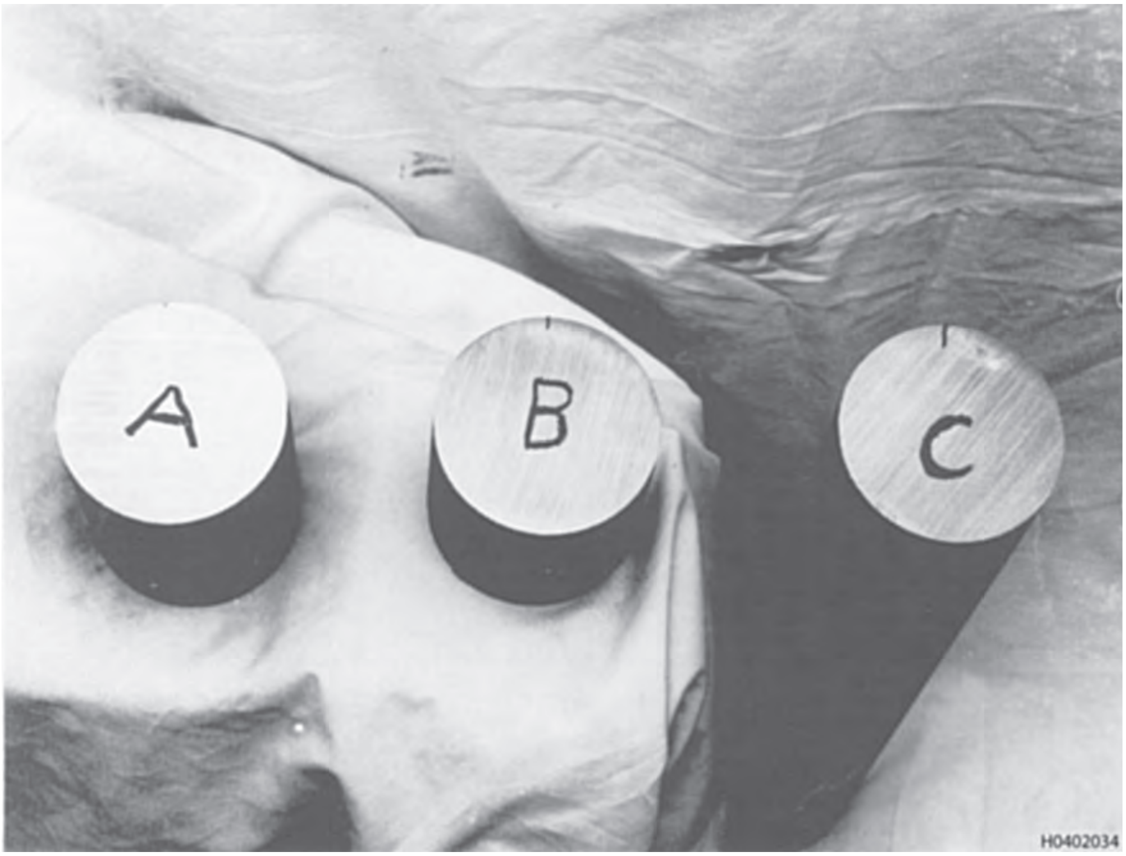
Figure 3-52. Section Through Severe Cupping in a 1 3/8-Inch Bar

3.5.4.1.2.4 Cooling Cracks. When alloy and tool steel bars are rolled and subsequently run out onto a bed or table for cooling, stresses may be set up due to uneven cooling, which can be severe enough to crack the bars. Such cracks are generally longitudinal, but not necessarily straight. They may be quite long and usually vary in depth along their length. The magnetic particle indications of such a crack are shown (Figure 3-53), along with sections through the crack at three points to illustrate the variation in crack depth. The magnetic particle indication varies in intensity, being heavier at points where the crack is deepest.

- Surface Indications.
- Cross-Section Showing Depth.



(a) Surface Indications



(b) Cross Section Showing Depth

Figure 3-53. Magnetic Particle Indications of Cooling Cracks in an Alloy Steel Bar

3.5.4.1.2.5 Hydrogen Flakes. Flakes are internal ruptures that may occur in steel as the result of internal stresses from metallurgical changes and decreased solubility of hydrogen from excessively rapid cooling. Flakes usually occurring in fairly heavy sections and on certain alloys are more susceptible than others. Magnetic particle indications of flakes exposed on a machined surface are shown (Figure 3-54). Since these ruptures are deep in the metal, usually half way or more from the surface to the center of the section, they will not be shown by magnetic particle testing on the original surface of the part.

Figure 3-54. Magnetic Particle Indications of Flakes in a Bore of a Large Hollow Shaft

3.5.4.1.2.6 Forging Bursts. When steel is worked at too high a temperature, it is subject to cracking or rupturing. Too rapid or too severe a reduction of section can also cause bursts or cracks. Such ruptures may be internal bursts, or they may be cracks at the surface. Cracks at the surface are readily found by magnetic particle testing. If interior, they are usually not shown except when they have been exposed by machining (Figure 3-55).

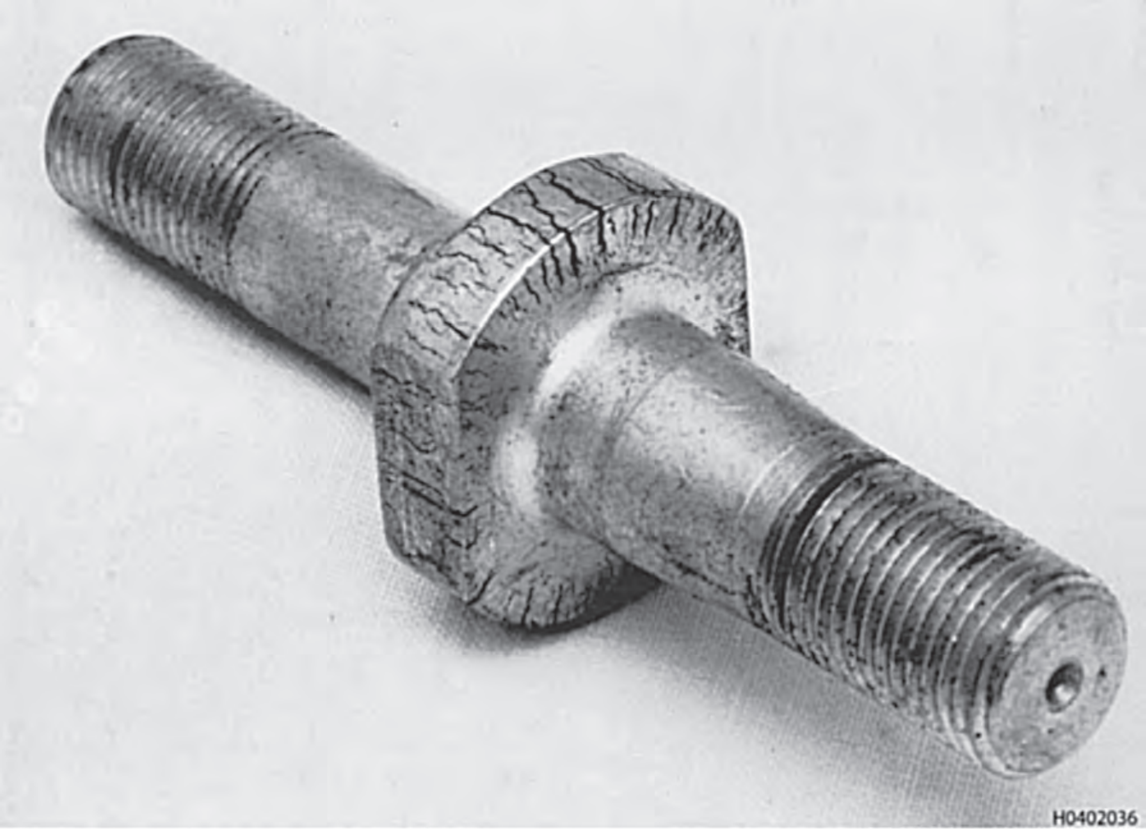


Figure 3-55. Magnetic Particle Indications of Forging Cracks or Bursts in an Upset Section, Severe Case

3.5.4.1.2.7 Forging Laps. As the name implies, forging laps or folds are formed when, in the forging operation, improper handling of the blank in the die causes the metal to flow so as to form a lap, which is later squeezed tight. Since it is on the surface and is oxidized, this lap does not weld shut. This type of discontinuity is sometimes difficult to locate because it may be open at the surface and fairly shallow, and often may lie at only a very slight angle to the surface. In some unusual cases, it also may be solidly filled with magnetic oxides (Figure 3-56) and (Figure 3-57).

Figure 3-56. Surface of a Steel Billet Showing a Lap

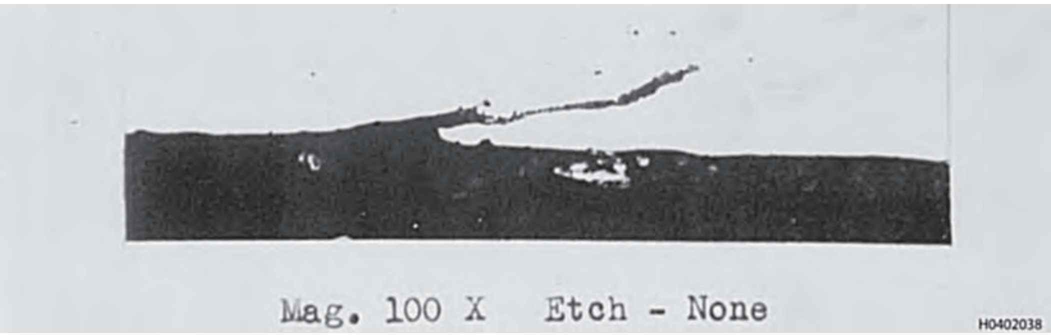


Figure 3-57. Cross Section of a Forging Lap (Magnified 100X)

3.5.4.1.2.8 Burning. Overheating of forgings to the point of incipient melting, which results in a condition that renders the forging unusable, in most cases is referred to as burning. However, the real source of the damage is not oxidation, but the material becoming partially liquefied due to the heat at the grain boundaries. Burning is a serious defect, but is not generally shown by magnetic particle testing.

3.5.4.1.2.9 Flash-Line Tears. Cracks or tears along the flash line of forgings are usually caused by improper trimming of the flash. If shallow, they may "clean up" during machining, otherwise they are considered defects. Such cracks or tears can easily be found by magnetic particles (Figure 3-58).

Figure 3-58. Magnetic Particle Indication of Flash Line Tear in a Partially Machined Automotive Spindle Forging

3.5.4.1.2.10 Casting Defects. Steel and iron castings are subject to a number of defects which magnetic particle testing can easily detect. Surface discontinuities are formed in castings due to stresses resulting from cooling and are often associated with changes in the cross section of the part. These may be hot tears or they may be shrinkage cracks that occur as the metal cools down. Sand from the mold can be trapped by the hot metal and form sand inclusions on or near the surface of castings. Gray iron castings may be quite brittle, and can be cracked by rough handling (Figure 3-59).

Figure 3-59. Magnetic Particle Indications of Defects in Castings

3.5.4.1.2.11 Weld Defects. A variety of discontinuities may be formed during welding. Some are at the surface and some are in the interior of the weldment. Some of the defects peculiar to weldments are lack of penetration, lack of fusion, undercutting, cracks in the weld metal, crater cracks, cracks in the heat affected zone, etc.

3.5.4.1.3 Secondary Processing or Finishing Discontinuities. In this group are those discontinuities associated with the various finishing operations after the part has been rough-formed by rolling, forging, casting, or welding. Discontinuities may be introduced by machining, heat treating, grinding, and similar processes. These are described below:

3.5.4.1.3.1 Machining Tears. These are caused by dragging of the metal under the tool when it is not cutting cleanly. Soft and ductile low carbon steels are more susceptible to this kind of damage than are the harder, higher carbon or alloy types. Machining tears are surface discontinuities and are readily found with magnetic particles.

3.5.4.1.3.2 Heat Treat Cracks. When steels are heated and quenched to produce desired properties for strength or wear, cracking may occur if the operation is not correctly suited to the material and shape of the part (Figure 3-60). Most common are quench cracks, caused when parts are heated to high temperatures and then suddenly cooled by immersing them in some cool medium, which may be water, oil, or even air. Such cracks often occur at locations where the part changes cross section or at fillets or notches in the part. The edges of keyways and the roots of splines or threads are likely spots for quench cracks to occur. Cracks may also result from too rapidly heating the part, which may cause uneven expansion at changes of cross section or at corners where heat is absorbed more rapidly than in the body of the piece. Corner cracking may also occur during quenching, because of more rapid heat loss at such locations. Heat treat cycles can be designed to minimize or eliminate such cracking; but for critical parts, testing with magnetic particle is a safety measure usually applied, since such cracks are serious and easily detectable.

Figure 3-60. Magnetic Particle Indications of Quenching Cracks Shown With Dry Powder

3.5.4.1.3.3 Straightening Cracks. The process of heat treating often causes some warping of the part due to non-uniform cooling during quenching. A hardened shaft, for example, may come from the heat treat operation not quite straight. In many cases, these can be straightened in a press, but if the amount of bend required is too great or if the shaft is too brittle, cracks may be formed. Again, these are very readily found with magnetic particles.

3.5.4.1.3.4 Grinding Cracks. Surface cracking of hardened parts as the result of improper grinding is frequently a source of trouble. Grinding cracks are essentially thermal cracks. They are caused by stresses set up by local heating under the grinding wheel. They are avoidable by using proper wheels, cuts, and coolants. They are sharp surface cracks and they are easily detected with magnetic particle inspection. Such surfaces usually crack severely and extensively, as illustrated in (Figure 3-61) and (Figure 3-62).

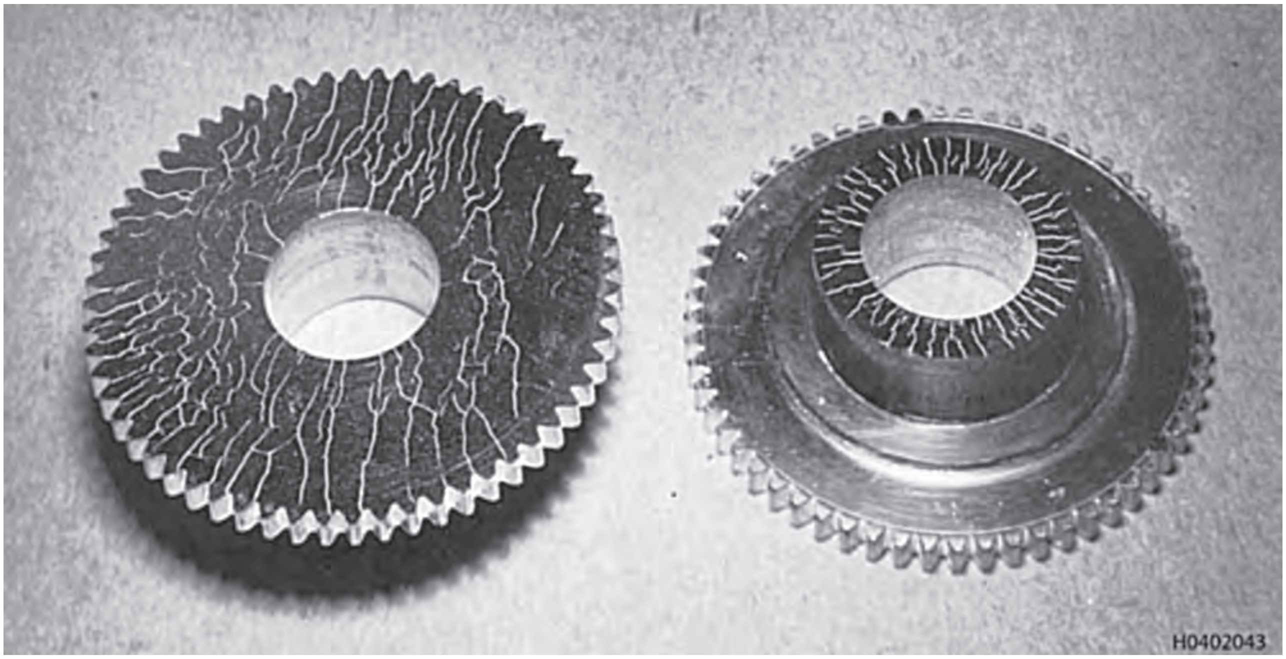


Figure 3-61. Fluorescent Magnetic Particle Indications of Typical Grinding Cracks

Figure 3-62. Magnetic Particle Indications of Grinding Cracks in a Stress-Sensitive, Hardened Surface

3.5.4.1.3.5 Etching and Pickling Cracks. Hardened or cold worked parts, that contain high internal and external residual stresses, may crack if they are pickled or etched in acid. Acid attack of the surface layers of the metal gives the internal stress a chance to be relieved by the formation of a crack. Before this action was fully understood, the heat treatment of the part was often blamed for the cracking. The heat treat operation did, however, deserve some of the blame by leaving the part with high residual stresses.

3.5.4.1.3.6 Plating Cracks. Plating can introduce high residual stresses at the plated surface and thus create the potential for cracking. The hot galvanizing process itself may also produce cracks in surfaces containing residual stresses by the penetration of hot zinc into the grain boundaries. Copper penetration during brazing may result in similar cracking if the parts contain residual stress (Figure 3-63).

Figure 3-63. Magnetic Particle Indications of Plating Cracks

3.5.4.2 Service Cracks.

CAUTION

> When performing magnetic particle inspection on landing gear parts, the paint SHALL be removed. Some landing gear components are vulnerable to stress-corrosion cracking and are cadmium plated for their protection. Thus, the primer layer MAY remain on the part. Damage to the cadmium plating SHALL be avoided.

The fourth major classification of discontinuities comprises those formed or produced after all fabrication has been completed and the part has gone into service. The objective of magnetic particle testing to locate and eliminate discontinuities during fabrication is to put the part into service free from defects. However, even when this is accomplished, failures in service still occur as a result of cracking caused by service conditions.

3.5.4.2.1 Fatigue Cracks. Fatigue stress will eventually cause cracks, and finally fracture. Fatigue cracks, even very shallow ones, can readily be found with magnetic particles (Figure 3-64) and (Figure 3-65).

Figure 3-64. Magnetic Particle Indication of a Typical Fatigue Crack

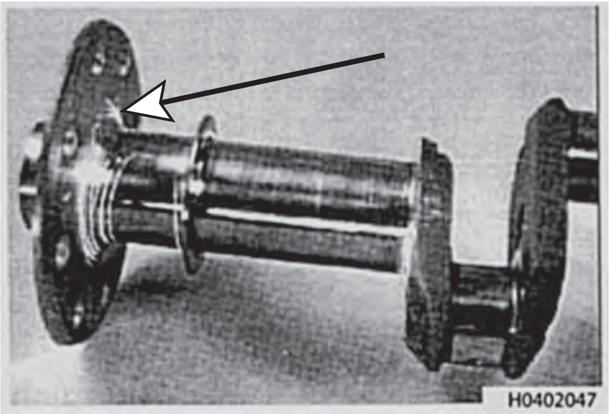


Figure 3-65. Fluorescent Magnetic Particle Indications of Cracks in Crankshaft of Small Aircraft Engine Damaged in Plane Accident

3.5.4.2.2 Stress-Corrosion Cracks. Parts under either residual or applied tensile stress and exposed to a corrosive environment may develop stress-corrosion cracking. The primary role of corrosion in this cracking mode is to produce hydrogen. The hydrogen migrates to the tip of a stress-corrosion crack where its presence increases the stresses at the tip, thus driving the crack even deeper. When corrosion is added to a fatigue-producing service condition, this type of service failure is called corrosion fatigue.

3.5.4.2.3 Overstressing. Parts stressed beyond the level for which they were designed can crack or break. Such overstressing may occur as the result of an accident, a part may become overloaded due to some unusual or emergency condition not anticipated by the designer, or a part may be loaded beyond its strength because of the failure of some related member of the structure. After complete failure has occurred, magnetic particle testing obviously has no application with regard to the fractured part. However, other parts of the assembly, that may appear undamaged, could have been overstressed during the accident or overloaded from other causes. Examination by magnetic particle testing is usually carried out in such cases to determine whether any cracks have actually formed.

3.5.4.3 Other Sources of Discontinuities. In this section, an attempt has been made to familiarize the reader with most of the common sources of discontinuities that can occur in iron and steel. Actually, the list given here is incomplete, but the inspector working with magnetic particle testing will encounter these discontinuities more frequently than those from less common conditions. The inspector will often have the metallurgical laboratory of a support organization available for consultation, and the metallurgist will usually be able to assign a cause to an indicated discontinuity and assess its importance.

3.5.5 Non-Relevant Indications.

3.5.5.1 Nature and Type.

NOTE

It is easier to distinguish between relevant and non-relevant indications when using fluorescent rather than visible magnetic particles.

It is possible to magnetize parts of certain shapes in such a way that magnetic leakage fields are created even though there is no discontinuity in the metal at that point. Such indications are sometimes called erroneous indications or false indications. They should be called "non-relevant indications" since they are actually caused by distortion of the magnetic field. They are true indications, but since there is no unintentional interruption of the material, they do not affect the usefulness of the part. It is important for the inspector to know how and why these non-relevant indications are formed and where they can occur.

3.5.5.2 Classes of Non-Relevant Indications.

3.5.5.2.1 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. In (Figure 3-66) the part in the top view is magnetized with a circular field. If another part made of magnetic material is rubbed against or comes into contact with the magnetized part, as in the second view, a weak field will be induced into the smaller part. After the smaller part has been removed, the circular field in the original part will be altered or distorted to some extent, as shown in the bottom view. Since there is no force to change the direction of the altered field, there will be some leakage at the point of distortion that will attract magnetic particles.

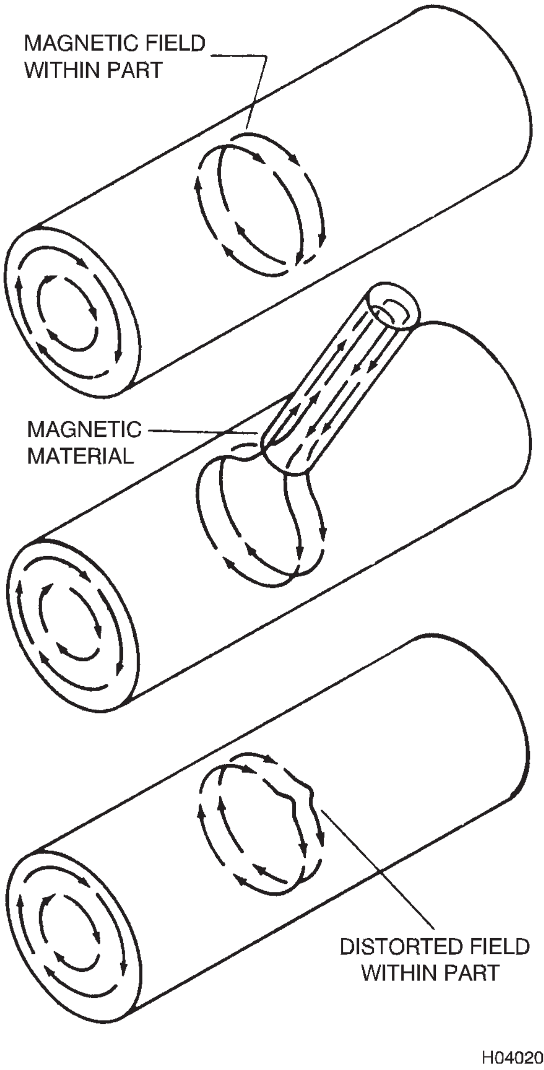


Figure 3-66. Creation of Magnetic Writing

3.5.5.2.2 Longitudinal Magnetization. When a part is longitudinally magnetized in a coil, there are always magnetic poles at the ends of the piece. Magnetic material such as chips, magnetic powder, or paste will be attracted to these poles. The same situation occurs when a yoke is used to create a magnetic field; poles are induced on the part in the areas where the yoke touches the part.

3.5.5.2.3 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 by a carpenter with a hammer, the nail is being cold worked. Cold working usually causes a change in the permeability of the metal where the change in size or shape occurs. The boundary of the area of changed permeability may attract magnetic particles when the part is magnetized.

3.5.5.2.4 Hard or Soft Spots. If there are areas of a part which have a different degree of hardness than the remainder of the part, these areas will usually have a different permeability. When a part with such areas of different permeability is inspected with magnetic particle inspection, the boundaries of the areas may create local leakage fields and attract magnetic particles to form indications.

3.5.5.2.5 High Temperature Exposure.

3.5.5.2.5.1 Boundaries of Heat Treated Sections. Heat treating a part consists of heating it to a high temperature and then cooling it under controlled conditions. The cooling may be relatively rapid or it may be done to decrease the hardness or the grain size of the metal 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 it won't shatter and break. The edge of the hardened zone frequently creates a leakage field when the chisel is inspected with magnetic particle inspection.

3.5.5.2.5.2 Delta Ferrite.

NOTE

> Delta Ferrite is brittle and has historically been considered a defect in applications such as aircraft exposed to tensile and cyclic loading. While the presence of delta ferrite does not indicate an actual defect, such a region would be a preferential crack initiation area.

Delta Ferrite is a ferromagnetic phase of steel that occurs at elevated temperatures. This phase primarily occurs at normal temperatures because of rapid cooling after prolonged exposure to high temperatures. A concentrated region of delta ferrite may cause non-relevant indications along the region's boundary due to the magnetic disturbance caused by its presence.

3.5.5.2.6 Abrupt Changes of Section. Where there are abrupt changes in section (e.g., 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 a part, as shown in (Figure 3-67), is magnetized in a coil, poles are setup at each end and some leakage occurs at A and B. Also, the change of section at C is quite abrupt and there may be a leakage across this corner as shown. These leakage fields will attract magnetic particles, thereby creating an indication. The indications formed at A and B are usually very easily interpreted; that at C may be more difficult to recognize as being non-relevant. If the indication is continuous around the shaft, it should be suspected as being caused by the shape of the part rather than by a discontinuity. The non-relevant indication at C will usually be "fuzzy" like an indication, which is produced by a defect beneath the surface. If there is a crack or discontinuity in that area, it will usually produce a sharper indication and it probably will not run completely around the part.

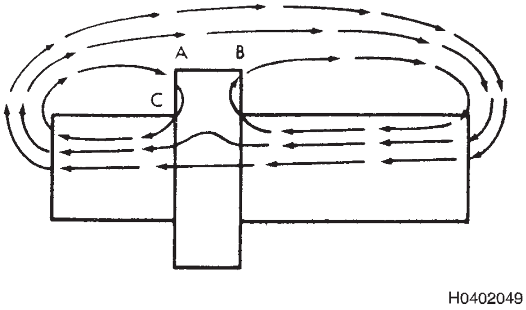


Figure 3-67. Local Poles Created by Shape of Part

3.5.5.2.6.1 On parts with keyways, a circular magnetic field can also setup non-relevant indications as in (Figure 3-68). Particle accumulations may occur at A where there are leakage fields. A keyway on the inside of a hollow shaft may also create indications on the outside, as indicated at area B in (Figure 3-69).

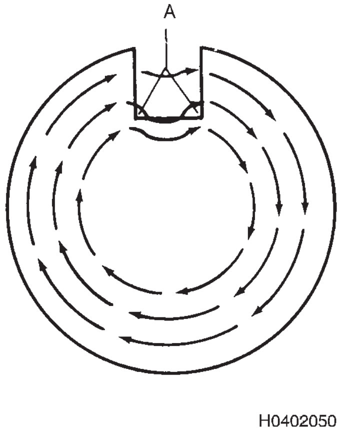


Figure 3-68. Concentration of Field in a Keyway

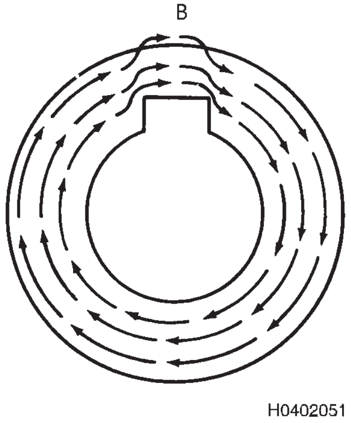


Figure 3-69. External Leakage Field Created by an Internal Keyway

3.5.5.2.6.2 The gear and spline shown in (Figure 3-70) were magnetized circularly by passing current through a central conductor. The reduced cross section created by the spline ways constricts the magnetic lines of force and some of them break the surface on the outside diameter. Particles gather where the magnetic lines of force break through the surface, thereby creating indications. A non-relevant indication is shown (Figure 3-71) on the underside of a bolt head. The slot in the head causes the indication here.

Figure 3-70. Non-Relevant Indications of Shaft Caused by Internal Spline

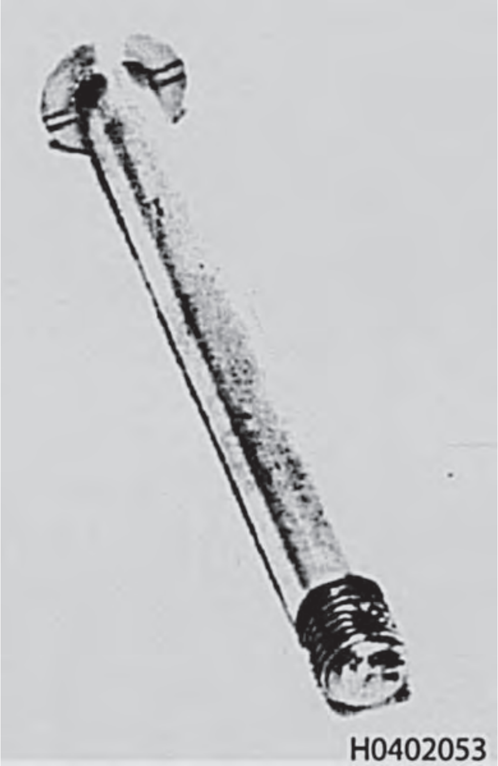


Figure 3-71. Non-Relevant Indications Under the Head Created by Slot in Bolt

3.5.6 Interpretation and Elimination of Non-Relevant Indications.

3.5.6.1 Interpretation. It may first appear to the inspector that some types of non-relevant indications discussed and illustrated in the preceding material would be difficult to recognize and interpret. For example, the non-relevant indications shown in (Figure 3-70) and (Figure 3-71) may look like indications of subsurface discontinuities. However, there are several characteristics of non-relevant indications that will enable the inspector to recognize them in the example cited and under most other conditions. These characteristics of non-relevant indications are:

- On all similar parts, given the same magnetizing technique, the indications will occur in the same location and will have identical patterns. This condition is not usually encountered when dealing with real subsurface defects.
- The indications are usually uniform in direction and size.
- The indications are usually ‘fuzzy‘ rather than sharp and well defined.
- Non-relevant indications can always be related to some feature of construction or cross section, which accounts for the leakage field creating the indication.

3.5.6.2 Elimination of Non-Relevant Indications. Although non-relevant indications can be recognized in most cases, they do tend to increase the inspection time, and under certain conditions may mask or cover up indications of actual defects. Therefore, it is desirable to eliminate them whenever possible.

3.5.6.2.1 In most cases, non-relevant indications occur when the magnetizing current is higher than necessary for a given part. Consequently, these indications will disappear if the part is demagnetized and reinspected using a sufficiently low magnetizing current. Under most conditions, the value of magnetizing current that is low enough to eliminate non-relevant indications will still be sufficient to produce indications at actual discontinuities. This will be true where the non-relevant indication is magnetic writing, and for several other types, but may not hold where there are abrupt changes of section. It is therefore desirable to determine whether the non-relevant indication was caused by an abrupt change of section before re-inspecting.

3.5.6.2.2 The proper procedure is to demagnetize and reinspect the part using a lower value of magnetizing current, repeating the operation with still lower current if necessary until the non-relevant indications disappear. Care SHALL be taken not to reduce the current below the value required to produce indications of all actual discontinuities. Where there are abrupt changes of section, two inspections may be required:

a. Conduct the first inspection at fairly low amperage, in order to inspect only the areas at the change in section.

b. Conduct the second inspection at a higher current value, in order to inspect the remainder of the part.

Another solution is to use AC magnetization for inspection. AC magnetization responds less to changes in cross section than DC magnetization and is acceptable when it is not necessary to inspect for subsurface defects.

3.5.7 Methods of Recording MPI Indications.

3.5.7.1 General. The full value of magnetic particle inspection can be realized only if records are kept of parts inspected and the indications found. As with any inspection, the size and shape of the indication and its location on the part should be recorded along with other pertinent information such as rework performed or disposition. The inclusion of some visible record of the indications on a report makes the report much more complete.

3.5.7.2 Type of Records. The simplest record is a sketch of the part showing location and extent of the indications. On large parts, it may be sufficient to sketch only the critical area. Other types of records include preserving the actual indication on the part (where the part is to be kept for reference), transferring the indication from the part to a record sheet or report, and photographing the indication. These last three methods will be discussed in this section.

3.5.7.3 Preserving Indications on a Part.

3.5.7.3.1 Fixing Indications with Lacquer. One of the advantages of magnetic particle inspection is the indication is formed directly on the part at the exact spot of the magnetic leakage field. This makes it possible to retain the part itself for record purposes, but it is necessary to fix or preserve the indication on the part; so the part can be handled and examined without smudging or smearing the indication. One method of fixing the indication semi-permanently on the part is by using clear lacquer. The part SHALL be dry to do this; if the wet method has been used to develop the indication, the vehicle

SHOULD be allowed to evaporate. Normal evaporation can be accelerated by heating the part and is usually sufficient for water; it is also possible to flow on isopropyl alcohol or other solvent that will evaporate rapidly and leave the indication dry on the part. For an oil vehicle, use of a solvent is almost necessary to provide a dry indication in a reasonable time. It is usually desirable to thin out the clear lacquer by adding lacquer thinner. The lacquer should either be sprayed on the part or flowed on since brushing would smear the indication.

3.5.7.3.2 Applying Transparent Tape. It is also possible to preserve an indication on a part by covering it with transparent pressure sensitive tape (such as Scotch brand). This method is not as neat looking as the lacquer method, but it is easier to apply. Before applying the tape, the vehicle used in the wet method SHOULD be removed in the same manner as when using lacquer.

3.5.7.4 Tape Transfers. An accurate record of an indication can be obtained by lifting the particles forming the indication from the part with transparent pressure sensitive tape (such as Scotch brand), and then placing the tape on stiff white paper. The procedure for taking tape transfers is simple and can be accomplished quickly and accurately with a little practice. If a report is being made and it is necessary to duplicate the indication, mount the tape transfer on a sheet of clear plastic and use a standard duplicating process or prepare a photographic negative and contact print. When tape transfers are taken of indications, it is customary to sketch the part and locate the position of the preserved indication on the sketch.

3.5.7.4.1 Dry Particle Tape Transfers. If the indication is formed of dry powder particles, excess powder can be removed from the surface by gently blowing. Use a piece of tape larger than the indication and gently cover the indication with the tape. Gentle pressure should be applied so the adhesive will pick up the particles; do not press too hard or the indication will be flattened too much and the tape may be difficult to remove. Carefully lift the tape from the part and press it onto the record sheet or report. It is easier to remove the tape if a corner of it is not pressed to the part. Leaving a tab for easy removal.

NOTE

Tape preserved indications are usually a little broader than indications on the part because of the flattening effect of the tape.

3.5.7.4.2 Wet Particle Tape Transfers. If the indication is formed of particles used with the wet method, it is necessary to dry the surface of the part prior to applying the tape as described in (paragraph 3.5.7.4.1).

3.5.7.4.3 Fluorescent Tape Transfers. Tape transfers can be taken of fluorescent particle indications, but there are some disadvantages to the process. Such preserved indications usually must be viewed under UV-A to properly interpret them since the number of particles in the suspension is much less than when using visible particles. Some transparent tape is fluorescent and the fluorescence of the tape may mask the fluorescence of the indication.

3.5.7.5 Alginate Impression Compound Method. The alginate impression compound method of "lifting" magnetic particle indications is a method of securing indications in areas inaccessible and that cannot be viewed with a UV-A lamp.

3.5.7.5.1 Alginates are hydrocolloid polysaccharides derived from seaweed kelp. Compounds such as those used for making dental impressions are based on mixtures of potassium alginate, calcium sulfate, sequestering agents such as sodium phosphate, and fillers such as silica, diatomaceous earth, or calcium carbonate. When the compound is mixed with the correct amount of water it forms a soft paste that sets up to a rubbery solid in three to four minutes. This rubbery material or gel has the property of accurately conforming to and taking an impression of the surface to which it is applied, and also absorbing or lifting traces of particulate material from the surface. This latter property is the basis for its use as an indication lifting material.

3.5.7.5.2 Transferring Indications with Alginate Impression Compound.

a. Perform the magnetic particle inspection of the area of interest in the usual manner.

b. The part does not have to be dried before taking an impression.

c. Using the plastic scoop and water measuring container, follow the directions given on the can of powder and mix the powder with water to obtain a smooth creamy paste.

d. Transfer the paste immediately to a piece of thin polyethylene film, and then apply the paste to the inspecting area. Gently press against the film to obtain a uniform contact of the paste against the inspection area. Avoid excessive working of the paste to avoid smearing of the indication. The plastic film prevents the paste from sticking to the hand. For cavities such as holes, the paste can be applied without the polyethylene film to form a plug when set.

e. After the paste has set to a rubbery gel, in about 3 - 4 minutes, gently remove the replica from the metal part and examine under ultraviolet light. The replica may be photographed with ultraviolet light if desired.

3.5.7.6 Photographing Indications. Photographs may also be taken of indications to produce records. Enough of the part should be shown to make it possible to recognize the part and the position of the indication. It is helpful to include in the picture some common object to show the size of the part. Sometimes this can be done with a finger pointing at the indication or by placing a ruler along the part to show relative size. In photographing indications on highly polished parts, care SHALL be taken to avoid highlights or reflections that may hide indications. Taking photographs of fluorescent indications calls for special photographic techniques referenced in the penetrant chapter, (paragraph 2.5.6.6), for additional information.

SECTION VI PROCESS CONTROL OF MAGNETIC PARTICLE INSPECTION

3.6 MAGNETIC PARTICLE PROCESS CONTROL.

3.6.1 Purpose and Scope. This section provides information necessary to ensure a high quality performance for the magnetic particle inspection system. This section discusses the reasons for process control, the use of the Quantitative Quality Indicators to confirm the adequacy of the magnetic field, and the various equipment and material control requirements. Specific procedures to accomplish process control of Magnetic Particle systems is published in TO 33B-1-2, WP 103 00.

3.6.2 General.

3.6.2.1 Need for Process Control. The presence of magnetic particle indications confirms the existence of discontinuities in the part. However, the absence of indications does not guarantee the absence of discontinuities. Flaws can be present and not be indicated for a number of reasons. Process controls exist to verify the performance of equipment, materials and the inspector. Inspector errors and poorly written procedures are the most common process deficiencies. Any of these deficiencies may occur without being evident during inspection of a part. It is necessary, therefore, to periodically examine the materials, equipment, and process parameters to be sure they are as required for adequate inspection results.

3.6.2.2 New Materials. Magnetic particle materials are subjected to testing during their formulation to ensure their proper composition. However, it is possible to receive materials which do not perform satisfactorily. If unsatisfactory material performance is not discovered until a number of parts have been processed, then extra time and expense is required to track down and reinspect each of the suspect parts, if it is not too late. Unsatisfactory materials can result from a number of causes. The cost of verifying adequate material performance is extremely low and the required tests can be performed at any field laboratory.

3.6.2.3 In-Use Materials. Some inspection processes use the magnetic particle materials only once. In these processes, spraying or dusting is usually the means used to apply the materials. The materials are stored in closed containers until they are used. These processes minimize the possibility of material contamination or degradation during use. More often, however, the materials are used in open tanks where the excess materials are allowed to drain from the part back into the tank. This method provides numerous opportunities for contamination, deterioration, and changes in concentration. Such materials SHALL be checked periodically to be sure they are functioning satisfactorily.

3.6.3 Causes of System Degradation.

3.6.3.1 Contamination. Contamination is a primary source of magnetic particle bath performance degradation. There are a number of contaminants, and their effects on performance can vary. Some of the common contaminants frequently encountered are:

3.6.3.1.1 Water is a common contaminant in petroleum-based baths. It may occur due to condensation, leaks, dripping overhead pipes, or moisture carryover on parts.

3.6.3.1.2 Organics such as paint, lubricants, oils, greases, and sealants are other sources of contamination. These materials are usually introduced into the magnetic particle bath on the parts being inspected, and can react with, or dilute a bath so it loses some or all of its ability to function.

3.6.3.1.3 Organic solvents such as degreaser fluid, cleaning solvent, gasoline, and antifreeze solution, are also potential contaminants. These materials can mix with the inspection bath or float on top of it reducing the bath’s effectiveness.

3.6.3.1.4 Dirt, soil, and other insoluble solids can be carried into the magnetic particle bath as a result of inadequate precleaning.

3.6.3.1.5 Acidic and alkaline solutions can contaminate the magnetic particle baths. Acidic and alkaline solutions can be residues of previous plating, paint stripping, and cleaning processes.

3.6.3.2 Evaporation Losses. Magnetic particle bath suspension/vehicle materials used in open tanks are continuously undergoing evaporation, resulting in an increase in particle concentration. The rate of evaporation increases with warmer temperatures and larger tank surfaces. Evaporation losses take place very gradually, so performance change may become significant before it is noticed.

3.6.3.3 Drag-Out. Particle concentration is reduced when particles adhere to parts being inspected and are not returned to the suspension. Like evaporation, the resulting change occurs slowly and would probably go unnoticed until significant performance loss is experienced.

3.6.3.4 Heat Degradation. Fluorescent dyes are sensitive to elevated temperatures. Temperatures of over 140° F (60° C) may reduce the fluorescence, and temperatures over 250°F (121°C), may destroy it completely. High temperatures in magnetic particle inspection materials usually occur when materials are improperly stored. For instances, a dark colored container stored in direct sunlight can reach temperatures above 140°F (60°C).

NOTE

Care SHALL be exercised when storing materials containing fluorescent dyestuffs. They SHALL be stored out of direct sunlight, in a cool dry location (40-80°F) (4-27°C).

3.6.3.5 Equipment Degradation. Similar to materials degradation, the performance of the equipment can also decline due to frequent use. The magnetizing equipment can lose power, while UV-A bulbs and LEDs age and become dirty.

3.6.3.6 Process Degradation. Critical procedural steps may be performed incorrectly or omitted completely. Periodic checks SHALL be accomplished to ensure satisfactory performance.

3.6.4 Frequency of Process Control. One of the factors influencing the degradation of a magnetic particle system (i.e., materials, equipment, and procedures) is the volume of parts being processed. Bath and equipment deficiencies can be expected to occur more often with increased workload volume. Since there is no uniformity in workload between activities, a single calendar schedule cannot be established. Each inspection activity SHALL set inspection intervals based on their workloads. Maximum inspection intervals are listed in TO 33B-1-2 WP 103 00 and SHALL be documented as shown in paragraph 1.5.5. (Navy activities MAY use a locally produced form.)

3.6.5 Evaluating the Magnetic Particle Process. It may be easier to complete these process control checks if we break them down into categories of equipment evaluations (meaning all equipment and area checks) and materials evaluation (meaning the suspension vehicle and all associated parts). Though some of these tests intertwine, we will first look at the equipment and then move on to the materials.

3.6.6 Evaluating Equipment Effectiveness.

3.6.6.1 General. Magnetic particle equipment SHALL be maintained according to applicable technical orders, commercial manuals, or Navy Maintenance Requirements Cards (MRCs). Specific procedures on how to perform all required checks are published in TO 33B-1-2 WP 103 00.

3.6.6.2 Equipment Tests. Intervals for process control checks are established in TO 33B-1-2 WP 103 00. There are various equipment tests designed to ensure MPI process meets acceptable operating standards. The minimum equipment tests which SHALL be accomplished to ensure the magnetic particle inspection process meets acceptable operating standards are as follows:

- System Effectiveness Check.
- Amperage Indicator Check.
- Quick Break Test.
- Dead Weight Check.
- Field Indicator Check.
- Lighting Checks.
- Inspection Area Cleanliness.

3.6.6.3 Evaluating Applied Magnetic Field Effectiveness.

3.6.6.3.1 Quantitative Quality Indicators (QQI). QQIs (paragraph 3.4.5.2.1) also called shims are used to evaluate the applied magnetic field and to perform system effectiveness checks. They are also a very useful tool for technique development.

NOTE

The QQI was designed to be used with the continuous method and the indications may disappear when the applied field is removed. Also, the QQI will not indicate background. The actual part SHALL be examined to determine the amount of background present.

3.6.6.3.2 Using the QQI.

WARNING

Cleaning solvent, A-A-59281, is flammable that also is harmful to the skin, eyes, and respiratory tract. To prevent injury, rubber gloves and goggles SHALL be used. Use in a well-ventilated area.

CAUTION

Exercise care when using QQIs on curved surfaces. Excessive bending will damage a QQI beyond use. Usually the thinner QQI will be used on curved surfaces; however they are fragile. The thicker QQI is less fragile, but can still be damaged by excessive bending.

NOTE

If the QQI is placed in an area where an actual crack may be present then a second magnetic particle or magnetic rubber inspection SHALL be performed without the use of QQIs.

The area where the QQI is to be placed SHALL be thoroughly cleaned and dried. Use cleaning solvent, A-A-59281. Place the appropriate QQI in place with the slot side against the surface of the part. In general, the 30-percent deep slot is adequate for most defects. Critical inspections may require the 15-percent deep slot and rough castings or weldments may require the 60-percent deep slot.

3.6.6.4 System Effectiveness Check.

3.6.6.4.1 Ketos/AS5282 Ring. The Ketos/AS5282 ring can be used to evaluate system effectiveness. While it is a useful tool, it has definite limitations and should not be the only system effectiveness method used. (e.g., Shortcomings include its limitation to central bar conductor DC and/or 3-phase AC units only.) There are two types of rings: Ketos and AS5282 certified rings. The AS5282 rings are certified by the manufacturer as conforming to SAE specification AS5282 and responds with more indications at given amperages than the traditional Ketos ring. Using Ketos ring amperages and requirements on an AS5282 ring may result in false system performance readings. Technicians must know what type of ring they have and work accordingly. AS5282 rings come from the manufacturer with a certificate, the manufacturer's name, serial number and ''AS5282'' marked directly on the ring. Even under optimum system conditions, there are cases where Ketos and AS5282 rings do not respond with the specified numbers of indications. Rings SHALL be baseline tested and the indications observed during baseline testing SHALL be documented and appear each time the system effectiveness test is conducted.

NOTE

Ketos/AS5282 rings that are plated or corroded SHALL NOT be used. Corrosion and plating can cause false readings (superficial cleaning of mild surface corrosion with scotchbrite pad manually is authorized).

3.6.6.4.2 Quantitative Quality Indicators (QQI). Test specimen(s) used with QQIs offer a versatile means of checking system performance in addition to the Ketos/AS5282 ring. The specimens can be real parts or designed to be representative of the most challenging inspection currently being performed. This combination is capable of providing an adequate check on any magnetic particle inspection system. Poor indications may require further process control evaluations to be performed (e.g., amp indicator check, concentration check, etc.). Even though QQIs respond to the applied magnetized force, not residual field, demagnetization is necessary of the specimen(s) in order to remove the previously applied inspection media.

3.6.6.4.3 Cracked Parts.

NOTE

(Air Force Only) The Ketos/AS5282 rings SHALL be the only tools approved to evaluate system effectiveness. Other devices such as cracked parts and QQIs may be used in addition to the Ketos/AS5282 ring to check system effectiveness

When available, cracked parts containing defects that are representative of the flaws that need to be detected may be used in addition to the Ketos/AS5282 ring to check system effectiveness. These reference parts must be examined in accordance with a written procedure and require careful handling to remain corrosion-free and retain their flaw size.

3.6.6.5 Amperage Indicator Check.

NOTE

The amperage indicator accuracy check SHALL be performed using a calibrated ammeter/shunt capable of: reading up to 12,000 amps in AC, HWDC and FWDC. The ammeter/shunt SHALL be calibrated as prescribed in TO 33K-1-100-CD-1. (Navy:) Amperage indicator accuracy check SHALL be performed using a calibrated shunt meter, P/N 10090 or equivalent. The shunt meter SHALL be calibrated as prescribed in the naval maintenance procedures.

3.6.6.6 Quick Break Test. A test SHALL be accomplished to ensure the presence of an accurate decay rate, which is sufficient for quick break magnetization. A quick break tester is authorized in AS-455 Operation for the quick break tester SHALL be accomplished according to the commercial manufacturer's operating instructions or TO 33B-1-2, WP103 00 if commercial manual is unavailable. Test failure SHALL necessitate locating the source of the failure and taking corrective action. (Navy:) A test SHALL be accomplished to ensure the presence of an accurate decay rate, which is sufficient for quick break magnetization. A quick break tester, P/N QBT-A or equivalent, shall be used for testing. Operation for the quick break tester SHALL be accomplished according to the commercial manufacturer's operating instructions. Test failure SHALL necessitate locating the source of the failure and taking corrective action.

3.6.6.7 Dead Weight Check. This test SHALL be conducted on portable induced field equipment (e.g., Parker Probes, magnetic yokes) IAW TO 33B-1-2 WP 103 00.

3.6.6.8 Lighting Checks. For additional information on UV-A and ambient light checks (see paragraph 2.5.4.1.3).

3.6.6.8.1 Black Lights.

a. Check the intensity of new UV-A bulbs and LEDs.

b. Check the intensity of in-use UV-A bulbs and LEDs.

c. Check the physical condition of the housing and filter. Housings and filters SHALL be kept clean, free of cracks or chips, and fit properly.

3.6.6.8.2 Ambient Light Requirements. Inspection booths of a stationary fluorescent magnetic particle system SHALL NOT exceed 2 foot-candles of ambient light. During portable inspections ambient light should be reduced as much as practical. However, it is not always possible to achieve ambient light levels as low as 2 foot-candles. When 2 foot-candles cannot be attained, increasing the UV-A intensity can partially compensate.

3.6.6.8.2.1 Measurement of Visible Light Intensity. Visible light intensity is easily measured with solid-state photometers. Measurements of visible light are keyed to the response of the visual system of a standard human observer. The unit of measure for visible light is the lumen. The lumen represents the amount of energy in the visible light spectrum specifically distributed to the response of the average human eye. Therefore, the lumen is actually the energy flux (energy per unit of time). The units of measurement for visible light intensity are foot-candles, where one foot-candle equals one lumen per-square-foot. Another term often used is lux, which equals one lumen per-square-meter. The conversion between the two terms is 1- foot candle equals 10.76 lux.

3.6.6.8.2.2 Excessive White Light. Some UV-A lamps may have excessive white light output due to construction, damage, and/or reflector used. Cumulative ambient light from the fully darkened booth, including white light emitted by the UV-A lamps SHALL not exceed 2 foot-candles. All UV-A lamps (portable and stationary) and inspection booths SHALL be checked in accordance with TO 33B-1-2 WP 103 00 for white light output and ambient light.

3.6.6.8.3 Dark Adaptation. The human eye becomes much more sensitive to light under dark conditions. This increased sensitivity gradually occurs when the light conditions change from light to dark. When entering a darkened area from a lighted area, the pupil of the eye must widen to admit additional light. The time required for the eye to adjust to the darkened condition depends upon the overall health and age of the individual. Full sensitivity or dark adaptation requires about 20-minutes. A minimum dark adaptation time of 5-minutes is usually sufficient to perform magnetic particle inspection under UV-A. Thus, an inspector entering a darkened area SHALL allow at least 5-minutes for dark adaptation before examining parts under UV-A illumination. Once the eyes have adapted to the dark, the pupils will respond very rapidly to bright light. A very short bright light exposure cancels the slowly acquired dark adaptation. Time for dark adaptation SHALL be allowed whenever an inspector enters the darkened booth, or is exposed to a bright light (e.g., someone opening or raising the shade). A timer capable of measuring the dark adaptation time SHALL be available within the darkened area.

3.6.6.9 Inspection Area Cleanliness. The inspection area, as well as, the hands and clothing of the inspector, SHOULD be clean and free of extraneous fluorescent materials. Non-relevant indications may be formed when parts contact extraneous fluorescent materials. In addition, the fluorescence from this material will raise the ambient light level, thus increasing the amount of UV-A necessary to produce a visible indication of a small defect.

3.6.7 Evaluating Material Effectiveness.

3.6.7.1 General. Magnetic particle materials SHALL be maintained according to applicable technical orders, commercial manuals, or Navy Maintenance Requirements Cards (MRCs).

3.6.7.2 Applicability. Material tests apply to both newly received and in-use materials. They are designed to ensure unsatisfactory materials do not enter the magnetic particle inspection process, and in-use materials continue to perform satisfactorily.

NOTE

Prior to bath replacement in a magnetic particle inspection unit, the equipment SHALL be thoroughly cleaned according to the equipment maintenance manual. This does not apply to the addition of materials (either vehicle or particles) to maintain concentration.

3.6.7.3 Material Tests. Frequencies of all process checks are established in TO 33B-1-2 WP 103 00. The following lists the minimum material tests which SHALL be accomplished to ensure the magnetic particle inspection process meets acceptable operating standards:

- Concentration Check.
- Settling Check.
    - Concentration Check.
    - Background Fluorescence.
    - Contamination.

- Acidity Test.
- Water Break Test.

3.6.7.3.1 New Material Tests. New materials SHALL be subjected to the following tests, as appropriate, prior to being put into use:

a. Perform a contamination and a background fluorescence check on petroleum based bulk vehicle.

b. Use the settling test to check the concentration level, background fluorescence, and for any contamination of the newly mixed bath.

c. Perform a system effectiveness test on both conventional magnetic particle inspection materials and magnetic rubber inspection materials (if used).

3.6.7.3.2 In-Use Material Tests. In-use materials SHALL be tested in accordance with the frequency established in TO 33B-1-2 WP 103 00.

3.6.7.4 Preparation of New Wet Suspension.

3.6.7.4.1 Tank Inspection and Cleaning. When new equipment is being installed, or after emptying dirty suspension from the in-use tank, the agitation/circulation system SHALL be inspected and cleaned as necessary to ensure it is not contaminated with particles or dirt.

3.6.7.4.2 Preparation of New Bulk Suspension Materials. Fluorescent materials also require an additional fluorescent background check (see TO 33B-1-2 WP 103 00). Fill the tank with oil or water, depending on which is chosen as the vehicle, and operate the agitation system to ensure it is functioning properly. If petroleum based, bulk vehicle is used, the following check SHALL be performed prior to formulating the inspection bath. This will prevent unsatisfactory bulk magnetic particle vehicle from being introduced into the magnetic particle inspection system.

a. Loosen the cap on the bulk vehicle container, and leave the container undisturbed for at least 1-hour.

b. After the time has elapsed, without disturbing the container, remove the cap, cover, seal, or plug from the bulk vehicle container.

c. Obtain a clean glass tube of sufficient length so it reaches from the bottom of the bulk vehicle container to at least 6-inches above the container opening when the tube is held in the vertical position.

d. Place your thumb over one end of the glass tube, and insert the other end of the glass tube slowly, in a vertical position, into the bulk vehicle.

NOTE

Ensure the tube goes all the way to the bottom of the container.

e. Release your thumb from the upper end of the glass tube for 5 to 10-seconds, and then replace your thumb over the end of the glass tube. Maintain its vertical position and remove the glass tube slowly from the bulk vehicle.

f. Prior to removing your thumb from the end of the glass tube, observe the level of the contamination in the glass tube. If present, water and other contaminants should be evident in the lower portion of the glass tube. (Depots: if the vehicle is suspected, the contents of the glass tube may be sent to the depot chemical laboratory for analysis).

g. If contaminants are evident in the bottom of the container, siphon off the good vehicle to within 2-inches of contamination level.

h. Disposition instructions for contaminated bulk vehicle are located in paragraph 3.6.9.

3.6.7.4.3 Particle Concentration Test.

NOTE

> Prior to adding the magnetic particles to the vehicle, they SHALL be demagnetized to eliminate any agglomeration that may have developed during storage due to magnetization.

The concentrates to be added to the bath, and the volume of solid materials which settle out when the bath is made up, should conform to the manufacturer's data supplied with the concentrate. Concentrate SHALL be added when the particle concentration is low. Evaporation or liquid drag-out SHALL be monitored and volume maintained when the level drops appreciably. Loss of liquid may be by either drag-out or by evaporation, and corrective measures are different for both types of loss. Adding additional oil or water is all that is required to make up for evaporation loss. To make up for the drag-out loss, the addition of bath liquid and particles may be required.

3.6.7.4.3.1 The strength of the bath is a major factor in determining the quality of the indications to be obtained. Too heavy of a concentration will give a confusing background with excessive adherence of particles at external poles. This will reduce the visibility of indications from very fine discontinuities.

3.6.7.4.3.2 It is difficult to know what the cause of volume loss is in any given case. For a unit used only occasionally, loss by evaporation is likely to be the major cause. For a unit in constant use, it can be assumed that more than 50-percent of the loss is due to drag-out. This problem is not serious, because with constant use, the accumulation of dirt, scraps, lint, etc. requires the disposing of the in-use bath and a new bath is typically prepared before loss of liquid becomes serious. Magnetic particle content is of most critical importance and SHALL be carefully watched at all times.

3.6.7.4.3.3 Dirt accumulation in the magnetic particle bath can usually be observed in the settling test. Dirt, lint, etc. are usually lighter and settle later. Dirt, lint, etc. are often seen as a second layer on top of the particles, or as a non-fluorescent band or strip in the particle layer. The layer of dirt and the vehicle immediately above it SHALL NOT fluoresce. For particle concentration determination, this layer of dirt SHALL be carefully excluded from the total volume read. Formation of proper indications will be impeded when the contamination exceeds 30-percent of the volume of the particle layer. At that point, the bath SHALL be properly disposed of and new bath placed into service. This may occur as often as once a week when a unit is in constant use. If oil is used as a suspension, the disposition of the bath SHALL conform to all applicable regulations for petroleum products.

3.6.7.4.3.4 The following ranges are rather broad for uniform results and are provided for maintaining magnetic particles suspension concentration. These ranges should be reduced by each laboratory depending on their specific requirements.

- Visible magnetic particle bath concentrations SHALL be 1.2 to 2.4-milliliters (ml) of particles per 100 ml of vehicle. The optimum range is 1.5 to 2.0 ml/100 ml.
- Fluorescent magnetic particle bath concentrations SHALL be 0.1 to 0.4-ml of particles per 100 ml of vehicle. The optimum range is 0.15 to 0.20 ml/100 ml.

3.6.7.4.4 Adding Dry Powder Concentrate. Measure out the required amount of powdered concentrate, and pour it directly into the bath within the tank. The agitation system should be running and the concentrate poured in at the pump intake. Therefore, it will be quickly drawn into the pump and dispersed into the bath. The new pre-wet concentrates will disperse very quickly even through the large volume of bath in large units. After 10-minutes of operation, the bath strength SHOULD be checked with a settling test.

3.6.7.4.5 Adding Paste Concentrate. This procedure is similar to the dry powder concentrates, except the paste SHALL be weighed instead of measured. The paste is transferred to a mixing cup or bowl, bath liquid is added a little at a time, and mixed until smooth, thin, slurry has been produced. This slurry is then poured into the tank at the pump intake and dispersed it into the bath. After agitating 10 minutes, the strength SHOULD be checked by the settling test as in the case of the dry powder concentrate.

3.6.7.5 Evaluating In-Use Wet Suspensions.

3.6.7.5.1 Suspension Maintenance. As the suspension bath is used for testing, it will undergo changes. Some of these changes are:

- Drag-out of magnetic particles by mechanical and magnetic adherence to parts.
- Drag-out of liquid due to the film that adheres to the surface of parts.
- Loss of liquid by evaporation.
- A gradual accumulation of contaminants: shop dust, dirt from parts improperly cleaned, lint from wiping rags, and oil from parts that carry a residual film of oil.
- Miscellaneous objects and materials which are dropped into the tanks.
- Dilution/contamination of the bath from wet test pieces, dripping overhead pipes, and moisture condensation.

3.6.7.5.2 Suspension Agitation. Magnetic particles are considerably heavier than the vehicle in which they are suspended. When the agitation system is shut off, the particles rapidly settle out. All particles SHALL be agitated into suspension before conducting any inspections or process control tests. The agitation time varies with downtime due to the compacting of the particles from their own weight.

3.6.7.5.3 Settling Test. Procedures for performing the settling test are listed in TO 33B-1-2 WP 103 00.

3.6.7.5.3.1 Additional Settling Test Requirements for Wet Fluorescent Suspension. There are three additional sources of deterioration that can occur in a bath of fluorescent particles. When the condition becomes excessive, dispose of the bath.

3.6.7.5.3.1.1 The first source of deterioration is the separation of the fluorescent pigment from the magnetic particles. Such separation causes a reduction of fluorescent brightness of indications and an increase in the overall fluorescence of the background. When this occurs to a noticeable degree, the bath SHALL be changed. This condition is difficult to detect in the settling test, but can be observed by directing a UV-A lamp at the settling tube after the normal settling period. Noticeable fluorescence of the solution, with a reduced fluorescence of the particles, signifies separation. Observation by the inspector in the way the bath performs is another method of detecting separation.

3.6.7.5.3.1.2 A second source of deterioration of the bath of fluorescent particles is the accumulation of non-fluorescent magnetic dust or dirt in the bath. When there is a considerable amount of finely divided magnetic material in the dust carried by the air, this material will accumulate in the bath along with other dust and dirt. In a bath of wet visible non-fluorescent particles this does no specific harm until the accumulation of total dirt is excessive. In the case of fluorescent particles, it tends to decrease the brightness of the indication. The fine magnetic material is attracted to indications along with the fluorescent particles, and it takes very little of such non-fluorescent material to significantly reduce the brightness or visibility of the indication.

3.6.7.5.3.1.3 A third source of deterioration of the fluorescent particle bath is the accumulation of fluorescent oils and greases from the surfaces of tested parts. Over time, this accumulation, builds up the fluorescence of the liquid vehicle to the point that it interferes with the visibility of fluorescent particle indications.

3.6.8 Additional Tests for Water Baths.

3.6.8.1 Wetting Agents and Corrosion Inhibitors. Usually magnetic particle concentrates provide the correct amount of wetting agent and corrosion inhibitor for initial use. However, these materials are also available separately so the concentrations can be maintained or adjusted to suit the particular conditions. If no corrosion can be tolerated, a higher concentration of corrosion inhibitor will be used.

3.6.9 Disposition for Nonconformance Materials.

NOTE

> Knowledge of problems, even relatively minor ones, is essential for improvement in the NDI program. Information copies of written correspondence concerning unsatisfactory magnetic particle inspection materials SHALL be furnished to: (Air Force NDI Office, AFLCMC/EZPT-NDIO, aflcmc-ezpt-ndio@us.af.mil, DSN 339-4931, DSN 339-4931 and AFRL/RXSA, 2179 Twelfth Street, Ste. R43, Wright-Patterson Air Force Base, OH 45433-7718); (Army: AMCOM Corrosion Protection Office - NDT, RDMR-WDP-A, Bldg. 7631, Redstone Arsenal, AL 35898; DSN 897-0211.). All materials which DO NOT meet the minimum requirements SHALL be rejected. Rejected materials SHALL be reported in accordance with TO 00-35D-54. (Navy: SHALL refer to OPNAV 4790.2 Quality Deficiency Reporting QDR requirements.)

3.6.9.1 Open tank baths SHALL be changed (replaced or replenished) when they do not meet the minimum inspection requirements.

3.6.10 Magnetic Particle Process Checklist. The following table contains process checks for the magnetic particle system. Table 3-8 is for self-assessment only, is for self-assessment only, and does not replace the required periodic process control requirements. The NDI supervisor SHALL perform an assessment of the magnetic particle process periodically. The interval of the assessment is at the NDI supervisor’s discretion and does not require documentation. It is recommended that the process checklist be performed and documented whenever a unit self-assessment is accomplished. The process checks are presented in checklist format including a criticality identification system used in most Air Force checklists. The criticality is relevant to the magnetic particle process alone and should not be used by outside inspection agencies during assessments of the NDI Laboratory to determine the severity of an inspection finding. The criticality identifiers are as follows:

3.6.10.1 **Critical Compliance Objectives (CCO).** Items identified as key result areas for a successful mission accomplishment including, but not limited to, items where non-compliance could result in injury, excessive cost, or litigation. CCOs are shown in "**BOLD AND ALL CAPS FORMAT.** "

3.6.10.2 **Core Compliance Items (CCI).** Areas that require special vigilance and are important to the over-all performance of the unit, but are not deemed "Critical". Non-compliance would result in some negative impact on mission performance or could result in injury, unnecessary cost, or possible litigation. CCIs are shown in "ALL CAPS FORMAT."

3.6.10.3 **General Compliance Items (GCI).** Areas deemed fundamental to successful overall performance of the unit, but non-compliance would result in minimal impact on mission accomplishment or would be unlikely to result in injury, increased cost, or possible litigation. GCIs are shown in "sentence case format."

3.6.10.4 **General Data Information (GDI).** Information required to validate equipment care and requisition priorities. GDIs are shown in *"italic sentence case format."*

Table 3-8. MT Process Checks

	Magnetic Particle Process Checklist	YES or NO
GCI.27	Pre-Cleaning.	
CCI.27.a.	ARE OILS, GREASE, MOISTURE, DIRT, RUST, SCALE, AND LOOSE PAINT REMOVED IN A SATISFACTORY MANNER?	
GCI.27.b.	Are cleaning residues removed?	
GCI.27.c.	Are parts adequately dried, especially in recessed areas?	
GCI.27.d.	Are all areas requiring masking and/or plugs covered satisfactorily?	
GCI.28	Inspection Operations.	
CCI.28.a.	IS THE CURRENT APPLICABLE TECHNICAL DATA AVAILABLE?	
GCI.28.b.	Is the appropriate magnetizing current used (AC, DC, rectified AC)?	
GCI.28.c.	Are the appropriate magnetic particles used (wet, dry, visible, fluorescent)?	
GCI.28.d.	Is the application of inspection media correct (continuous, residual)?	
CCI.28.e.	ARE THE REQUIRED FIELD DIRECTIONS INDUCED?	
GCI.28.f.	Are the sequences of induced fields (circular versus longitudinal) acceptable? Whenever practical, the circular field SHOULD be indicated first to facilitate the demagnetization process.	
CCI.28.g.	IS THE REQUIRED MAGNETIZING AMPERAGE USED AND THE PART CHECKED FOR PROPER MAGNETIZATION?	
GCI.28.h.	Is the UV-A allowed to warm up for a minimum of 10-minutes, or until the required intensity (1000 mwatts/cm^2) is achieved?	
GCI.28.i.	Is the required demagnetization procedure is used (30-point step-down, AC coil, etc.)?	
GCI.28.j.	Are the field-indicators working properly and capable of determining the adequacy of demagnetization?	
GCI.28.k.	Was the demagnetization process effective?	
GCI.29	Post Cleaning	
GCI.29.a.	Are all inspection materials removed?	
GCI.29.b.	Are all masking and plugging materials removed?	

SECTION VII MAGNETIC PARTICLE INSPECTION EQUATIONS

3.7 MAGNETIC PARTICLE EQUATIONS.

3.7.1 Rule-of-Thumb Formulas. Rule of thumb guidance for circular magnetization can be found in paragraph 3.4.4.5.3. Rule-of-thumb formulas have been developed to help determine the amount of amperage required to induce an adequate longitudinal magnetic field in a part. These formulas apply particularly well to cylindrically shaped parts and are explained with examples shown in the following paragraphs. However, as discussed previously, blind adherence to these "rules of thumb" can result in over magnetization with a subsequent loss of inspection sensitivity.

3.7.2 Cross-Sectional Area. It is critical to determine the relationship between the cross-sectional area of the part and the cross-sectional area of the coil(s). This relationship/ratio will determine whether the part can be inspected within a coil of a given diameter by laying the part in the bottom or next to the side of the coil wall, or by centering the part in the coil, and which formula will be used for estimating the amperage required. The cross-sectional area for the part and coil are determined as follows:

$A = \Pi r^2$

Where: A = Cross-sectional Area

$\Pi = 3.1416$

r = radius (1/2 of the diameter). The diameter of the part SHALL be taken as the largest distance between any two points on the outside circumference of the part.

Example: A 12-inch diameter coil is to be used to inspect a part having a 2-inch diameter.

Area of Coil (12″ diameter)	Area of Part (2″ diameter)
$A = \Pi r^2$	$A = \Pi r^2$
$A = \Pi(6)^2$	$A = \Pi(1)^2$
A = 113 sq. inches	A = 3.14 sq. inches

3.7.2.1 When the cross-sectional area of the part is less than one-tenth of the cross-sectional area of the coil, the part SHOULD be magnetized lying in the bottom of the coil.

3.7.2.2 When the cross-sectional area of the part is greater than one-tenth of the cross-sectional area of the coil, the part must be magnetized in the center of the coil.

3.7.2.3 When using a cable wrap or when the cross-sectional area of the part exceeds one-half of the cross-sectional area of the coil, the part SHOULD be centered in the coil and the formula for high fill factor coils SHALL be used for estimating the required amperage.

3.7.2.4 The diameter of the largest part that can be magnetized lying in the bottom of a coil or placed next to the coil wall for some typical coil sizes is listed in Table 3-9. For any given coil diameter, parts with diameters larger than those listed SHALL be magnetized by some other method, such as centering them in the coil, using a cable wrap, or using a larger coil.

Table 3-9. Coil Size Vs. Maximum Diameter for Parts Magnetized in Bottom of Coil

Coil Diameter (inches)	Maximum Part Diameter (inches)
8	2.5
12	3.8
15	4.8
18	5.7
20	6.3
24	7.6

3.7.3 Calculating Coil Current. Two rule-of-thumb formulas have been developed for use in estimating the coil current levels to be used for longitudinal magnetization. One formula is for a part centered in the coil and the other for a part lying in the bottom of the coil. These formulas apply to cylindrical and irregularly shaped parts and at one time were thought to estimate the required current to within 10-percent. Recent studies show in almost all instances they overestimate the required current by at least 50-percent. They use the part length-to-diameter (L/D) ratio. The useful magnetizing field produced by an encircling coil extends approximately 6 to 9-inches to either side of the coil. For parts longer than the effective field distance, one or more inspections are required along the length of the part. When repositioning these longer parts in the coil, allow a 3-inch effective field overlap. The formulas are intended for part with a L/D ratio between 2, and 15. To inspect parts with an L/D ratio of 2 or less, (paragraph 3.7.3.6). For parts with an L/D ratio greater than 15, use 15 as the value for the ratio.

3.7.3.1 Formula for Part Lying in Bottom of Coil. The following formula can be used when the cross-sectional area of the part is less than one-tenth the cross-sectional area of the coil(s) and SHALL be used whenever the part is lying in the bottom of the coil, or is placed next to the coil wall during magnetization. If the part has hollow portions, replace D with D_{eff} (paragraph 3.7.3.4).

$$I = \frac{KD}{NL}$$

Where:

I = Current through coil (amperes)

K = 45,000 (a constant, ampere-turns)

L = Length of the part (inches)

D = Diameter of the part (inches)

N = Number of turns in coil

Example: Determine the current required to longitudinally magnetize a steel part, 10-inches long with a diameter of 2-inches using a 12-inch diameter coil having 5 turns. To determine cross-sectional area ratio between part and coil, refer to (paragraph 3.7.2). Substituting the known values and doing the calculations gives:

$$I = \frac{45000 \times 2}{5 \times 10}$$

I = 1800 amperes

Typical currents for a five turn coil with the parts lying in the bottom of the coil or held next to the coil wall are provided in (Table 3-10).

Table 3-10. Typical Coil-Shot Current for a Five-Turn Coil With Part in Bottom of Coil

Part Length in Inches (L)	Part Diameter in Inches (D)	L/D Ratio	Ampere-Turns Required	Amperes Required
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 1/2	12	3,750	750
14	1	14	3,214	643

3.7.3.2 Formula for Part in Center of Coil. This formula SHALL be used when the cross-sectional area of part is greater than one-tenth and less than one-half of the cross-sectional area of the coil(s).

$$I = \frac{KR}{N(6(L/D) - 5)}$$

Where:

I = Current through coil (amperes) (paragraph 3.7.3.1)
K = 43,000 (a constant, ampere-turns) (paragraph 3.7.3.1)
R = Radius of coil (inches)
N = Number of turns in coil (paragraph 3.7.3.1)
L = Length of part (inches)
D = Diameter of the part (inches) (paragraph 3.7.3.1)

The term 6(L/D)-5 is called the effective permeability.

Example: Determine the current needed to longitudinally magnetize a 12-inch long part with a diameter of 4-inches and using a 5 turn, 12-inch diameter coil. To determine the cross-sectional area ratio between the part and the coil, refer to (paragraph 3.7.2). If the part contains hollow portions, D should be replaced with $D_{\mathbf{eff}}$ (paragraph 3.7.3.4).

Substituting known values gives:

$$I = \frac{43000 \times 6}{5(6(12/4) - 5)}$$

$$I = 3969 \text{ amperes}$$

3.7.3.3 Formula for Cable Wrap or High Fill-Factor Coils. When using a cable wrap or when the cross-sectional area of the part is greater than one-half of the cross-sectional area of the coil, the following formula SHALL be used for estimating the current required to longitudinally magnetize a part centered in the coil. If the part has hollow portions, replace D with $D_{\mathbf{eff}}$, in the formula (paragraph 3.7.3.4).

$$I = \frac{K}{N((L / D) + 2)}$$

Where:

I = Current through coil (amperes) (paragraph 3.7.3.1)
K = 35,000 (a constant, ampere-turns) (paragraph 3.7.3.1)
N = Number of turns in coil (paragraph 3.7.3.1)
L = Length of part (inches)

D = Diameter of the part (inches) (paragraph 3.7.3.1)

Example: Determine the required current to longitudinally magnetize a part, 12-inches long with a 4 inch diameter using the cable wrap technique with a 3 turn wrap.

Substituting known values gives:

$$I = \frac{35000}{3((12/4) + 2)} \qquad I = 35000/3(12/4 + 2)$$

I = 2333 amperes

3.7.3.4 Formula for Hollow Parts or Parts Having Hollow Portions. If a part has hollow portions, replace the diameter (D) with the effective diameter (D_{eff}), which is calculated using:

3.7.3.4.1 Determining the Effective Diameter. For hollow and cylindrical test parts, the diameter of the test part is substituted with the calculated effective diameter. Calculate the effective diameter as follows:

$$D_{eff} = \sqrt{(OD)^2 - (ID)^2}$$

3.7.3.4.1.1 Example: Determine the effective diameter of a tube-shaped part with an outside diameter equal to 5-inches and an inside diameter of 4.5-inches.

$$= \sqrt{(25 - 20.25)}$$

$$= \sqrt{4.75}$$

$$D_{eff} = 2.179$$

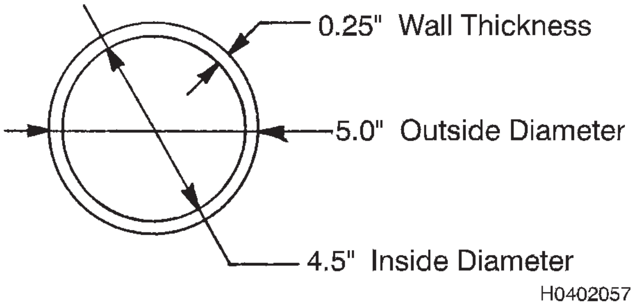


Figure 3-72. Calculating Effective Diameter

3.7.3.4.1.2 To calculate the current required to longitudinally magnetize the part in the above example, use the formula from (paragraph 3.7.3.1) for the part in the bottom of a 12-inch diameter coil with 5 turns, except replace D with D_{eff}. (2.179):

$$I = \frac{KD}{NL}$$

$$I = \frac{45000 \times 2.179}{5 \times 10}$$

$$I = 1961 \text{ amperes}$$

3.7.3.5 In the examples of (paragraph 3.7.3.1) and (paragraph 3.7.3.4) above, the differences in the current required to longitudinally magnetize the solid and hollow parts are compared in Table 3-11. The only difference in the two parts is one was hollow and the other was solid. If the effective diameter D_{eff} had not been considered, the current for the hollow part would have been over estimated by 927 amperes. This additional amperage would certainly result in excessive background and possibly false indications from over-magnetizing the part.

Table 3-11. Comparison of Coil Amperages for Solid vs. Hollow Parts

	Solid Part	Hollow Part
Part Length	10 inches	10 inches
Part Diameter	2 inches	2 inches
Coil Description	5-turn, 12-inch diameter	5-turn, 12-inch diameter
Amps Required	1800	873

3.7.3.6 If the need arises to inspect parts having L/D ratios of 2 or less, the effective L/D ratio SHALL be increased by placing the part between two 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. Solid steel pole pieces may be used when direct current is used in the coil and the continuous method of inspection is used. If the continuous method is used with either AC or half-wave DC current in the coil, the pole pieces SHALL be made from laminated magnetic material similar to the silicon steel legs of a hand probe with articulated legs. This is also true for residual inspection. Pole pieces SHALL be made from the ferromagnetic if residual inspection, or the wet continuous method of inspection with AC or half-wave DC, is to be used.

NOTE

Pole piece may be needed on some parts with an L/D ratios greater than 2, especially if the area of interest on part is close to the end.

SECTION VIII MAGNETIC PARTICLE INSPECTION SAFETY

3.8 MAGNETIC PARTICLE SAFETY.

3.8.1 Safety Requirements. Safety requirements SHALL be reviewed by the laboratory supervisor on a continuing basis to ensure compliance with provisions contained in AFI 91-203 as well as provisions of this technical order and applicable weapons system technical orders. Recommendations of the installation Bioenvironmental Engineer and the manufacturer regarding necessary personnel protective equipment SHALL be followed.

NOTE

Air Force Instruction 91-203 or appropriate service directive SHALL be consulted for additional safety requirements.

3.8.2 General Precautions. Precautions to be exercised when performing magnetic particle inspection include consideration of exposure to oils, pastes, and electrical current. The following minimum safety requirements SHALL be observed when performing magnetic particle inspections.

3.8.3 Floor Matting. Use rubber insulating floor matting in front of magnetic particle units. This matting SHALL be rated for the voltage of the equipment being utilized. This matting SHALL be replaced when it is worn to one-half the original thickness (approximately 1/8-inch). Use only one continuous length of matting and ensure it continues beyond the ends of the equipment for at least 24-inches. If facility construction or safety walkways prevent extension beyond equipment, local safety office may approve deviation IAW 91-203 or other service directive.

3.8.4 Wet Suspension Precautions. Wet magnetic particle materials are normally nontoxic, but continuous exposure to oils and pastes used in the wet bath method may cause dermatitis or cracking of the skin. Protective gloves SHALL be worn during this process.

3.8.4.1 If a magnetic particle suspension oil, with a flash point of less than a 200° F is maintained in a Type II stationary magnetic particle unit, the following minimum safety requirements apply:

- Provide an adequate surface area exhaust ventilation system as determined by the local base bioenvironmental engineer.
- Maintain less than 25 gallons of liquid suspension in the tank.
- Cover the liquid suspension by a screened drain board.
- Provide a portable fire extinguisher, sufficient in size and/or volume to suppress any fire which could occur from the magnetic particle suspension oil. The fire extinguisher size and/or volume SHALL be determined by the local fire chief.

3.8.5 Arcing Precautions. Arcing may be caused by poor contact between the head stocks of the stationary magnetic particle unit. This arcing or excessive magnetizing current may injure the eyes. Arcing may also ignite combustible magnetic particle baths (e.g., oil). Ensure good electrical contact between the heads and the inspected part to prevent this possibility. The head stocks SHALL be wetted with the magnetic particle bath prior to energizing to reduce the possibility of arcing. Even the smallest of arc burns can seriously damage a part if it occurs in a highly stressed location. If written direction on dealing with an arc burn is not available, cognizant engineering should be contacted for disposition.

NOTE

The use of prods is prohibited on aircraft parts. Ensure they are not used in any hazardous area.

3.8.6 Head Stocks. Many units can be hand cranked to hold the part in place between the head stocks, and then air controlled pressure is applied with a foot pedal to ensure a solid fit between the stocks. In order to avoid injuring the inspector’s hands, extreme care SHALL be maintained when placing articles between the head stocks of a magnetizing unit.

3.8.7 UV-A Hazards.

WARNING

Unfiltered ultraviolet radiation can be harmful to the eyes and skin. UV-A lamps SHALL NOT be operated without filters. Cracked, chipped, or ill-fitting filters SHALL be replaced before using the lamp

Prolonged direct exposure of hands to the filtered UV-A lamp main beam may be harmful. Suitable gloves SHALL be worn during inspections when exposing hands to the main beam.

3.8.7.1 The temperature of some operating UV-A bulbs reaches 750°F (399°C) or more during operation. This is above the ignition or flash point of fuel vapors. These vapors will burst into flame if they contact the bulb. UV-A lamps SHALL NOT be operated when flammable vapors are present.

3.8.7.1.1 Exercise care when using hot mercury vapor or gas discharge lamps so as not to burn hands, arms, face, or other exposed body areas. Do not lay hot UV-A lamps on combustible surfaces. The bulb temperature also heats the external surfaces of the lamp housing. The temperature is not high enough to be visually apparent, but is high enough to cause severe burns with even momentary contact of exposed body surfaces. Extreme care SHALL be exercised to prevent contacting the housing with any part of the body. Consult your local bioenvironmental office for specific guidance.

3.8.7.1.2 When practical, provide brackets or hangers in the area of UV-A lamps use to permanently lamps at the wash station and within the inspection booth.

3.8.7.1.3 UV-A filtering safety glasses are specifically designed for penetrant and magnetic particle inspections and are recommended as they will filter out glare and reduce eyestrain. Install ultraviolet filters on all mercury vapor lamps used for penetrant inspection. Replace cracked, chipped, or broken filters before using the light. Injury to eyes and skin will occur if the light from the mercury vapor bulbs is not filtered. UV-A filtering safety glasses, goggles, or face shields SHALL be worn and precautions SHALL be taken to cover exposed skin that is exposed to the direct beam of any UV-A. This includes mercury vapor lamps, gas discharged lamps, and LED lights.

3.8.8 Hazards of Aerosol Cans. Aerosol cans are a convenient method of packaging a wide variety of materials. Their wide use, both in industry and the home, has led to complacency and mishandling. Some of the hazards in the use of aerosol cans are discussed below.

3.8.8.1 The containers are gas pressure vessels which when heated to temperatures above 120°F (49°C) increases the gas pressure resulting in possibly bursting the container. Any combustible material, regardless of flash point, can ignite with explosive force when it is finely divided and dispersed in air. Magnetic particle materials SHALL be stored in a cool dry area, protected from direct sunlight.

3.8.9 Magnetic Rubber Precautions. General safety precautions are applicable to magnetic rubber inspection. The silicon rubber, dibutyltin dilaurate, stannous octoate, cure stabilizers, cleaners, and release agents are or can be skin and eye irritants, skin sensitizers (causing allergic reactions), inhalant and ingestion hazards. For specific information concerning any of the materials used as magnetic rubber, magnetic rubber catalysts, release agents, or cleaners consult the Material Safety Data Sheets, or contact the appropriate Safety Officer. Silicon oil is an ingredient in the material and can result in very slippery surfaces, especially floors, if not well controlled. When performing magnetic rubber inspection on aircraft using electromagnets to magnetize, the aircraft SHALL be grounded.