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Study Guide
Magnetic Particle
Testing Method

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by Charles W. Eick

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References

1. **Reference A**
   Betz, C.E., *Principles of Magnetic Particle Testing*, Magnaflux, Chicago, Illinois, 1997.

2. **Reference B**
   Schmidt, J. Thomas, and Kermit Skeie, technical editors, Paul McIntire, editor, *Nondestructive Testing Handbook*, second edition, Volume 6, *Magnetic Particle Testing*, the American Society for Nondestructive Testing, Inc., Columbus, Ohio, 1989.

3. **Reference C**
   General Dynamics, *Classroom Training Handbook: Nondestructive Testing, Magnetic Particle*, CT-6-3, second edition, the American Society for Nondestructive Testing, Inc., Columbus, Ohio, 1977.

Chapter 1

The History of Magnetic Particle Testing

The magnetic particle equipment and testing processes we use today have a long and interesting history. In the mid–1800s some of the first magnetic particle testing was completed using natural magnets to test rifle barrels for defects. From this early testing to today's modern multidirectional units is a very large step.

Alfred Victor de Forest completed some of the first real magnetic particle testing in the late 1920s. His early work was the foundation of the testing methods that are used today and produced the idea of using current passed through a part to produce a magnetic field in the part. In addition, he developed the process of using magnetic particles to detect discontinuities in parts. In the very last part of the 1920s Foster B. Doane joined him. Their work and vision resulted in the establishment of the Magnaflux Corporation.

Throughout the 1930s, de Forest and Doane continued to develop the magnetic principles that are used today. In addition, work in Germany resulted in the development of magnetic particles suspended in water being used to increase the sensitivity of tests.

While some of the first applications in the 1930s were in the aviation industry, other industries were also quickly applying the magnetic particle testing process. Many of these applications were driven by the need to improve safety and reliability. One interesting application was the use of magnetic particle tests on steering parts of the racecars competing at the Indianapolis Motor Speedway in the mid–1930s.

It was also during the 1930s that great strides were made in developing magnetic particle testing equipment and introducing training and technical books on the subject.

In the 1940s the world was at war. As is often the case, wars advance technology at a faster pace and magnetic particle testing was no exception. Production on a mass scale was necessary. Several important events occurred during this period. One was the development of the quick break design necessary when testing with coils. Another development was the use of fluorescent magnetic particles. It was also during this time period that training and qualification of personnel became a requirement due primarily to government manufacturing quality requirements. The training of personnel resulted in some of the first organized training classes being developed and conducted for magnetic particle testing.

The 1950s saw the development of magnetic particle testing in many industries. The aerospace industry was entering an era where jet engines were beginning to replace reciprocating engines. Whereas the older reciprocating engines put magnetic particle testing to good use, the newer jet engines with very high rpm turbine components placed additional demands for higher quality tests. In addition, during this period magnetic particle testing was increasingly being used on new and overhauled automotive parts, buildings and bridges. In the later part of the 50s, the first multidirectional magnetic testing unit was introduced. One additional and very important development during the 1950s was the publication of the first edition of the *Nondestructive Testing Handbook.* The handbook was made up of two volumes and was by far the most complete document on nondestructive testing. It remained one of the primary resources of the nondestructive testing industry for several decades.

The 1960s saw the introduction of truly portable magnetic testing equipment. This equipment was first used in the ship building industry, but quickly became a common piece of testing equipment at high rise building and bridge sites, offshore drilling platforms and on pipelines. This period also saw the introduction of devices, such as quantitative shims, to improve technique development and the quality of results. Fluorescent magnetic particle bath in pressurized cans was also introduced.

The 1970s and 1980s saw the introduction of improved fluorescent particles and the use of solid state components in magnetic particle equipment.

There have been continuing improvements in equipment, particles, quality verification devices and techniques during the last part of the 20th century. And the future holds even more opportunities for improvement.

This section has provided only a very brief overview of the history of magnetic particle testing. This overview is based on information obtained primarily from the references identified below. Readers who wish to further expand their knowledge of the rich history of magnetic particle testing should review the following references:

A. Chapter 1
B. Section 3, Parts 1 and 2

Basic Procedure

The magnetic particle testing process is not complicated. Most technical publications state that the only process requirements are the application of the field, application of particles and testing of the part. Whereas this is basically true, every Level II technician knows that there are usually several more steps required. Therefore, it could be said that the basic steps for a magnetic particle test are:

1. precleaning of the part;
2. application of the magnetic force to establish the field in the part;
3. application of the particles to detect any flux leakage;
4. testing of the part;
5. demagnetization of the part;
6. postcleaning of the part.

The amount of precleaning is directly dependent on the process application and sensitivity required. For example, underwater testing does not require the degree of precleaning that a jet engine turbine part requires.

Application of the magnetic field is a must for the test. The method and number of shots can vary from part to part, but a field must be established.

Application of the particles is a process requirement, however, the process could require dry particles or wet fluorescent particles. In addition, the application method could be residual or continuous.

The testing of the part is basically a visual inspection, though it could be automated. In addition, the process may require white light or ultraviolet light.

Demagnetization of the part is required by most standards. However, if the part will be heat treated in the next manufacturing stage, demagnetization might not be required.

Postcleaning of parts is normally required. However, an additional step to the postcleaning could be preventive corrosion treatment.

While the basic magnetic particle process is not complicated in theory, the application of the process can involve many additional steps. It is important that the Level II technician understand the procedure or process specification he or she is working under to ensure that all steps are followed.

References

A. Chapter 2
B. Section 1, Part 1

Advantages

Some advantages of magnetic particle testing are:

1. sensitivity to detecting very fine surface cracks and near surface discontinuities in ferrous metals;
2. portability for field use;
3. relatively simple and inexpensive to perform;
4. can be performed on thinly coated, painted or plated parts;
5. process can be automated;
6. training of personnel is not complicated or expensive.

Limitations

Some limitations for magnetic particle testing are:

1. can be used only on ferrous metals;
2. magnetic field and discontinuity orientation is critical;
3. postcleaning of parts may be necessary;
4. amperage requirements on large parts can be very high;

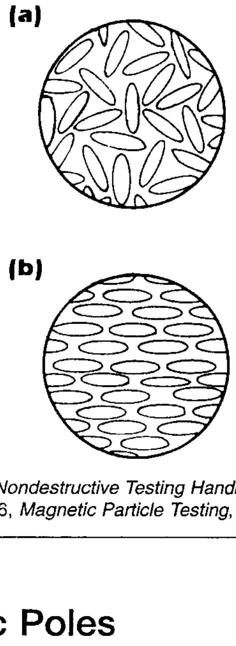
5. parts can be damaged by arcing while in the headstocks or when using prods;
6. demagnetization may be required;
7. multiple shots may be necessary depending on the complexity of the part.

Chapter 2
Theory of Magnetism

Magnetic Domains

The theory of magnetism begins with submicroscopic areas in metals that are called *magnetic domains*. Theory states that these domains have negative and positive ends and are randomly oriented in nonmagnetized materials. When the domains come under the influence of a magnetizing force, they tend to line up parallel to the field's lines of force. (See Figure 2.1.) The degree that they line up is proportional to the strength of the magnetizing force.

Figure 2.1: Orientation of magnetic domains: (a) in a nonmagnetized material; and (b) in a magnetized material



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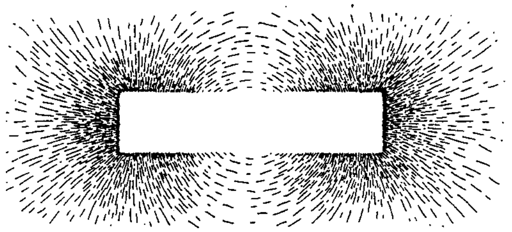
Magnetic Poles

Magnetic poles are points on a magnetized piece where the magnetic flux lines enter and leave the piece. Enter and leave does not mean that there is an actual flow of magnetism in the part. When a piece of plain paper is placed over a bar magnet and dry, colored magnetic particles are lightly dusted onto the paper, the magnetic flux lines can be easily seen. This type of illustration is called a *magnetograph* as seen in Figure 2.2.

Figure 2.2: Magnetic field surrounding a bar magnet



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The most notable natural magnet with a north and south pole is the Earth. However, the magnetic north and south poles are not at the same locations as the north and south poles on a map, but are located slightly off the normal axis of the Earth. While the Earth's magnetic field is not strong, it can cause ferrous materials to become magnetized and in some cases can interfere with the demagnetization of large parts.

"Opposites attract and likes repel" is a principle that applies to magnetic poles. When two north poles are brought into close proximity, they will repel each other. The same goes for south poles.

In addition, a bar magnet does not necessarily have just one north and one south pole. Long bar magnets could have several north and south poles. When this occurs the poles are said to have *consequent* poles. This is important to know because when a long part is magnetized with several coil shots, different poles are established along the axis of the bar. The inspector must be aware of this to ensure that possible nonrelevant indications caused by these poles are not incorrectly identified.

References

A. Chapter 6
B. Section 1, Part 3
C. Chapter 2, Section 201

Types of Magnetic Materials

Magnetism affects all materials to some degree because all matter is made up of atoms with negatively charged electrons and positively charged protons. The degree that the material is affected varies and is a product of the material's permeability.

Permeability is the ease that a magnetic field can be set up in a material. It is not a fixed number but a ratio of magnetizing force (*H*) to the produced flux density (*B*). Therefore as *H* is varied the flux density *B* will vary.

There are different types of permeability. In simple terms, the *material permeability* is a factor in circular magnetism and *effective permeability* is a factor in longitudinal magnetism. Material permeability deals with the magnetic field established in the entirety of the part. Effective permeability deals with the magnetic field established outside of the part. Note that both are ratios of *H* and *B*, but are measured at different points.

Materials are classified into three groups for the purposes of magnetism. These three groups are diamagnetic, paramagnetic and ferromagnetic.

Diamagnetic materials have a permeability less than one and are opposed to magnetic fields. Gold and copper are examples of this type of material.

Paramagnetic materials have a permeability slightly greater than one and are attracted to magnetic fields. The amount of this attraction is very slight and as soon as a strong magnetic field is removed the attraction is gone. Aluminum is an example of this type of material.

Ferromagnetic materials have high permeability and when subjected to a magnetic field, domains align parallel to the field's lines of force. When the magnetic field is removed, these types of materials retain a substantial portion of the field. Steel is an example of this type of material.

References

A. Chapter 5 and 9
B. Section 1, Part 3
C. Chapter 2, Section 202

Sources of Magnetism

There are four sources of magnetism: permanent magnets, the Earth's field, mechanically induced magnetism and electrically induced magnetism. Of the four, only permanent magnets and electrically induced magnetism are practical for nondestructive testing. And of these two, electrically induced magnetism is by far the most practical and widely used.

References

A. Chapter 7
B. Section 1, Part 3

Chapter 2 Review Questions

Q.2-1 Based on the domain theory, an unmagnetized part has domains that are:

a. randomly oriented.
b. aligned north to south.
c. aligned east to west.
d. aligned 90 degrees to the current flow.

Q.2-2 The areas on a magnetized part from which the magnetic field is leaving and entering the part are called:

a. salient points.
b. discontinuities.
c. magnetic poles.
d. nodes.

Q.2-3 The pattern of iron powder sprinkled on a paper placed over a bar magnet is called a:

a. field survey.
b. magnetometer.
c. magnetograph.
d. flux meter.

Q.2-4 The permeability of a material describes:

a. the ease with which it can be magnetized.
b. the depth of the magnetic field in the part.
c. the length of time required to demagnetize it.
d. the ability to retain the magnetic field.

Q.2-5 Materials that are weakly attracted magnetically are called:

a. paramagnetic.
b. diamagnetic.
c. ferromagnetic.
d. nonmagnetic.

Q.2-6 A part is adaptable to magnetic particle testing if:

a. it is attached to an electrostatic field.
b. the material is ferromagnetic.
c. the material is nonferrous.
d. the material is an electric conductor.

Q.2-7 Of the four sources of magnetism, which one is most often used in magnetic particle testing?

a. The Earth's field.
b. Permanent magnets.
c. Mechanically induced magnetism.
d. Electrically induced magnetism.

Chapter 3
Magnetic Flux Theory

Magnetic Flux Lines

Magnetic flux lines are found around a conductor with current passing through it and in or around a metal that contains a magnetic field. Magnetic flux lines are also called *lines of force* or *lines of magnetic flux*. Why they are called *flux* is not really known since the term would indicate movement and there is no proof that there is movement or flow inside the lines of force. We do know that magnetic flux lines exist. The lines around a conductor with current passing through can easily be detected and, as shown in Figure 2.2, the flux lines around a magnetized metal can also be detected.

Magnetic flux lines have basic characteristics:

1. Flux lines never cross each other.
2. Flux lines tend to *flow* in a continuous loop.
3. The strength or density of the flux lines is strongest near the poles.
4. Flux lines will always travel the path of least magnetic resistance or highest permeability.

A group of magnetic flux lines make up a magnetic field. Magnetic flux density is measured in tesla (gauss), whereas the magnetic field strength is measured in weber (oersted).

The magnetic flux density in different metals is not always the same for the same magnetizing force. This difference is caused by several factors such as each metal's permeability, hardness or alloy make up. For example, if two ferrous metals, one soft steel (low carbon) and the other tool steel (high carbon), are subject to the same magnetizing force, the residual field strength in the soft steel will be weaker than the field strength in the tool steel. This is a result of the soft steel having a higher permeability than the tool steel.

References

A. Chapters 5 and 6
B. Section 1, Parts 4 and 7
C. Chapter 2, Section 203

Magnetic Hysteresis Curve

At the heart of understanding magnetism in materials is the *magnetic hysteresis curve*. From this simple curve a Level II technician can come to a more complete understanding of why certain magnetic particle testing process steps are used. Some of these process steps are: strength of the inducing magnetism, the advantage of continuous versus residual fields during application of particles and the principle of diamagnetism of materials.

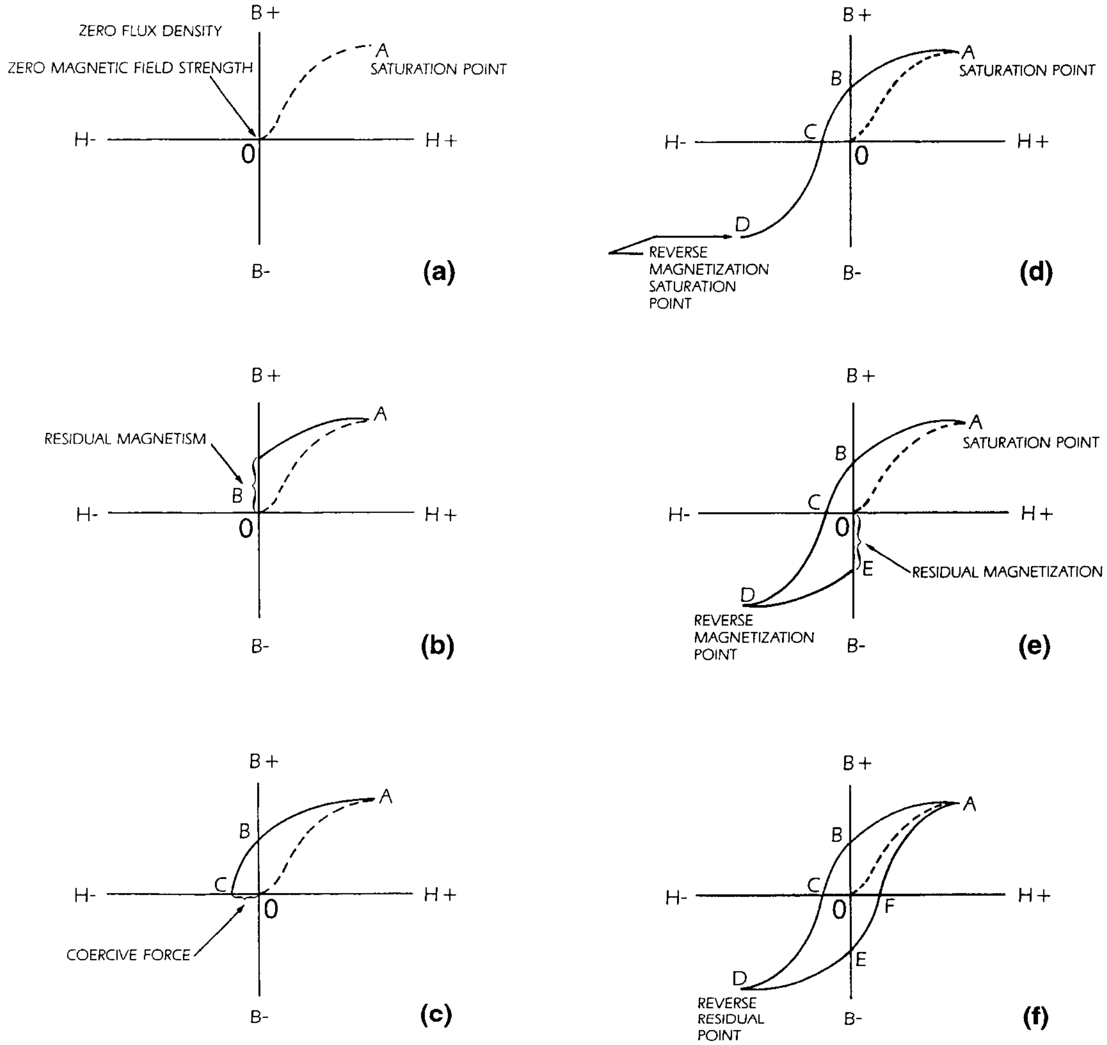
The magnetic hysteresis curve is also called the *hysteresis loop*. The steps of its development are shown in Figure 3.1.

In Figure 3.1 the *H* line represents the magnetizing force induced into a material. This force could be a magnetic field or an electrical current. The *B* line is the resulting magnetic flux density that is established in the part. The hysteresis loop shows the relationship between the magnetizing force applied and the resulting magnetizing field in the part.

Note in graph 3.1a the 0 point of the two intersecting lines indicates no magnetic field in the material. As a positive magnetizing force is applied, a magnetic field is created in the material. As the magnetizing force reaches point *A* the virgin curve line begins to go flat. Regardless of how much more magnetizing force is applied, there will not be an increase in the magnetic field or flux density of the material. This is called the *saturation point*.

In graph 3.1b the magnetizing force begins to decrease. The relationship of lines *H* and *B* do not follow the virgin curve. This is caused by the material's ability to retain magnetism and is called *residual magnetism* or *remanence*. At the

Figure 3.1: Hysteresis data for unmagnetized steel: (a) virgin curve of a hysteresis loop; (b) hysteresis loop showing residual magnetism; (c) hysteresis loop showing coercive force; (d) hysteresis loop showing reverse saturation point; (e) hysteresis loop showing reverse residual magnetism; and (f) complete hysteresis loop



Legend

B	Magnetic Flux Density
H+	Positive Magnetic Field Strength
H-	Negative Magnetic Field Strength

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point that the magnetizing force reaches 0, notice that the magnetic field strength in the bar is now at point *B*. The measurement from point 0 to *B* is the residual magnetism in the part and shows the material's *retentivity*.

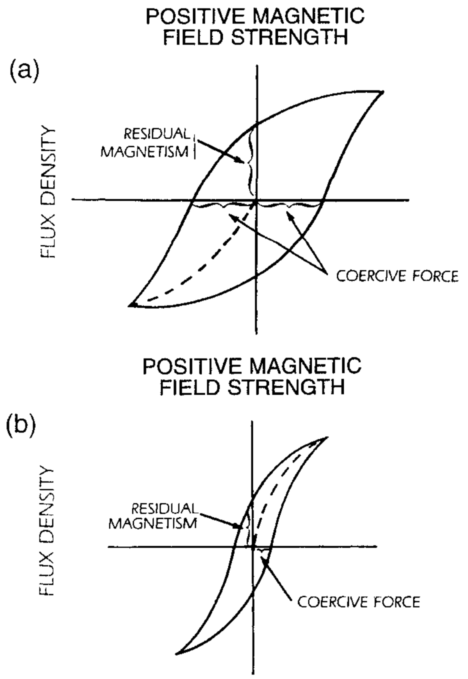
Graph 3.1c shows that to remove residual magnetism takes a certain amount of negative or opposite magnetizing force. This force is called the *coercive force*. The amount of force is shown from point 0 to point *C*.

In graph 3.1d as the negative or opposite magnetizing force continues, the ratio of the magnetizing force and magnetic field begins to again build. This will continue until the magnetizing force reverses direction or the reverse saturation point is reached. The magnetizing force then goes in the opposite direction as shown in graph 3.1e. The magnetic field strength in the bar again lags behind the reducing magnetizing force and the residual magnetic field strength at *E* is established with the magnetizing force at 0. The magnetizing force begins to again go in the positive direction as shown in graph 3.1f and the part proceeds to decrease its magnetic field and build it in the opposite direction.

A hysteresis loop for a metal is dependent on the material's alloy or chemical composition, microstructure and grain size. As noted in the magnetic flux section, parts made of low carbon and high carbon content have different hysteresis loops as can be seen in Figure 3.2.

Note in Figure 3.2 that a high carbon steel part will have a stronger residual field than a low carbon steel part when each is magnetized at the same amperage level. In addition, this graph shows that the materials will require different amounts of coercive force to remove the residual magnetism. In this case, the high carbon steel with take a great coercive force. This will have a direct affect on the ability to demagnetize a part.

Figure 3.2: Hysteresis loops: (a) hardened steel hysteresis loop; and (b) annealled low carbon steel hysteresis loop



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A Level II technician does not need to know the hysteresis of the material being inspected. However, by having a better understanding of what a hysteresis loop shows, a technician can obtain a better understanding of the processes of magnetizing a part, applying particles, evaluating indications and demagnetizing a part.

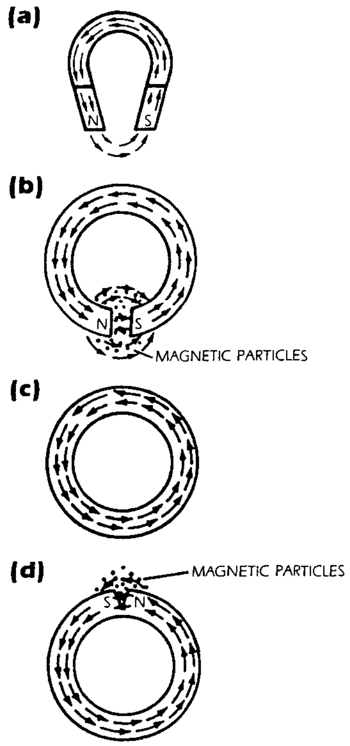
References

A. Chapter 5
B. Section 1, Part 7
C. Chapter 2, Section 203

Flux Leakage

Flux leakage is defined as the magnetic field that is outside of the normal configuration of a part and is caused by an interruption in the

Figure 3.3: Horseshoe magnet illustrating the principle of circular magnetism: (a) direction of magnetic flux; (b) magnet flux in air around poles; moving poles close together raises the magnetic flux density;
(c) fusing the poles forms a circularly magnetized object; and (d) a discontinuity in a circularly magnetized object and its resulting flux leakage field



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material. This interruption could be caused by a discontinuity, either internally or externally, in the part's structure.

When a circular magnetic field exists in a material, there is a continuous loop of the magnetic lines of force. If an interruption occurs in this path there is a direct effect on the lines of force. (See Figure 3.3.)

In 3.3a the horseshoe magnet shows the lines of force passing though the material and the air. This is *flux leakage.* In 3.3b the magnet's ends are being forced together and the area of leakage is decreasing, but now it is small enough to attract metal particles if they were introduced. View 3.3c shows the ends of the magnet fused together; here there is no interruption and therefore there is no leakage. View 3.3d shows why magnetic particle testing is used to detect discontinuities in ferrous parts. Here is a small interruption in the part, for example a crack. The lines of force cannot all pass around the crack so some are forced to pass through the air. The crack faces form small north and south poles. When ferromagnetic particles are applied the particles are attracted to the poles. This gathering of the particles produces the indication to identify the discontinuity in the material.

References

A. Chapter 5 and 6
B. Section 1, Part 4
C. Chapter 2, Section 200

Basic Magnetic Particle Testing Theory

Magnetic particle testing theory is based on the fact that when a magnetizing force is induced into a material, a magnetic field is formed. This magnetic field is made up of continuous lines of force in or around the part. If these continuous lines of force are disturbed or distorted they form magnetic flux leakage areas. As ferromagnetic particles are applied to the part, the particles are attracted to the magnetic flux leakage and form indications that can be evaluated for severity.

References

A. Section 1, Part 1
B. Chapter 2

Chapter 3 Review Questions

Q.3-1 The lines of magnetic flux within and surrounding a magnetized part or around a conductor carrying a current is known as:

a. saturation point.
b. magnetic field.
c. ferromagnetic.
d. paramagnetic.

Q.3-2 The end of a magnet at which the lines of flux are thought of as entering the bar is:

a. the north pole.
b. the south pole.
c. both north and south poles.
d. none of the above.

Q.3-3 The lines of force that form a path around and above a crack in a ring magnet are called:

a. magnetic lines.
b. flux leakage.
c. field strength.
d. longitudinal field.

Q.3-4 A curve is sometimes drawn to show graphically the relationship of the magnetizing force to the strength of the magnetic field produced in a material. This curve is known as the:

a. magnetic force curve.
b. hysteresis curve.
c. saturation curve.
d. induction curve.

Q.3-5 The point at which the flux density in a material cannot be increased even though the magnetizing force continues to increase is known as the:

a. salient pole.
b. saturation point.
c. residual point.
d. remnant point.

Q.3-6 The magnitude of the residual magnetic field in a specimen is dependent on:

a. the length to diameter ratio.
b. the strength of the applied magnetizing force.
c. the right hand rule.
d. the left hand rule.

Q.3-7 Coercive force:

a. describes the means by which the magnetic particles are suspended in the liquid when using the wet method.
b. describes the magnetizing force used with the continuous method.
c. represents the reverse magnetizing force necessary to remove the residual magnetism in a material.
d. is not a term used in magnetic particle testing.

Q.3-8 If a crack exists in a circular magnet, the attraction of magnetic particles to the crack is caused by the:

a. coercive force.
b. leakage field.
c. Doppler effect.
d. high reluctance at the crack.

Chapter 4
Electrically Inducing Magnetism

Electrical Currents

Inducing magnetism by electrical means is the most common method used today. Alternating current and three types of direct current are used. Each has advantages and disadvantages.

Alternating Current

Alternating current is an electrical flow that reverses every half cycle. Due to the reversing current, the magnetic field in a part is also reversing. This increases the mobility of the applied particles. In addition, the frequency of reversals limits the magnetic field to the surface of the part and produces a *skin effect*. Because of this skin effect, alternating current is a more sensitive test for surface type discontinuities. One final advantage is that the lack of depth of the magnetic field makes demagnetization of the part easier.

Half Wave Direct Current

Half wave direct current is produced in the equipment by rectification of the alternating current. Note in Figure 4.1 that alternating current passes through the rectifier and half wave direct current is the output.

This type of rectification produces current pulses that induce direct current magnetism in the part. This type of current is sometimes called *pulsating direct current*. The advantages of this type of current are that the magnetic field has a deep penetration and the pulses increase the sensitivity of the test. This type of current is very effective for detecting subsurface discontinuities, especially with dry particles. A disadvantage is that this current cannot be used to demagnetize a part.

Full Wave Direct Current

Full wave direct current is created by rectifying alternating current and inverting the negative pulse. The result of this process is the waveform shown in Figure 4.2.

Note that this is single phase alternating current that is rectified. One advantage of full

Figure 4.1: Half wave direct current waveform

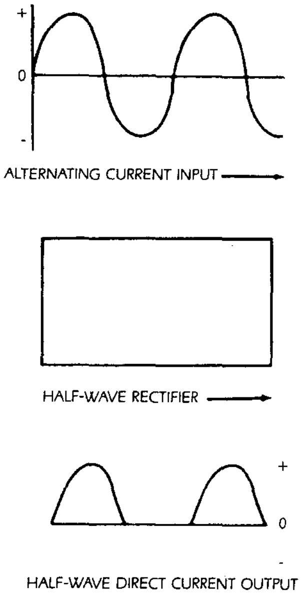

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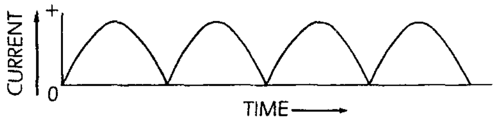
Figure 4.2: Single phase full wave direct current waveform



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wave direct current is that it can be reversed, thereby enabling the demagnetization of very thick parts requiring demagnetization. This demagnetization method is often called the *step down method*. A disadvantage of full wave is that it requires greater input current. This tends to limit the higher amperage requirements for large parts.

Three Phase Full Wave Direct Current

Equipment powered by 220 and 440 V alternating current can use three phase full wave direct current to magnetize parts. Taking three phase alternating current and rectifying and inverting all of the alternating current phases produces this current. This creates a direct current with very little pulsation. This type of current allows for high amperage induced magnetism with low current draw on the incoming alternating current lines. In addition, this type current allows for the use of quick break currents used in the longitudinal magnetism of parts.

References

A. Chapter 7, Sections 15 - 27
B. Section 1, Part 8
C. Chapter 2, Section 207

Circular Magnetic Fields

Field in and Around Parts

Materials with a circular field have a magnetic field that is contained *inside* the material and is perpendicular to the longitudinal axis of the material. This type of magnetic field does not have a north or south pole unless there is an interruption of the material. This interruption would cause a north and south pole to form and result in flux leakage at the interruption. An easy way to determine the direction of the magnetic field is to wrap your right hand around the part with your thumb pointing in the direction of the current flow. The fingers of your hand are in the same direction as the magnetic field. This method is commonly called the *right hand rule* as shown in Figure 4.3.

Methods of Inducing Circular Fields

There are two primary methods to induce a circular magnetic field in a material. The first method is to apply a current through the material. Figure 4.4 shows two ways of creating a circular magnetic field by passing current through a material. The first method is accomplished by placing the part between two headstocks and the second method is by using prods to couple the current through the material.

The other means of inducing a circular magnetic field in a material is by using a central bar conductor as shown in Figure 4.5. Note that the current is passed through the conductor, establishing a magnetic field. The magnetic field, preferring to pass through the material

Figure 4.3: The right hand rule indicates the direction of magnetic flux flow based on the direction of the magnetizing current

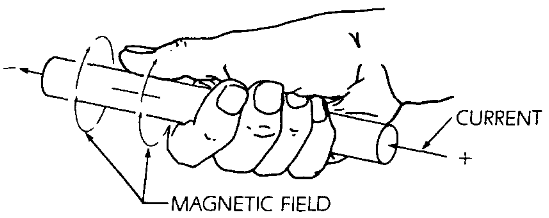

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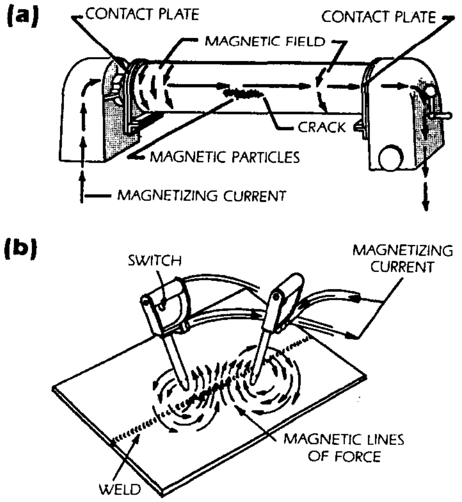
Figure 4.4: Circular magnetization of typical test objects: (a) circular magnetization caused by passing electric current from contact plates through the test object; and (b) production of a localized circular field by passing electric current between contact prods



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rather than the air, induces a circular magnetic field in the material. Central bar induced circular magnetic fields are especially effective in detecting discontinuities on the inner surface of hollow parts.

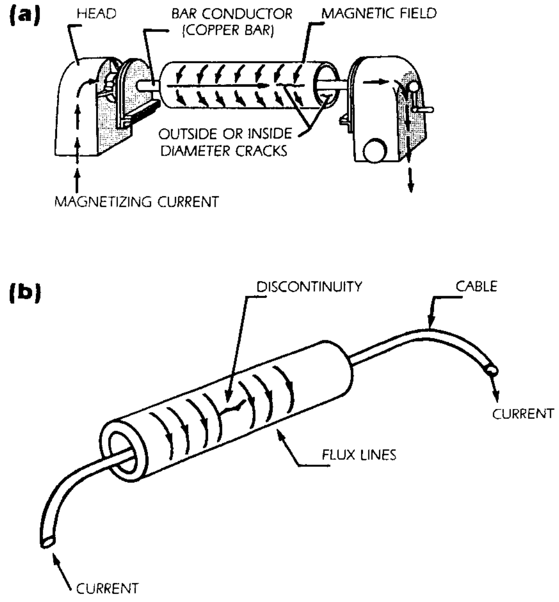
Circular Magnetic Field Strength

Note that the following information for computing current requirements is general in nature. Specific current requirements should always be determined by the controlling process data. The controlling process data, as referred to in this study guide, could be a customer specification, an industrial standard or a similar type document.

As a general rule, current requirements for directly inducing circular magnetism are between 300 to 800 A per inch of material cross section. The length of the part is not a factor in determining the current requirement. Therefore two parts, one measuring 2 in. × 8 in. and the other 2 in. × 20 in. would both require between 600 to 1600 A to directly induce a satisfactory circular magnetic field.

When using prods to induce the magnetic field the spacing between the prods must be controlled. The amperage required to induce a satisfactory field is directly related to the thickness of the material and the distance between the prods. This tends to be a disadvantage of using prods because at larger distances the current requirement can be very high thereby increasing the chances of damaging the material by arcing.

Figure 4.5: Circular magnetization of cylindrical objects using an internal current carrying conductor: (a) internal bar conductor and (b) internal cable conductor



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When inducing a circular magnetic field in hollow parts the amperage required to induce a satisfactory field depends on several things. First, if only the internal surface is to be tested and the central bar conductor is not offset, only the distance between internal surface areas of the part need be used to calculate the amperage.

If the central bar conductor is offset then the amperage requirement is directly proportional to the diameter of the conductor plus two times the part's wall thickness. In addition, when an offset central bar conductor is used the effective distance of satisfactory magnetism is considered to be four times the diameter of the central bar conductor. This means that the part will have to be magnetized several times with each effective area being overlapped by approximately 10 percent.

Discontinuities

Discontinuities found with circular magnetism can be reliably detected when oriented from approximately 45 to 90 degrees to the magnetic field. It can also be said that for materials with circular magnetic fields, discontinuities will be parallel to the longitudinal axis of the material. Both statements say the same thing but from a different perspective. The directions of the discontinuities that can be found are shown in Figures 4.4 and 4.5.

References

A. Chapter 7, Sections 11-14
B. Section 1, Part 5, Section 6, Part 2 and Section 17, Part 2
C. Chapter 2 Section 203 and 208

Longitudinal Magnetic Fields

Field in and Around Parts

Materials that have a longitudinal field have a magnetic field that passes through and outside the part and is parallel to the longitudinal axis of the material. This type of magnetic field creates a north and south pole at the ends of the material. However, in the case of a very long part, north and south poles could occur at several places along the length of the part. These are referred to as *consequent poles.*

Figure 4.6: Longitudinal or coil magnetization: (a) longitudinal magnetic flux within a current carrying magnetization coil; (b) longitudinal magnetization with a coil; and (c) typical arrangement of coil and test object for longitudinal magnetization

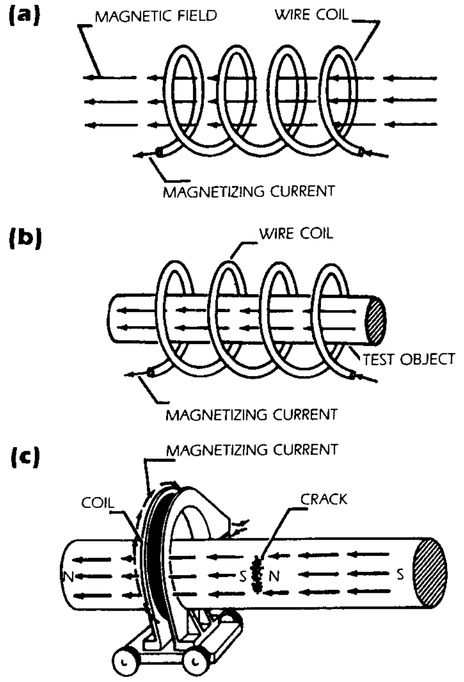

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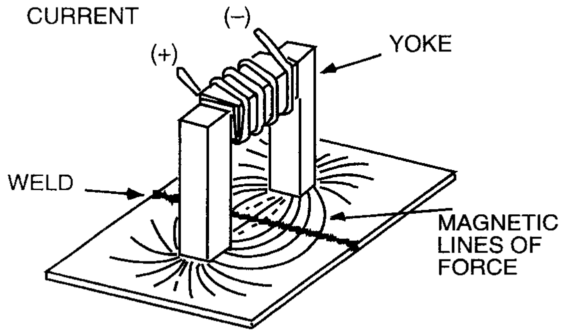
Figure 4.7: Longitudinal magnetic field generated by a yoke



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Methods of Inducing Longitudinal Magnetic Field

The primary method of inducing a longitudinal magnetic field in a material is with a coil. As the current passes through the coil a longitudinal magnetic field is created as shown in Figure 4.6a.

When a material is magnetized in the coil the magnetic lines of force enter the material and create a longitudinal field as shown in Figure 4.6b. The longitudinal field in the part creates a readily detectable north and south pole at opposite ends of the part. Figure 4.6c shows a part in a stationary magnetic particle machine's coil.

A second method of inducing a longitudinal magnetic field is by using a yoke. This method is shown in Figure 4.7. Note that the current is passed through a coil on the yoke. The resulting magnetic lines of force are passed through the yoke and into the part. This is a very portable and effective method to induce longitudinal magnetism.

A third method is by using permanent magnets.

Longitudinal Magnetic Field Strength

Note that the following information for computing current requirements is general in nature. Specific current requirements should always be determined by the controlling process data, which could be a customer specification, an industrial standard or a similar type document.

There are several formulas for determining the amperage requirements for inducing longitudinal magnetism in a material. The first thing a technician must determine is the degree of fill factor between the coil and part. The three factors are:

- Low fill factor – The cross sectional area of the coil is ten times or greater than the cross sectional area of the material being magnetized.
- Intermediate fill factor – All situations between low fill factor and high fill factor.
- High fill factor – The cross sectional area of the coil is less than two times the cross sectional area of the material being magnetized.

The second thing that must be determined is the placement of the part in the coil. For most situations the part may be placed against the inside wall of the coil. In other situations the part may be centered in the coil. Each situation creates a different ampere requirement.

The third thing to consider is the length to diameter ratio of the item. This ratio assumes the part is solid. If the part is hollow then D effective (D_{eff}) must be used for the diameter of the part. D_{eff} is calculated using the following formula:

$$D_{\text{eff}} = \left[(OD)^2 - (ID)^2\right]^{1/2}$$

Equation 1

The basic formula for calculating the ampere requirements for inducing longitudinal magnetism where there is a low fill factor, the part is solid and against the coil wall is:

$$\text{Ampere turns} = \frac{45\ 000}{L/D}$$

Equation 2

There are several things to understand about this formula. First, *ampere turns* is made up of two components: amperes and turns. *Ampere* is the required current the machine will need to produce to induce a satisfactory longitudinal magnetic field in the material. *Turns* is the number of turns in the coil of the machine. For example, the result of this formula may be 15 000 ampere turns. To determine the shot's actual ampere requirements, the 15 000 would have to be divided by the number of coil windings used. For a five-turn coil, the required amperage would be 3000 A. Therefore, the number of coil turns must be known.

Second, 45 000 is considered a constant for situations where the coil has a low fill factor. In situations where the part is centered or there is an intermediate or high fill factor, the constant changes.

Third, the result of the length to diameter ratio must be between two and fifteen or special considerations must be made. End pieces can be used to increase the length of short parts thereby increasing the ratio. Because the normally effective magnetic distance on either side of coils is considered to be 9 in., the length of the part that can be effectively magnetized is limited and this must be taken into consideration when performing the calculations. This does not mean that longer parts cannot be magnetized. Longer parts require more shots to effectively magnetize them.

Consider the use of this formula for a part 8 in. long and 2 in. in diameter.

$$\text{Ampere turns} = \frac{45\ 000}{8/2}$$

The result would be 11 250 ampere turns. If the number of coils used is five then the ampere requirements would be 2250 A.

Discontinuities

Referring again to Figure 4.6c, note that this type of magnetism can detect discontinuities that are approximately 45 to 90 degrees to the longitudinal magnetic lines of force. It can also be said that this method can detect circular or circumferential discontinuities.

References

A. Chapter 7, Sections 4-10 and Chapter 9, Section 8
B. Section 1, Part 5, Section 6, Part 2 and Section 17, Part 2
C. Chapter 2 Section 203 and 208

Chapter 4 Review Questions

Q.4-1 Alternating current produces a magnetic field in a part that has a better sensitivity to detect:

a. surface discontinuities.
b. subsurface discontinuities.
c. surface and subsurface discontinuities.
d. none of the above.

Q.4-2 Which type of current is limited to the surface because of skin effect?

a. alternating current
b. direct current
c. half wave rectified direct current
d. full wave rectified direct current

Q.4-3 How is half wave direct current created?

a. By alternating applications of battery power.
b. By transforming alternating current.
c. By rectifying alternating current.
d. None of the above.

Q.4-4 Which current is best for detecting fine surface cracks?

a. alternating current
b. direct current
c. half wave rectified direct current
d. full wave rectified direct current

Q.4-5 Which current is best for detecting subsurface discontinuities using magnetic particle testing with dry particles?

a. alternating current
b. direct current
c. half wave direct current
d. full wave direct current

Q.4-6 What effect does the length of the part have in determining the correct amperage to induce a circular magnetic field?

a. As the length increases the amperage must increase.
b. As the length decreases the amperage can be decreased.
c. The length does not have any affect on the required amperage.
d. The length is restricted to ensure a ratio between 2 and 15.

Q.4-7 Circular magnetism can be induced in a material by:

a. placing the material in headstocks and passing a current through it.
b. placing prods on the material and passing current through it.
c. putting a central bar conductor through a tubular part and passing current through the bar.
d. all of the above.

Q.4-8 To ensure the inside of a hollow part is properly tested for lengthwise discontinuities, the part should by magnetized by:

a. passing current through the part.
b. placing the part in a coil.
c. passing current through a central bar conductor.
d. any of the above would provide satisfactory results.

Q.4-9 What is the effective test area in a part magnetized with an offset central bar conductor?

a. Two times the diameter of the central bar conductor.
b. Four times the diameter of the central bar conductor.
c. Nine inches on either side of the coil.
d. None of the above because the entire part will be magnetized.

Q.4-10 Longitudinal magnetism is induced in a material by:

a. probes.
b. coil.
c. a yoke.
d. both b and c.

Q.4-11 What determines the correct ampere turns for inducing a longitudinal magnetic field in a part?

a. The diameter and length of the part.
b. The placement of the part in the coil.
c. The amount of fill factor between the part and coil.
d. All of the above are factors.

Q.4-12 Where is the strongest magnetic field in a coil?

a. Along the outside edge.
b. Along the inside surface.
c. In the center of the coil.
d. All of the above because the field distribution must be equal.

Q.4-13 The ampere turns for inducing a longitudinal field has been determined to be 15 000 ampere turns. If the stationary unit's coil has five windings, what amperage should the unit be set for to properly magnetize the part?

a. 3000 A
b. 5000 A
c. 7500 A
d. 15 000 A

Q.4-14 When is it necessary to use D_{eff} to calculate ampere turns?

a. When there is a low fill factor.
b. When there is a high fill factor.
c. When the part is hollow.
d. At all times when calculating length to diameter ratios.

Q.4-15 Which type of magnetic field produces a readily detectable north and south pole in a part?

a. circular
b. longitudinal
c. circular when a central bar conductor is used
d. circular when a yoke is used

Q.4-16 Magnetic flux lines that are parallel to a discontinuity produce:

a. strong indications.
b. weak indications.
c. no indications.
d. fuzzy indications.

Chapter 5
Magnetic Particle Testing Particles

General Requirements

Without particles the ability to detect flux leakage created by discontinuities would be next to impossible and would render the magnetic particle testing method ineffective for all but very special applications. Therefore the particles are critical to the testing process.

The ability of an indication to be formed during a magnetic particle test is very dependent on the types of particles used to form the indication. Dry and wet are the two major classifications of particles. Of these, dry particles are normally visible while wet particles are either visible or fluorescent. Of the wet particles, fluorescent are used more frequently than visible.

There are several key factors that must be taken into consideration when choosing the particles to be used. First, the particles must be ferromagnetic and must have high permeability and low retentivity. This means that particles must be easily attracted by a magnetic field but also easily demagnetized. This is important if the particles are to be attracted to weak areas of flux leakage created by small discontinuities, such as small stress cracks. However, when a test is completed, the particles must be easily demagnetized for removal from the part.

Another key factor is the mobility of the particles. When applied, the particles must be able to move to the areas of flux leakage and form indications. Along with mobility, the particles that form an indication must be of sufficient contrast to the part or material to be readily visible. For this reason particles come in different colors to increase their contrast to the material's color. Visible particles are viewed under the proper strength of white light, whereas fluorescent particles must be viewed under the proper strength of ultraviolet light with minimal ambient white light levels. In darkened conditions the human eye is very sensitive to the light emitted by fluorescent particles viewed under ultraviolet light, making these particles preferred for detecting fine stress cracks.

From a safety standpoint, the particles should be nontoxic and should not cause damage to the item being tested.

Application Methods

Particles, either wet or dry, are applied by two methods: *residual* and *continuous*.

In the residual application method the magnetic field is established in the part or material and then the particles are applied. This method requires that the part or material have a retentivity that results in a high residual magnetic field. This method can be used with either dry or wet particles.

In the continuous method the particles are applied to the part or material first, the application is stopped and the magnetizing current is immediately applied. This method is more sensitive than the residual method because the magnetic field strength when applied to a part is higher than the residual field, therefore there is a strong flux leakage produced if a discontinuity is present. When the magnetizing current is first applied the current reaches a peak and then decreases. At this peak, there is a stronger magnetic field in the part or material than when the current is removed. This can be easily seen in a hysteresis loop of a material. Therefore it follows that a flux leakage will also be stronger during the magnetization of the part or material, which results in a greater attraction of the particles to the flux leakage.

In the residual and the continuous methods, the actual application of the particles is important. If the wet particles are applied too forcefully the flux leakage may not be able to attract them. If they are applied too sparingly, there may not be sufficient particles to form an indication that can be seen. Generally dry particles are dusted or gently blown onto the material being tested. Wet particles, as the name implies, are suspended in a liquid medium and are flowed, sprayed or poured over the part.

Dry Particles

The sensitivity of dry visible particles is in several ways directly related to the size of the particles. While there is an increase in sensitivity as the particle size becomes smaller, the smaller size is also more difficult to see, requires a higher concentration and can be masked by backgrounds of the material under test. Therefore, most dry particle mixtures are made up of a range of sizes. In addition, to increase the mixture's sensitivity, the choice of the color of the particles is usually one that results in a high contrast to the background of the part or material.

Dry particles are applied to the surface in a manner that provides for a uniform dusting of the surface. Some specifications use the term *float* to describe the application process. One important point is that once applied, the particles lose mobility. This can be overcome by gently tapping the part. In addition, the use of alternating current and half wave rectified alternating current tends to increase the mobility of the dry particles with the latter providing the best mobility.

Generally, dry particles used in magnetic particle testing are said to be visible because they reflect light from the visible range of the spectrum. This is not to say that dry particles could not be fluorescent. The advantage of dry particles is that they tend to be highly portable and excellent for remote field applications. In addition, dry particles are more sensitive for detecting subsurface discontinuities.

Wet Particles

Ferromagnetic particles used in stationary magnetic particle testing equipment are suspended in a liquid vehicle that increases the mobility of the particles and provides a means for easy application. The liquid vehicle can range from water to special petroleum based liquids. Two disadvantages of this method are that the particles must be continuously agitated in the liquid and the concentration must be controlled.

In stationary wet baths, particle concentration levels are very critical. Concentration levels must be verified according to the controlling process data or procedure. A variation in the concentration level can result in masking of indications if the concentration is too high or no particle build up if the concentration is too low. This can lead to missed discontinuities or erroneous identification of indications. Wet particles also come in aerosol sprays that increase the portability of the method and decrease concentration level concerns.

Wet particles may be applied by pouring or spraying the particles onto the part or material. In addition, parts can be dipped in an agitated bath. If the parts are dipped, they must remain in the bath for a sufficient time to allow the particles to be attracted to any flux leakage areas.

In many cases where wet particles are used, the particles are colored with a fluorescent dye. This requires that the particles be used in a darkened work area [usually 21.5 lux (2 ftc) or less] and inspected under an ultraviolet light. Wet fluorescent particles are very sensitive to the detection of fine surface discontinuities such as stress cracks.

References

A. Chapter 11
B. Section One, Part 10
C. Chapter 4, Sections 401 and 402

Chapter 5 Review Questions

Q.5-1 What is a major consideration when selecting the particles to be used to perform a magnetic particle test?

a. The particles must be very small.
b. The particles provide a high contrast to the surface under test.
c. The particles must be able to absorb the vehicle to increase their mobility.
d. All of the above.

Q.5-2 Why do dry particles come in different colors?

a. To increase the ability of the technician to detect indications.
b. To increase the color contrast of the particles to the surface under test.
c. Different colors represent different sensitivity levels.
d. a. and b.

Q.5-3 A key factor for selecting magnetic particles for magnetic particle testing is that they have:

a. good mobility.
b. high permeability.
c. low retentivity.
d. all of the above factors to be an acceptable testing medium.

Q.5-4 What method of applying magnetic particles is considered the most sensitive?

a. residual
b. continuous
c. modified residual
d. multidirectional residual application

Q.5-5 When the residual application method is used, what magnetic characteristic must the part have?

a. low permeability
b. high retentivity
c. high permeability
d. low retentivity

Q.5-6 When applying the magnetic bath during the continuous application method, when is the flow of the bath stopped?

a. While the current is being applied.
b. Just before the current is applied to the part.
c. After the current has been applied to the part.
d. All of the above are acceptable for the continuous application method.

Q.5-7 When inspecting a weld for subsurface indications using dry particles, which current will provide the best results?

a. direct current
b. alternating current
c. half wave rectified direct current
d. full wave rectified direct current

Q.5-8 What is the proper method to apply dry particles?

a. Pour on the part and gently blow off.
b. Blow onto the part with a particle/fluid mixture.
c. Gently float onto the part providing a uniform dusting.
d. All of the above are acceptable methods of applying dry particles.

Q.5-9 If the concentration level of the magnetic particle bath is not maintained at the proper level, possible indications may be:

a. missed.
b. masked.
c. erroneously identified.
d. All of the above.

Q.5-10 What is a major advantage of dry visible particles over wet fluorescent particles?

a. They come in only one color.
b. They are more sensitive to small stress cracks.
c. They do not require an ultraviolet light or darkened area.
d. All of the above.

Chapter 6
Method Selection Criteria

Knowing the principles of magnetic particle testing and applying them correctly requires that nondestructive testing personnel understand method selection criteria. This section does not explain how to choose the proper methods to perform a satisfactory magnetic particle test. It does present many factors that must be considered in selecting the proper methods. As in all nondestructive testing methods, the inspector is required to perform the test according to the established procedure or specification. However, by knowing the method selection criteria, the inspector can better understand the procedure or specification, or recognize the lack of required data and take appropriate steps to correct the situation.

Standards and Specifications

Every magnetic particle test should be covered by a procedure based on acceptable standards and/or specifications. A *standard* is a document that covers broad and general information on the testing method. It can usually be applied across a wide spectrum of materials or industries.

A *specification* is a more specific document that covers the testing of an item or class of items. A specification is often written into a contractual agreement and places testing requirements on one or all parties to the agreement.

A *procedure* is usually a brief document that specifies the exact steps to perform magnetic particle testing on a particular part. The procedure is written by the agency performing the testing and is based on a specification or standard. In some cases, such as the aerospace industry, a procedure is written into the aircraft maintenance manual and becomes part of the routine maintenance actions performed to maintain airworthiness.

All magnetic particle tests should be completed according to written documentation. The degree of specificity of the document is dependent on the industry, the contractual parties or a governing body.

References

A. Chapter 25
B. Section 17, Part 1
C. Chapter 1, Section 106 and 107

Part Geometry

When selecting the test criteria, the geometry of the part must be considered. Failure to do so can cause discontinuities to be missed. When considering the part geometry, understanding the type of discontinuity the part is being tested for and the general orientation of the discontinuity should be addressed first.

For optimal results the discontinuity and the magnetic field should be oriented 45 to 90 degrees to each other. In some cases the geometry of the part can cause a distortion of the magnetic field. Different diameter sizes in the same part can cause the procedure to require multiple shots at increasing amperages. Or a part with a *Y* configuration might require multiple shots at the same amperage but at different locations. Also the use of alternating current can be more effective on parts with small varying diameters because this type of current follows the contour of the part.

Parts with hollow areas may require not only the inspection of the external surface but also the inner surface. In this case, a central bar conductor test would be required to induce circular magnetism.

In addition, locations on a part that could cause nonrelevant indications should be considered. Keyway slots, cotter pin holes, sharp radius or different material junctions, such as heat treated areas, could cause nonrelevant indications.

When procedures are written for a part that has a complex geometry, the writer of the procedure must validate the individual shots. This validation is completed by not only using mathematical formulas but also quality indicators that can demonstrate the procedure's ability to detect discontinuities in areas under inspection.

References

A. Chapter 9, Section 15 and Chapter 10
B. Section 6, Parts 3 and 7
C. Chapter 2, Section 206

Part Size

A part's size is an important consideration in determining the amperage required to induce a satisfactory field. In circular magnetism the key element of the part's size is the diameter. A part with multiple diameters may require progressively stronger amperage shots to test the entire part. While length is not a factor in determining the amperage required, it is a factor in determining the type of equipment that can be used.

In a longitudinal magnetic particle test, the size of the part has an affect on the length to diameter ratio. The length to diameter ratio must be from 2 to 15 for effective magnetization. In some cases short parts will need extensions and long parts will require multiple shots for effective magnetization. Parts with large diameters will require either stationary units with very large coils or the use of cables to induce a satisfactory field.

References

A. Chapter 10
B. Section 6, Part 3
C. Chapter 2, Section 208

Types of Discontinuities

It is important to know what type of discontinuity is suspected in a part or material to determine the proper process. It has already been pointed out that surface discontinuities are better found with alternating current, while subsurface discontinuities are better found with half wave rectified direct current. Therefore, by knowing the type of suspected discontinuity, the selection of current can be made with better certainty of finding the discontinuity. There are other factors to consider.

The orientation of the possible discontinuity should be known to a reasonable degree. This is important because the discontinuity will be most detectable if it is 45 to 90 degrees to the magnetic field. By knowing the orientation, an inspector will have a better understanding of which method to use to induce the magnetic field.

Another factor to consider is whether the suspected discontinuity is on the outer or inner surface of a hollow part. This knowledge determines if a central bar conductor should be used to induce the circular magnetic field as opposed to a head shot. A head shot will produce a strong field at the outside diameter, while a central bar conductor will induce a stronger field at the inside diameter.

Finally, consider how and when the suspected discontinuity was formed or created. This is often overlooked in the training of personnel. A technician must understand the primary forming process and subsequent primary and secondary processes used to make the part. In addition it is important that the technician understand how the part or material is used while in service. Obviously if the testing takes place during one of these processes, the subsequent processes will not be a factor.

A more comprehensive discussion on discontinuities is contained in Chapter 7 of this study guide. Suffice it to say that it is important for the technician to understand the type of discontinuities a part is being tested for to increase his or her ability to find them.

References

A. Chapter 22, Sections 4, 5 and 6
B. Section 1, Part 2
C. Chapter 5, Section 511

Selection of Technique

The selection of the magnetic particle testing technique to be used on a part must take into consideration several basic factors including type of current, type of particle, method of application, type of magnetism, amperage, equipment to be used and testing environment.

Current

As previously presented, the type of current is to a degree dependent on the location of the discontinuity to be detected but also on the equipment available.

Particles

The key factor in choosing magnetic particles is which particles will provide the best sensitivity for the acceptance criteria. For stress cracks, fluorescent particles in a wet bath are preferred. For subsurface discontinuities in welds, dry, color contrast particles are best.

Application

While the continuous method of particle application is very sensitive, there may be valid tests that require residual application.

Magnetism

Either circular or longitudinal magnetism must also be considered. In some applications only one may be required, while in others both may be required. In addition, depending on the part geometry there may be a need for multiple shots or the use of a central bar conductor.

Longitudinal should generally be done after circular to aid demagnetization verification.

Amperage

The amperage used to induce the magnetic field or fields must also be considered, and this will be addressed in the next section.

Equipment and Environment

While it may be preferable to do a test in a large stationary unit, one may not be available. In this event, a large mobile unit that requires cables and prods might be used. Of course, the type of part can affect the method of inducing the current. For example, prods used to induce circular magnetism cannot be used on aerospace parts because of the chance of creating arc burn marks.

Availability of lighting greatly affects the test environment. While visible dry particles work well in bright daylight, fluorescent particles do not. Many specifications require 21.5 lux (2 ftc) or less of ambient light in the testing environment during fluorescent magnetic particle testing. Consideration of the test environmental conditions is a must.

References

A. Chapter 12
C. Chapter 5

Determination of Field Strength

There is a relationship between the strength of the magnetic field and the sensitivity of the results. Without the proper field strength, sufficient flux leakage will not be created at the discontinuity site to attract the magnetic particles. However, too much field strength can cause accumulation of particles over the entire part surface, masking indications and causing discontinuities to be missed. So how is the proper field strength determined?

There are general rules that apply to determining the amperage to use to induce sufficient current to produce a satisfactory magnetic field. For circular magnetism the general rule is 300 to 800 A to each 1 in. cross section. For longitudinal magnetism there are several formulas that can be used depending on the size of the part and amount of fill factor for the coil. However, these general rules are only starting points.

Once an inspector knows the starting point, he or she can use other methods to determine the proper strength. One method is by using a pie gage as shown in Figure 6.1. A pie gage is a device with several sections of very permeable material separated by nonmagnetic material. The gage is placed onto the part, with the copper shim facing the technician, a bath is run over the gage and a current is applied. By viewing the indications on the gage the technician can determine the direction of the magnetic field and the approximate strength.

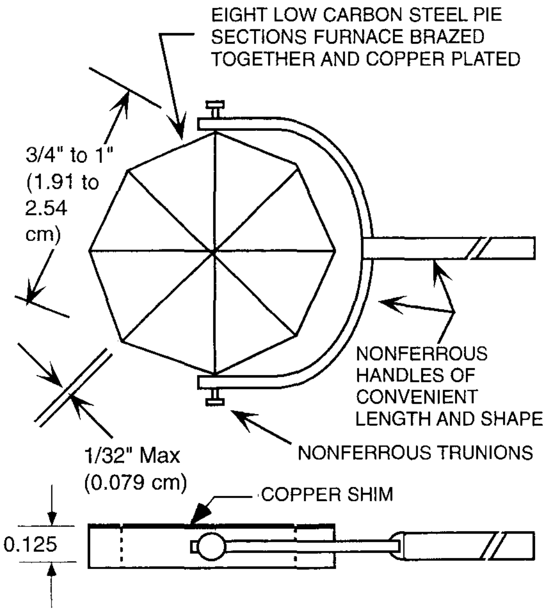
Another device used to determine field strength and direction is the *quantitative shim* with an artificial discontinuity also called a *quantitative quality indicator* (QQI). This shim is made of a very permeable material and has an etched impression on it, such as a circle with a cross hair. The shape of the impression varies.

The shim is glued or taped to the part, impression side down, at the location where discontinuities are to be found. The part is then processed through the magnetic particle procedure. The resulting indications on the shim are used to determine if a satisfactory field direction and strength has been established.

It must be kept in mind that both the pie gage and the quantitative shim only indicate external fields and the approximate field orientation and strength. However, they are widely used and accepted in most industries.

The most common electronic means to measure the external field strength on a part are hall effect meters or gaussmeters. However,

Figure 6.1: Pie gage magnetic field indicator comprises eight low carbon steel triangles, furnace brazed together and copper plated



Reprinted from *ASNT Level III Study Guide: Magnetic Particle Testing Method*, second edition, pg 31.

these devices also measure only the external surface field strength.

One last method to determine the proper field strength is to run a test on a part with a known discontinuity. This method is acceptable if the discontinuity is truly representative of the type and size to be found in a part. Given the choice between gages, shims and electronic devices, this would be the preferred method to determine the proper field strength and develop a procedure.

There is no known nondestructive technique to determine the field strength inside a part. While one might consider drilling a hole and measuring the strength in the hole, this would not be a true strength measurement because the hole would distort the magnetic field.

References

A. Chapter 8, Section 2
B. Section 9, Part 4 (page 241 and 242) and Section14, Part 3 and 4
C. Chapter 2, Section 208

Part Preparation

While the preparation of a part for a magnetic particle test is not as stringent as for a penetrant test, there are steps that must be taken. Basically, parts must be free of dirt, grease, rust, scale or organic materials that could interfere with the development of flux leakage indications and contaminate magnetic particle baths.

The basic process should include a solvent cleaning of the part. If there is a heavy build up, mechanical cleaning can be used. One word of caution is that soft steels should be shot or grit blasted carefully to avoid masking any surface indications. While the masked surface indications may still show up as subsurface indications, this is not an acceptable practice.

Painted parts can present a problem if circular magnetism is to be used. With the exception of a central bar conductor induced field, current must be passed through the part to create the circular field. Therefore the paint must be removed to a limited degree to ensure good electrical contact between the contact heads and the part. Some specifications limit the thickness of paint to 0.003 in. Thicknesses greater than that require the paint to be removed. In addition, the paint surface can decrease the sensitivity of tests for fine stress cracks. Surface indications on painted parts will appear somewhat fuzzy and lack good clear definition.

Plated parts can present additional problems. Though most plating is very thin, it can cause fine cracks in the base metal to appear as subsurface indications. In addition, the reverse is true; very hard plating may crack but not the base metal. Nickel platings are themselves ferromagnetic. Chrome plating may crack and be a source of nonrelevant indications. Thick or nonferrous plating may cause discontinuities in the base metal to be missed completely. It is important that the technician check the specification or procedure when testing plated parts.

References

A. Chapter 13, Section 5 and Chapter 14, Section 12
B. Section 6, Part 3, page 154 and Section 17, Part 2
C. Chapter 5, Section 510

Sequence of Operations

After considering the technique selection criteria already discussed, the next step is to determine the sequence of operations that must take place to complete a magnetic particle test. While this would appear to be very straightforward, many factors must be taken into consideration. The following steps must be completed for a test in a stationary unit:

1. Part preparation.
2. Setting up the equipment.
3. Application of the particles.
4. Application of the current.
5. Inspection of the part.
6. Demagnetization.
7. Postcleaning of the part.
8. Documentation of the test.

There can be many variations to this list. There can be multiple shots with demagnetization steps in between. The procedure might require residual application of the particles instead of continuous. The important point to remember is that testing should be completed based on procedures. The procedures will establish the sequence of operations to conduct a satisfactory test. It is only through the use of procedures that tests can be standardized and parts processed in the same manner.

References

A. Chapter 12, Section 2
B. Section 17, Part 1

Chapter 6 Review Questions

Q.6-1 A document that specifies the step-by-step directions to complete a magnetic particle test would be called a:

a. specification.
b. standard.
c. procedure.
d. None of the above.

Q.6-2 A hollow part's geometry would require what type of magnetic particle test to detect longitudinal stress cracks on the inner surface?

a. Circular magnetism applied with a head shot.
b. Circular magnetism applied with a central bar conductor.
c. Longitudinal magnetism applied with a head shot.
d. Longitudinal magnetism applied with a central bar conductor.

Q.6-3 In which type of magnetism is the length of a part not a criterion for determining the amount of current to be used?

a. Circular magnetism applied with headstocks.
b. Circular magnetism applied with prods.
c. Circular magnetism applied with a coil.
d. Both a. and b.

Q.6-4 Why should a technician know what type of discontinuity the magnetic particle procedure is designed to detect?

a. Knowing the type of discontinuity can save time and money.
b. Knowing the type of discontinuity enhances the chances of finding it.
c. Knowing the type of discontinuity can eliminate doing the magnetic particle test.
d. Both a. and b.

Q.6-5 Selecting the technique for doing a magnetic particle test includes:

a. knowing the amount and type of current.
b. knowing the manner to apply the particles.
c. knowing the type of equipment.
d. All of the above.

Q.6-6 A pie gage is used to determine:

a. the general direction and approximate strength of the magnetic field induced in a part.
b. the specific direction and strength of the magnetic field induced in a part.
c. the strength of the internal magnetic field.
d. to cut pies into equal portions.

Q.6-7 When do painted parts need the paint removed?

a. When the current is applied in a coil.
b. When the current is applied with a central bar conductor.
c. When the current is applied with headstocks.
d. All of the above, because paint removed is always required for magnetic particle tests.

Chapter 7

Testing and Evaluation of Indications

Terms

The terms used during the testing of parts are sometimes misused and misleading. More than one inspector has found himself or herself in a difficult position when explaining that the *defect* found was only a *nonrelevant indication*. This misuse of terms clouds the reliability of the test and can cause the customer to question the test results. It is therefore important to understand that when a test is conducted there is a progression of terms to identify the results.

When a magnetic particle test is conducted, *indications* may be seen. These indications must be interpreted as either *relevant* or *nonrelevant*. The basic difference between a relevant or nonrelevant indication is whether the indication is a *discontinuity* (relevant) or an indication formed by the way the test was performed or the normal configuration of the part, such as a safety wire hole in the head of a bolt (nonrelevant).

If the interpretation of the indication results in it now being classified as a *relevant discontinuity*, then further evaluation must be conducted. This further evaluation determines if the discontinuity is a *defect*. The primary difference between a *discontinuity* and a *defect* is the acceptability of the item. A discontinuity whose size, shape, orientation or location make it detrimental to the useful service of the test object or which exceeds the accept/reject criteria of an applicable specification is considered a defect. However, there are other factors to consider. There can be a situation where a crack in a part may eventually be detrimental, but is within acceptable limits. In such cases, the test interval may be reduced to closely monitor the crack for growth.

In addition to understanding the terms used during the testing process, Level II personnel should understand the basic categories of discontinuities and when and how they are formed in metals.

Discontinuity Categories

There are four broad categories for discontinuities:

1. inherent discontinuities,
2. primary processing discontinuities,
3. secondary processing discontinuities,
4. in service discontinuities.

Inherent Discontinuities

Inherent discontinuities occur as the base metal is taken from a molten state to a solid state. Discontinuities formed during this process include blow holes, cold shuts, hot tears, inclusions, pipe, porosity and segregation.

Primary Processing Discontinuities

Primary processing discontinuities occur during the forming or fabrication stage of making a part. Forming and fabrication operations include: rolling, forging, drawing, extruding and welding in the case of fabrication. Discontinuities that can be formed during these operations include seams, laminations, laps, bursts and cooling cracks.

Seams are formed either during the rolling or drawing process. Figure 7.1 shows how a seam is formed during a rolling operation. Seam indications can appear as very fine cracks, but normally as edges that can be intermittent in length.

Laminations are separations caused by the rolling of a base metal that had inherent discontinuities such as inclusions or blowholes. Lamination indications are often found on the edge of the material after it has been cut and are parallel to the direction of rolling.

Laps are areas where the metal has been rolled or forged in a misaligned die thereby squeezing out material that is rolled or forged over. Figure 7.2 shows how a lap is formed. Lap indications are normally very fine and not jagged.

Bursts are either internal or external and are formed when a metal is worked at the improper temperature or at too high a rate of speed or material feed. Burst indications can occur in different directions and can be very deep.

Cooling cracks, as a primary processing discontinuity, may form during a rolling operation when cooling of the material is not properly controlled. The uneven cooling causes internal pressures that are released by the cracking of the material. Cooling crack indications are normally forked and do not necessarily follow any pattern or direction in the part.

Figure 7.1: Formation of a seam: (a) underfill results when there is not enough metal to fill the rolls; and (b) a seam in the finished bar occurs when underfill is squeezed tight on a subsequent rolling pass

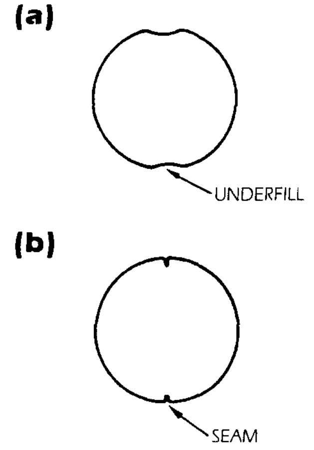


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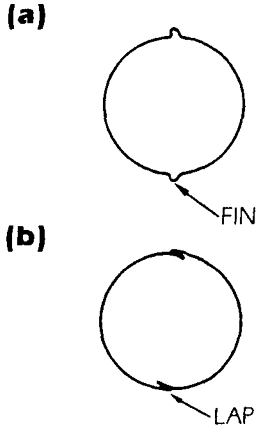
Figure 7.2: Formation of a lap: (a) an overfill produces excess metal squeezed out of the rolls causing a fin; and (b) a lap results when the projection is folded over and forced back into the bar's surface during a subsequent pass



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Forging Discontinuities

Forging operations can develop discontinuities unique to the forging operation. Such discontinuities include forging bursts, forging laps and flash line tears.

Forging bursts are the rupture of the material caused by working the material at an improper temperature or at too high a rate of speed or material feed. These ruptures can be internal or external. The external bursts can be easily detected by magnetic particle testing. The indications can be very jagged and vary in length and width. Internal bursts are not normally detected by magnetic particle testing.

Forging laps are caused by the misalignment of the dies as the material is worked, blanks that are too large for the dies or improper placement of the blanks in the dies. (See Figure 7.2.) Forging lap indications are usually smooth and straight or slightly curved.

Flash line tears are formed when a small amount of material from the die is squeezed between the dies and forms what is known as *flash.* After the forging operation the flash is trimmed from the forging. If the trimming operation is not done properly a tear or crack will form.

Casting Discontinuities

Casting operations involve the pouring of molten metal into molds to form objects. These operations can result in cold shuts, hot tears or shrinkage cracks, among others, being formed in the final product.

Cold shuts are formed when molten metal splashes inside the mold and solidifies on the mold wall before the remaining molten metal is poured. Cold shuts vary in size based on the size or shape of the mold, the amount of molten material being poured, or the temperature conditions of the molten material or the mold. Cold shuts often look very similar to a forging lap.

Hot tears are caused by uneven cooling between different sections of the casting. They usually occur at the junction of thick and thin sections of a casting. Hot tear indications look very much like cracks.

Shrinkage cracks occur as the molten material cools. As the material cools, it gets smaller or contracts, causing stress factors within the casting. These stresses are sometimes relieved by the formation of shrinkage cracks.

Welding Indications

Welding indications occur during the primary process stage and usually consist of lack of penetration or lack of fusion in the weld. Both of these indications are usually subsurface. The lack of penetration indication will normally be fuzzy and appear to progress down the center of the weld bead. The lack of fusion indication will be fuzzy and normally be to either side of the center of the weld bead.

In addition to these two welding indications, welding operations can also cause cracks, crater cracks, porosity, inclusions, overlap and undercut, among others.

Secondary Processing Discontinuities

Secondary processing discontinuities are formed during the manufacture or fabrication of products. These secondary processing operations involve taking products that have been forged, casted, extruded, or made by another primary processing method and performing finishing operations such as machining, heat treat and grinding.

During machining operations metal surfaces can be torn or burned. The tearing of the metal surface results from a tool bit dragging the metal surface instead of cutting it. A dull tool bit usually causes this tearing of the surface, although an improperly shaped tool bit can cause metal tears also. The burning of the metal surface can be caused by performing the machining operation at the improper speed or by a dull bit. Machining tears are normally very smooth and parallel to the direction of machining.

While heat treat cracks can be formed during the heating of the product, they often form during the cooling down operation. One type of crack is the quench crack that is formed when the heated part is cooled too rapidly by quenching it in a cooling medium. Other cracks can be formed when a heat treated part of varying thicknesses is allowed to cool in an uncontrolled manner. Heat treat cracks are normally jagged and do not follow any defined pattern.

Grinding cracks are caused by the overheating of a localized area by excess grinding. Grinding cracks usually appear as very fine localized cracks with no discernible pattern. They have also been described as having the appearance of lightning in the sky, or as a series of parallel indications, or when severe, as a lattice network. Grinding cracks are not normally deep, however, they are very serious because they do form stress risers in the product.

In Service Discontinuities

In service discontinuities are formed while the product or part is in use. There are basically two types of in service discontinuities: fatigue cracks and corrosion cracking.

Cracking can be caused by the overloading or cyclic loading of a part. The crack indication (fatigue cracks) has a very distinctive jagged appearance under magnetic particle testing.

Corrosion is the basic process by which a material returns to its natural form. Magnetic particle testing is not normally used to detect corrosion, however, in some cases where a metal is exposed to a corrosive environment and stress loads, stress corrosion cracking will form and can be found by magnetic particle testing.

References

A. Chapter 3
B. Section 1, Part 2 and Section 4, Parts 1 through 4
C. Chapter 7, Section 703 and 706 through 732

Surface and Subsurface

Magnetic particle testing is effective at detecting surface discontinuities and is also capable of detecting near surface discontinuities. However, several factors such as the type and shape of the material, the type of discontinuity, the type of current and the type of particles must be considered when testing for subsurface discontinuities.

As a general rule, surface indications appear as very sharp and distinct formations of particles caused by the flux leakage from the break in the material's surface. Subsurface indications appear as fuzzy formations of particles.

References

A. Chapter 20, Sections 4 through 9
B. Section 1, Part 4
C. Chapter 6, Section 601

Nonrelevant Versus Relevant

A *nonrelevant indication* is an indication caused by something that does not interfere with the use of a part, whereas a *relevant indication* is caused by something that may interfere with the use of the part. These two very simplistic definitions point out the major factor that separates nonrelevant and relevant indications, the potential impact of the indication on the usefulness of the part.

Nonrelevant indications can be caused by any of the following situations:

1. magnetic writing,
2. over magnetization,
3. sharp fillets,
4. external magnetic poles,
5. part construction or geometry,
6. heat treating boundaries,
7. grain boundaries,
8. dissimilar metals,
9. pressed fits,
10. lack of process control,
11. lint in the bath.

In each case the indication must be evaluated to determine its true cause and, if required, must be corrected. The correction may be necessary because the nonrelevant indication may mask a relevant indication.

In contrast, a relevant indication is one caused by an unintentional discontinuity in the part. While the indication may be relevant, it may not be considered a *defect*. A relevant indication caused by a discontinuity is only a defect when it interferes with the usefulness of the part or does not meet the acceptance criteria.

References

A. Chapter 3, Section 1 – 3 and Chapter 21
B. Section 9, Part 3
C. Chapter 6, Section 601

Acceptance and Rejection Criteria

The magnetic particle testing process performed on a part is not overly complicated. The average technician usually does not have a problem determining the difference between a nonrelevant or relevant indication. However the determination of whether the relevant indication is a *defect* can be difficult.

It would be simplistic to say that all parts with relevant indications should be rejected. The resulting loss of useful product, labor hours, materials and profits would soon confirm that technicians must be provided with acceptance and rejection criteria. For these reasons, and others, most specifications require that procedures contain acceptance and rejection criteria for a part.

References

A. Chapter 20, Sections 4 through 9
B. Section 9, Part 3 and Section 17, Part 2, 3.5
C. Chapter 6, Section 601

Aids for Indication Evaluation

Aids used to assist inspectors in the evaluation of an indication can be very valuable. For example, by using a magnifying lens a technician can better see details that may assist in identification.

Another aid in indication interpretation is the viewing of the indication as it forms. Removing the indication and reapplying the particles or bath can also be an effective way to determine if the indication is relevant or nonrelevant.

Discontinuity Evaluation

The process of discontinuity evaluation as presented here should not be confused with establishing the acceptance/rejection criteria, which is outside the responsibilities of a Level II.

The process of discontinuity evaluation presented in this section is based on the principle that a Level II technician needs to understand basic facts about the part being tested. Understanding these basic facts helps the inspector determine the difference between nonrelevant and relevant indications and properly identify relevant indications that can cause a part to be rejected.

History of Part

Knowing the history of a part may be unnecessary when testing production line parts. However, for the testing of in service parts, this knowledge can be vital. Parts that have been brought into the testing area may have been subjected to excess stress, which may cause discontinuities not normally associated with the routine testing of the part. For example, aircraft wheel bolts are routinely tested during tire changes. However, if the wheel bolts being tested were from a tire that failed on landing, the criteria may require that when a cracked bolt is found, the bolt on each side of the cracked bolt must also be replaced. In this case, historical knowledge allows the inspector to know that there is a special handling requirement for the bolts.

Manufacture Process

Knowledge of the manufacturing process helps the technician to better understand the different types of discontinuities he or she may need to identify. For example, knowing that a forged part was tested after the forging process lessens the need to look for forging related discontinuities when, later in the manufacturing process, that same part is tested for heat treat discontinuities.

Possible Causes

Understanding the possible causes for a part's failure helps the technician concentrate the testing effort. For example, in the casting process the part may have several areas where there are changes between thick and thin sections. By knowing where hot tears can develop during the cooling process, the technician can concentrate added attention to these areas.

Use of Part

The use of a part and the history of the part can be closely related. It is important to know how the part is used while in service. With that information, the technician can better understand how and where a crack may form. For example, by knowing that a part is used in a corrosive environment and under cyclic stress loading, the inspector can place added emphasis on looking for the early signs of stress corrosion cracking.

Tolerances

It has already been pointed out that relevant indications may be valid discontinuities in a part but not defects. However, in some situations those discontinuities may have tolerances placed on them. For example, a part may have repair tolerances for cracks found in certain areas. If the crack exceeds the repair tolerance, the part is rejected. However if the crack is within the repair tolerance it should not be rejected but properly identified and sent to the appropriate area for rework and retesting.

References

A. Chapter 22, Sections 1 through 6
C. Chapter 6, Section 600

Chapter 7 Review Questions

Q.7-1 The interruption in the normal physical structure of a part that causes a flux leakage and thus a magnetic particle indication that may or may not affect the serviceability of the part is a:

a. defect.
b. discontinuity.
c. bleed out.
d. all of the above.

Q.7-2 A magnetic particle indication on the surface of the part caused by a crack or seam that exceeds the acceptance and rejection criteria is called:

a. an indication.
b. a discontinuity.
c. a defect.
d. a repairable nonrelevant discontinuity.

Q.7-3 A gear that had secondary processing grinding operations performed is magnetic particle tested. The technician notes that there are fine, forked linear indications with no definable pattern, but appear to be like lightning in the sky. What are these indications?

a. forging bursts
b. fillet cracks
c. grinding cracks
d. hot tears

Q.7-4 A bolt with a safety wire hole drilled through the bolt head was magnetically tested. The technician found a fuzzy indication on the very top of the bolt's head that crossed the entire head. This indication can best be classified as:

a. a relevant indication.
b. a nonrelevant indication.
c. a discontinuity.
d. a defect.

Q.7-5 A subsurface discontinuity can be detected by magnetic particle testing. What factor limits the ability to detect subsurface discontinuities?

a. The type of material being tested.
b. The geometry of the part being tested.
c. The type of current and particle medium used.
d. All of the above.

Q.7-6 Which of the following can cause a nonrelevant indication?

a. lint in the bath
b. heat treating boundaries
c. pressed fits
d. All of the above.

Q.7-7 To better understand and evaluate discontinuities found in an in service part during a magnetic particle test, the technician should know information about:

a. how the part is used in service.
b. how the part was manufactured.
c. the rejection criteria.
d. All of the above.

Chapter 8
Demagnetization Principles

Residual Magnetism

All parts that have been magnetic particle tested have residual magnetism in them. If this magnetism is longitudinal the field strength of the residual magnetic field can be detected and measured. The amount of the residual magnetism is dependent on the type and amount of current used to magnetize the part and the material of the part. Compared to a soft steel, a part made of very hard steel will require a very high coercive force to remove the magnetism.

Because longitudinal magnetism in a part results in an external magnetic field, it is often considered the most objectionable in relation to returning a part to service. This is usually due to the problems the external magnetic field may have on items near the part.

Reasons for Demagnetization

There are good reasons for a part to be demagnetized. While demagnetization is usually associated with the final operations of a magnetic particle test, it can also occur as a preparation step. If ferrous parts are used in strong magnetic fields, before they are tested they should be demagnetized to ensure any field in the part will not interfere with the test.

When a part is to be remagnetized in a different direction, demagnetization may be required. This operation is sometimes misunderstood because demagnetization is not always required between magnetization operations. Demagnetization is only required when the subsequent or next magnetization step is of equal or less amperage or strength than the preceding operation. Failure to demagnetize the part can result in vector fields that can cause discontinuities to be missed.

Other reasons for demagnetization are:

1. when subsequent processing operations, such as machining or painting, could be impaired by residual magnetic fields;
2. when instruments, such as those in an aircraft, could be affected by the residual field;
3. when welding operations could be affected by the residual field;
4. when the residual field could cause in service problems with the operation or use of the part, such as a crankshaft in an engine holding particles that would increase bearing wear;
5. when the residual field will adversely affect the proper cleaning of the part;
6. when it is required by the specification, procedure or standard that controls the magnetic particle testing process.

There are also reasons when demagnetization may not be required. Some of these reasons are:

1. when the part is to be heat treated above the curie point in the next manufacturing or repair process step;
2. when the part will be remagnetized by a stronger magnetizing force;
3. when the part, if serviceable, will be used in a strong magnetic field that would not be affected by the residual field;
4. when the part is from a very large structure and the residual field will not affect the operation of the part;
5. when the residual field in the part is of such a small intensity that it will not interfere with the part's serviceability or will disappear after the testing is completed.

Retentivity and Coercive Force

Retentivity is defined as the ability of a material to retain a magnetic field. *Coercive force* is defined as the strength of an opposing magnetizing force required to bring the level of residual magnetism to zero. These two factors are not necessarily directly related. The ability to remove a residual field is a direct function of coercive force and not retentivity.

Demagnetization Methods

There are several methods to demagnetize a part: heat treat to a temperature above the curie point, alternating current or reversing step down direct current and electromagnetic.

Heat Treating Demagnetization

When a ferrous metal is heated to its curie point it is transformed from ferromagnetic to paramagnetic. When the part cools below the curie point, the material returns to a ferromagnetic unmagnetized condition.

Alternating Current Demagnetization

The most common method of demagnetization with alternating current is to pass the magnetized part through a coil energized with alternating current. The part should move beyond the end of the coil a distance of approximately three to four times the diameter of the coil. This distance may vary depending on the coil current strength and the shape of the coil. Procedures should be established to verify the most effective process for demagnetization. For optimal results, parts should pass as close as possible to the inner wall of the coil.

Another method of alternating current demagnetization is to place the part in the coil and use a decaying strength alternating current. This method requires the magnetic particle machine to be capable of this operation.

Demagnetization can also be completed with a yoke and alternating current. In this method the yoke is energized and pulled away from the part or the part is pulled away from the yoke. Either way will demagnetize parts.

The major limitation with alternating current demagnetization is the lack of penetration. The alternating current does not provide an effective demagnetization method for large parts or parts with deep magnetic fields.

Direct Current Demagnetization

Demagnetization with direct current requires that the current be reversed and decreased at progressive steps. Many stationary and mobile magnetic particle units can perform this operation. This operation is often called the *step down method.*

Direct current is most effective for the demagnetization of large parts or parts with deep fields.

Electromagnetic Demagnetization

There are several techniques for demagnetizing an object using electromagnetic energy. All of these techniques subject a magnetized object to a magnetic force that is continually reversing its direction and gradually decreasing in intensity.

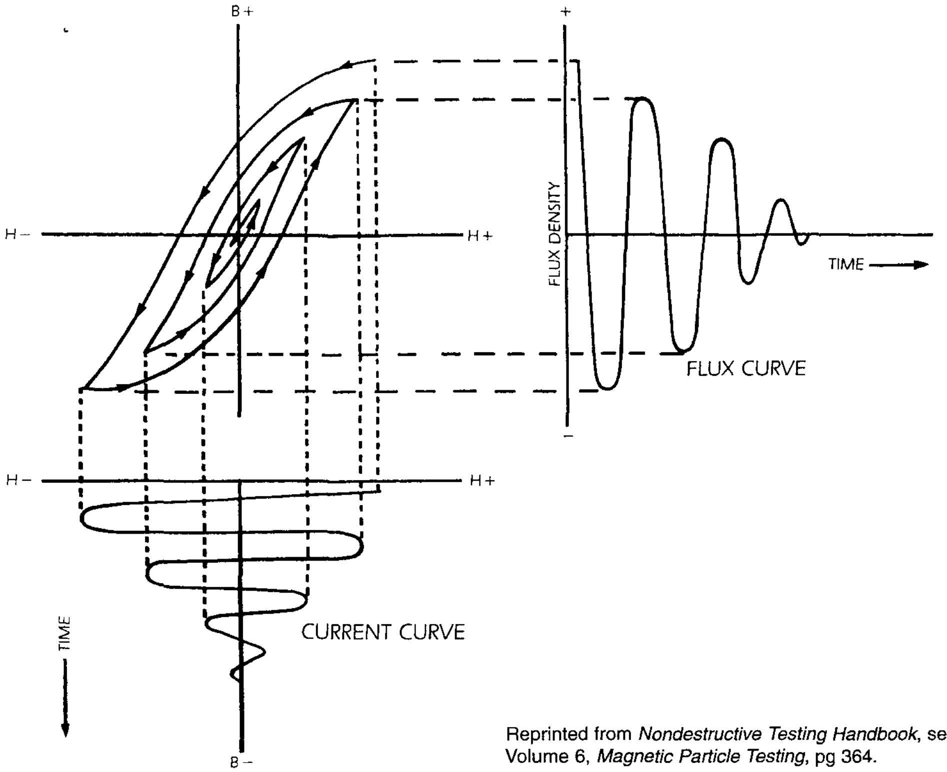
In Figure 8.1, the top curve illustrates the magnetic field strength used to generate the flux intensity curve below. As the current diminishes in value with each reversal, the hysteresis loop traces an increasingly smaller path. The bottom curve illustrates the decreasing residual flux intensity in the object, indicated by the shrinking hysteresis loops. The magnetizing current and flux intensity curves are plotted against time. When the current reaches zero, the residual magnetism approaches zero.

Successful demagnetization depends on several requirements. First the magnetic field strength at the start of the demagnetizing cycle must be high enough to overcome the coercive force and to reverse the direction of the residual field. This is accomplished by demagnetizing at a slightly higher current than that used in the magnetizing cycle. The second requirement is that, in each successive cycle, the reduction of magnetic field strength must be small enough that the reverse magnetic field strength exceeds the coercive force and reverses the flux direction from the previous reversal. This requires a number of cycles, depending on the permeability of the material. Ten to thirty reversals are often required.

Demagnetization Verification Methods

Once the demagnetization process has been completed, the remaining residual magnetism must be measured. The most common method of checking for residual magnetism is with a field indicator. The procedure or specification

Figure 8.1: Demagnetization hysteresis loops with current and flux intensity curves



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should indicate the allowable residual magnetism and if a calibrated field indicator is required.

A field indicator cannot reliably measure the residual magnetism in a part that has been magnetized with a circular field. To assist in the demagnetization process, procedures will normally have the circular magnetic particle test performed before the longitudinal. This allows the technician to have a means to determine if the final demagnetization process was successful.

When it is necessary to achieve the greatest amount of demagnetization, the Earth's magnetic field must be taken into consideration. By positioning the axis of the demagnetization coil in an east-west direction, long parts can be more effectively demagnetized.

References

A. Chapter 17
B. Section 1, Part 9
C. Chapter 2, Section 209

Chapter 8 Review Questions

Q.8-1 Which type of material would have the greatest resistance to demagnetization:

a. a part made of soft steel.
b. a part made of hard steel.
c. the resistance is the same regardless of the type of steel.
d. the resistance to demagnetization is dependent on the type of field established in the part.

Q.8-2 Two identical parts are magnetized, one with circular magnetism and the other with longitudinal. Which one will have the most objectionable magnetic field if not demagnetized after the magnetic particle test?

a. longitudinal
b. circular
c. vectored
d. residual

Q.8-3 What is coercive force?

a. The strength of the magnetizing force to induce a satisfactory magnetic field into a part.
b. The strength of the magnetizing force to remove the residual magnetic field in a part.
c. The strength of the magnetizing force to reverse a magnetic field in a part.
d. None of the above.

Q.8-4 Why should parts be demagnetized?

a. To prevent interference with welding operations.
b. To prevent interference with electrical instruments.
c. To allow for proper post cleaning of a part.
d. All of the above.

Q.8-5 A part must be magnetized in two directions. The first part of the procedure requires a circular field be established at 800 A. The second part of the procedure requires a longitudinal field be established at 750 A. Which of the following actions should take place?

a. The part should be longitudinally magnetized directly after the circular test.
b. The part should be demagnetized between the first and second part of the test.
c. The part should be magnetized at a higher amperage during the first part of the procedure.
d. The part should be magnetized at a higher amperage during the second part of the procedure.

Q.8-6 What is the major limitation of using alternating current for demagnetization?

a. It requires large amounts of electricity and therefore is not economical.
b. It is only effective on hard steel parts.
c. It is limited in its ability to remove deep magnetic fields.
d. Alternating current does not have any limitations.

Q.8-7 How is a yoke with alternating current used to demagnetize a part?

a. By energizing the yoke and drawing it away from the part.
b. By energizing the yoke and drawing the part away from the yoke.
c. By energizing the yoke near the part.
d. Both a. and b. will effectively demagnetize a part using a yoke.

Q.8-8 Which of the following methods of demagnetization is the most effective for a very large casting with deep magnetic fields?

a. heat treatment below curie temperature
b. alternating current coil
c. reversing direct current fields
d. All are equally effective.

Q.8-9 What equipment is used to determine if a part has been demagnetized?

a. a pie gage
b. a multimeter
c. a field indicator
d. two paper clips held close to the part

Q.8-10 When it is necessary to achieve the greatest amount of demagnetization of a part, what direction should the demagnetization coil be located?

a. east-west
b. north-south
c. north-east
d. south-west

Chapter 9
Magnetic Particle Testing Equipment

The purpose of magnetic particle testing equipment is simple: to induce a magnetic field into a part. For ease of discussion and classification, magnetic particle testing equipment can be divided into three categories:

- stationary equipment,
- mobile equipment,
- portable equipment.

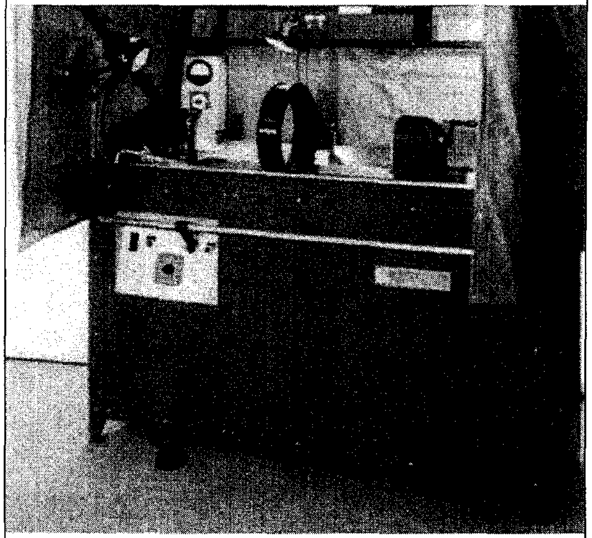
They all share the same purpose, but are used in different situations.

Stationary Equipment

Stationary magnetic particle testing units are usually large, not easily moved, are hard wired to a commercial source of electricity and have a wet bath built into them. In addition, these units normally have adjustable head stocks and a coil incorporated into the unit. These units can deliver very high amperages to effectively magnetize parts using either alternating or direct current. A small stationary unit can be seen in Figure 9.1.

Automated systems will normally fall into this category.

Figure 9.1: Typical wet horizontal magnetic particle test system



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Mobile Equipment

Mobile magnetic particle testing units, while able to deliver high amperages, are usually on wheels and can be moved without a great deal of effort. These units normally use cables and portable coils to induce the magnetizing amperages. The cables are normally fitted with clamps or prods. Care should be taken when using clamps or prods to prevent arcing or burn marks on the part or material.

The major advantage of these units over stationary units is the ability to move them to the location of large or heavy castings, forgings or structural items. Visible dry particles or fluorescent particles in spray cans are used with mobile units. A typical mobile magnetic particle testing unit is pictured in Figure 9.2.

Portable Equipment

Portable magnetic particle testing units can be moved easily from one job site to another. Usually one person can handle the movement of these units. Like mobile equipment, portable units use cables and portable coils to induce magnetizing amperages. Handheld prods and yokes are considered portable equipment. Figures 9.3 and 9.4 show typical portable magnetic particle units.

References

A. Chapter 18
B. Section One, Part 6
C. Chapter 3, Section 302 through 304

Ultraviolet Light

When fluorescent particles are used as the test medium an ultraviolet light is required. Though commonly called *black light*, the more correct terminology is *ultraviolet lamp*.

Ultraviolet lamps operate in an electromagnetic spectrum of 320 to 400 nm. Output of the ultraviolet lamp is measured in microwatts per square centimeter (µW/cm^2). An ultraviolet lamp with a new 100 W lamp and clean filter can produce well over 3000 µW/cm^2 at 38 cm (15 in.).

Figure 9.2: Typical mobile magnetic particle test system

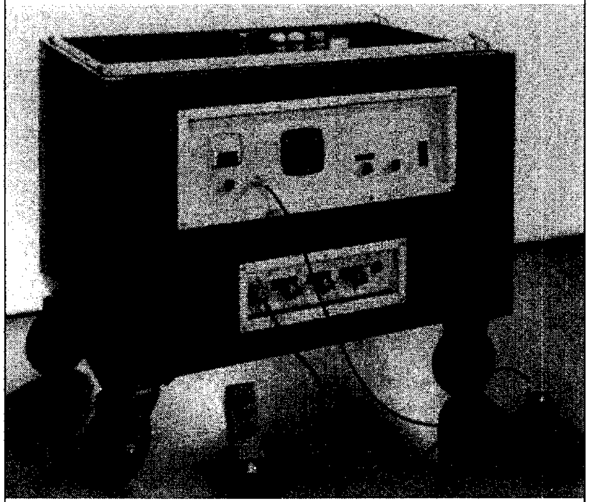

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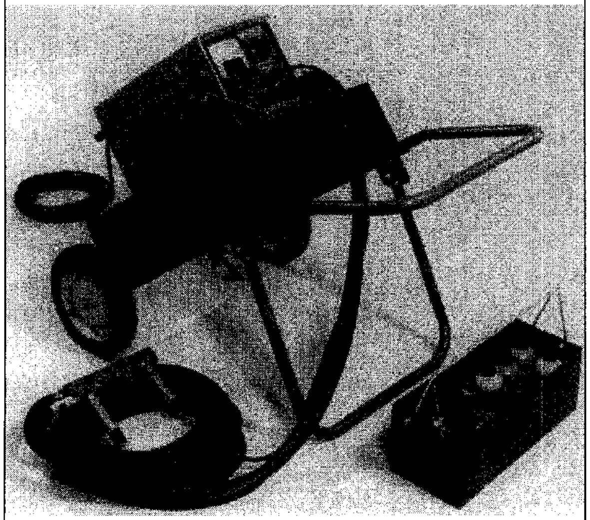
Figure 9.3: Portable magnetic particle testing system with fixed distance prod assembly



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The measured output of an ultraviolet lamp should always be made with a calibrated ultraviolet light meter. In addition, this check should be made under the same conditions as the lamp will be used at the test surface. For example, if a lamp is to be used in the field with a portable generator, it should be checked with the lamp powered by that generator. A decline in only a few volts can adversely affect the output of the lamp.

Technicians should never look directly into an ultraviolet lamp while it is operating. In addition, those who work under ultraviolet light on a constant basis should take measures to protect their exposed skin from the harmful ultraviolet rays, and in some lights, the excessive heat.

Visible Light

Generally 1076.4 lux (100 ftc) minimum is required for using visible particles.

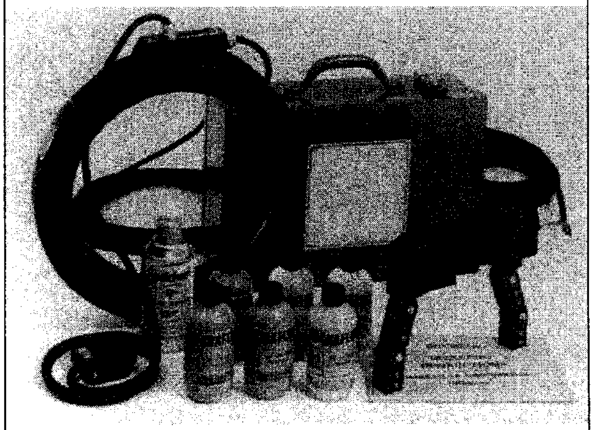
References

A. Chapter 16
B. Section 15, Part 8
C. Chapter 3, Section 308

Baths

Stationary units contain a bath of liquid and particles that is used for the testing of parts. The liquid used in these baths is usually a light

Figure 9.4: Hand yoke with a preformed coil assembly



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petroleum product, but may be water with conditioners added.

The baths must be checked regularly for particle concentration. A bath that has a concentration too low may miss discontinuities and a bath that has too high of a concentration may mask discontinuities.

The most common and accepted way of checking the bath concentration is by performing a settling test with a centrifuge tube. In this test, a sample of the well circulated bath is poured into a centrifuge tube to the 100 mL level. The sample is then demagnetized and placed in a stand in a vibration free area away from any magnetic field influences. After the prescribed settling time, usually 1 h with a petroleum liquid and 30 min for water, the concentration level is read at the bottom of the centrifuge tube. This test can also be used to check the bath for fluorescence and contamination.

References

A. Chapter 16
B. Section 8, Part 8, pages 208–211
C. Chapter 4, Section 402

Quality Control Factors

A successful magnetic particle testing process depends on an acceptable procedure, qualified personnel and equipment that meets specifications. The lack in any one of these three parts of the process can degrade a test and cause discontinuities to be missed. While all are important, the control of the quality of the equipment is vital. The best procedure or the most competent technician cannot perform a successful test without proper and acceptable equipment.

Quality control of the equipment begins with system performance. The equipment must be checked on a regular basis to ensure that it is functioning properly. The checking of the equipment will vary depending on the type of equipment. Some specifications may call for the system performance check to be performed with a ketos ring, whereas other specifications may require the use of a part with a known discontinuity.

In addition to system performance checks, selected parts of stationary equipment must be checked, including ammeter accuracy, timer control and the quick break function.

Mobile equipment requires routine checks similar to stationary equipment.

Portable equipment, such as yokes and permanent magnets, require dead weight checks to ensure they produce sufficient magnetic fields.

Ultraviolet lamps should be checked with a calibrated ultraviolet meter at prescribed intervals.

Specifications and/or standards from the customer should dictate the required quality control checks that need to be performed and the required frequencies in which they need to be completed.

References

A. Chapter 26
B. Section 17, Part 2

Chapter 9 Review Questions

Q.9-1 Why should magnetic particle testing equipment be checked on a regular basis?

a. To improve the quality of the test.
b. To improve the technician's ability to detect defects.
c. To improve the documentation of test results.
d. None of the above.

Q.9-2 Which category of equipment usually has a bath incorporated into the unit?

a. stationary equipment
b. mobile equipment
c. portable equipment
d. All of the above.

Q.9-3 Which category of equipment is best for parts or structures that cannot be moved, but require a magnetic particle test?

a. stationary equipment
b. mobile equipment
c. portable equipment
d. either b. or c.

Q.9-4 The output of an ultraviolet lamp should be checked with:

a. a field indicator.
b. a white light meter.
c. an ultraviolet light meter.
d. either b. or c.

Q.9-5 Which is the proper sequence for checking the concentration level of a magnetic particle bath?

a. Agitate the bath, pour the sample and allow to settle in a vibration free area.
b. Agitate the bath, pour the sample, demagnetize and check with an ultraviolet light.
c. Agitate the bath, pour the sample, demagnetize and allow to settle in a vibration free area.
d. Agitate the bath, pour the sample and allow to settle in the magnetic particle station unit.

Q.9-6 What will be the results if a bath concentration is too high?

a. The testing amperage will have to be reduced to prevent masking.
b. The testing amperage will have to be increased to ensure adequate flux leakage to attract the additional particles.
c. The part will have to be allowed to drain longer to reveal all indications
d. Discontinuities may be missed due to the masking of indications.

Appendix 1
Glossary

acceptance standard: A specimen test object similar to the product to be tested, containing natural or artificial discontinuities that are well defined and similar in size to, or extent of, the maximum acceptable in the product.

alternating current: An electric current that reverses the direction of its flow at regular intervals.

alternating current field: The active magnetic field produced around a conductor by an alternating current flowing in the conductor.

alternating current magnetization: Magnetization by a magnetic field that is generated when alternating current is flowing.

ampere: A unit of electric current. Abbreviated A or *amp.*

ampere per meter: The magnetic field strength in air at the center of a single turn circular coil having a diameter of 1 m, through which a current of 1 A is flowing. Abbreviated $A \bullet m^{-1}$ or *A/m.*

ampere turns: The product of the number of turns of a coil and the current in amperes flowing through the coil.

arc: A luminous high temperature discharge produced when all electric current flows across a gaseous gap.

arc burn: Localized burn damage to an object from the arc caused by breaking an energized electric circuit. Also called *arc strikes.*

arcing: Current flow through a gap, often accompanied by intense heat and light.

artificial discontinuity: A manufactured material anomaly. See *acceptance standard* and *reference standard.*

background: In magnetic particle testing, the appearance of the surface against which test indications are viewed.

bath: See *suspension.*

berthold penetrameter: A magnetic flux indicator containing an artificial discontinuity in the shape of a cross, mounted below an adjustable cover plate.

black light: See *ultraviolet light.*

carrier fluid: The liquid vehicle in which fluorescent or nonfluorescent magnetic particles are suspended for ease of application. See *vehicle.*

central bar conductor: An electric conductor passed through the opening in a part with an aperture, or through a hole in a test object, for the purpose of creating a circular magnetic field in the object.

circular magnetic field: The magnetic field surrounding an electrical conductor (test object) when a current is passed longitudinally through the conductor.

circular magnetization: The magnetization in an object resulting from current passed longitudinally through the object itself or through an inserted central conductor.

circumferential magnetization: See *circular magnetization.*

coercive force H_C: The magnetizing field strength required to bring the magnetic flux density of a magnetized material to 0.

coil method: A method of magnetization in which all or a portion of the object is encircled by a current-carrying coil.

coil shot: A technique of producing longitudinal magnetization by passing electric current through a coil encircling the test object.

coil technique: See *coil method.*

conditioning agent: An additive to water suspensions that imparts specific properties such as proper wetting, particle dispersion or corrosion resistance.

consequent poles: North and south poles that occur at several places along the length of a very long magnetized part.

contact head: Electrode assembly used to clamp and support an object to facilitate passage of electric current through the object for circular magnetization.

contact method: See *current flow technique.*

continuous technique: A sequence where magnetic particles are applied to the test object while the magnetizing force is present.

curie point: The temperature at which ferromagnetic materials can no longer be magnetized by outside forces and at which they lose residual magnetism — between 650 and 870 °C (1202 and 1598 °F) for most metals.

curie temperature, T_C:The transition temperature above which a material loses its ferromagnetic properties. Approximately 760 °C (1400 °F) for iron.

current flow technique: A means of magnetizing by passing current through an object using prods or contact heads. The current may be alternating current or rectified alternating current.

current induction technique: A means of magnetization in which a circulating current is induced in a ring component by the influence of a fluctuating magnetic field.

defect: A discontinuity whose size, shape, orientation or location make it detrimental to the useful service of the test object or which exceeds the accept/reject criteria of an applicable specification.

demagnetization: The reduction of residual magnetism to an acceptable level.

demagnetizing coil: A coil of conductive material carrying alternating current used for demagnetization.

diamagnetic material: A material with magnetic permeability less than one.

direct current: An electric current flowing continually in one direction through a conductor.

direct current field: A residual magnetic field or an active magnetic field produced by direct current flowing in a conductor.

discontinuity: A change in the physical structure or configuration of an object. May be intentional or unintentional.

domains: Submicroscopic areas in metals that have negative and positive ends and are randomly oriented in nonmagnetized materials.

dry method: A magnetic particle testing method in which the ferromagnetic particles are applied in a dry powder form.

dry powder: Finely divided ferromagnetic particles selected and prepared for magnetic particle testing.

electrode: A contact where current passes into or out of a test object.

electromagnet: A soft iron core surrounded by a coil of wire that temporarily becomes a magnet when an electric current flows through the wire.

false indication: An indication that may be interpreted as being caused by a discontinuity but is located where no discontinuity exists.

ferromagnetic material: Materials that have high permeability and when subjected to a magnetic field, domains align parallel to the field's lines of force. When the magnetic field is removed, these types of materials retain a substantial portion of the field. Steel is an example of this type of material.

field strength, *H*: The parameter characterizing the amplitude of the magnetizing field strength.

fill factor: In the coil method of magnetization, the ratio of the cross sectional area of the object within the coil to the cross sectional area of the coil.

fluorescence: The emission by a substance of visible radiation as a result of, and only during, the absorption of ultraviolet energy.

fluorescent magnetic particle testing: The process using finely divided ferromagnetic particles that fluoresce when exposed to ultraviolet light (320 to 400 nm).

flux density, B: The corresponding parameter for the induced magnetic field in an area perpendicular to the flux path. See *magnetic flux density.*

flux density, saturation, B_S: The maximum intrinsic induction possible in a material.

flux indicator: A small device, generally a metal strip or disk, containing artificial discontinuities. Used to determine when correct magnetizing conditions or magnetic field direction have been achieved.

flux leakage: The magnetic field that leaves or enters the surface of an object.

flux leakage method: A method for the detection and analysis of a discontinuity using the flux that leaves a magnetically saturated, or nearly saturated, test object at a discontinuity.

flux lines: See *lines of force.*

full wave direct current: A single phase or three phase alternating current rectified to produce direct current characteristics of penetration and flow.

gauss: A unit of magnetic flux density or magnetic induction. Magnetic field strength B is measured in gauss (G); 1 G is one line of magnetic flux per square centimeter of area. 10^4 G=1 T. See *tesla.*

gaussmeter: A magnetometer using gauss to register field strength.

half wave current: A unidirectional rectified single phase alternating current that produces a pulsating unidirectional field.

heads: The clamping contacts on stationary magnetic particle systems.

head shot: A short pulse of magnetizing current passed through an object or a central conductor while clamped between the head contacts of a magnetizing unit, generating circular magnetization of the object. Duration of the current is usually less than 1 s.

horseshoe magnet: A bar magnet bent into the shape of a horseshoe so that the two poles are adjacent. The term usually applies to a permanent magnet.

hysteresis: (1) The lagging of the magnetic effect when the magnetizing force acting on a ferromagnetic body is changed. (2) The phenomenon exhibited by a magnetic system wherein its state is influenced by its previous history.

hysteresis curve: A curve showing flux density B plotted as a function of magnetizing force H as the magnetizing force is increased to the saturation point in both the negative and positive directions sequentially. The curve forms a characteristic S shaped loop. Intercepts of the loop with the BH axis and the points of minimum and maximum magnetizing force define important magnetic characteristics of a material.

indication: A magnetic particle accumulation that serves as evidence of a leakage field and requires interpretation to determine its significance.

induced magnetization: A magnetic field generated in an object when no direct electrical contact is made.

induced current technique: See *current induction technique.*

inductance: The magnetism produced in a ferromagnetic body by some outside magnetizing force.

inherent fluorescence: Fluorescence that is an intrinsic characteristic of a material.

inherent discontinuity: A discontinuity that occurs as the base metal is taken from a molten state to a solid state.

inspection: See *examination.*

inspection medium: See *examination medium.*

internal conductor: See *central conductor.*

interpretation: The determination of a magnetic particle indication's source and relevancy.

leakage field: See *flux leakage field.*

lines of force: A conceptual representation of magnetic flux based on the line pattern produced when iron filings are sprinkled on paper laid over a permanent magnet.

lines of magnetic flux: See *lines of force.*

longitudinal magnetic field: A magnetic field wherein the flux lines traverse the component in a direction that is essentially parallel with its longitudinal axis.

longitudinal magnetization: Magnetization in which the flux lines traverse the component in a direction essentially parallel to its longitudinal axis.

magnetic circuit: The closed path followed by any group of magnetic flux lines.

magnetic domains: Submicroscopic areas in metals that have negative and positive ends and are randomly oriented in nonmagnetized materials. When the domains come under the influence of a magnetizing force, they tend to line up parallel to the field's lines of force.

magnetic field: Within and surrounding a magnetized object, the space in which the magnetic force is exerted.

magnetic field indicator: A device used to locate or determine the relative intensity of a flux leakage field emanating from an object.

magnetic field leakage: See *flux leakage field.*

magnetic field strength: The measured intensity of a magnetic field at a specific point. Expressed in amperes per meter (oersted).

magnetic flow technique: When an object or a portion of it closes the magnetic circuit of an electromagnet. The resulting field is longitudinal in direction.

magnetic flux: The total number of lines of force existing in a magnetic circuit.

magnetic flux density: The normal magnetic flux per unit area. Expressed in tesla (gauss).

magnetic flux leakage: See *flux leakage field.*

magnetic leakage field: See *flux leakage field.*

magnetic particle test: A nondestructive test method utilizing magnetic leakage fields and suitable indicating materials to disclose surface and near surface discontinuities.

magnetic particle test system: Equipment providing the electric current and magnetic flux necessary for magnetic particle discontinuity detection. Provides facilities for holding components of varying dimensions and for adjusting and reading the magnetizing current.

magnetic particles: Finely divided ferromagnetic material capable of being individually magnetized and attracted to flux leakage fields.

magnetic permeability: See *permeability.*

magnetic pole: One of two sites on a magnet that generates magnetic fields. Flux leakage sites on an object.

magnetic powder: Magnetic particles in dry or powder form with size and shape suitable for discontinuity detection.

magnetic rubber: A specially formulated testing medium containing magnetic particles. Used to obtain replica castings of component surfaces with discontinuities being reproduced within the replica. A suitable magnetizing technique causes the migration of magnetic particles within the medium to the position of the discontinuity.

magnetic saturation: In a specific material, the degree of magnetization where an increase in H produces no further increase in magnetization.

magnetic writing: A nonrelevant indication sometimes caused when the surface of a magnetized object comes in contact with another piece of ferromagnetic material or a current carrying cable.

magnetism: The ability of a magnet to attract or repel another magnet or to attract a ferromagnetic material. A force field surrounding conductors carrying electric current.

magnetization: The process by which elementary magnetic domains of a material are aligned predominantly in one direction.

magnetizing current: The electric current passed through or adjacent to an object that gives rise to a designated magnetic field

magnetizing force: The magnetizing field strength applied to ferromagnetic material to produce magnetism.

magnetometer: A device for measuring the strength of magnets or magnetic fields.

multidirectional magnetization: Two or more magnetic fields in different directions imposed on an object sequentially and in rapid succession.

near surface discontinuity: A discontinuity not open to but located near the surface of a test object. Produces broad, fuzzy, lightly held dry particle indications.

nonrelevant indication: An indication produced by an acceptable discontinuity or by spurious effects such as magnetic writing, changes in section, or the boundary between materials of different magnetic properties.

oersted: The cgs unit of magnetic field strength. Replaced by the SI system's ampere per meter.

overall magnetization: Magnetizing a complete object with a single energizing cycle.

parallel magnetization: A magnetic field induced in magnetizable material placed parallel to a conductor carrying an electric current. Not a recommended practice for magnetic particle testing.

paramagnetic material: A material with magnetic permeability slightly greater than one.

permanent magnet: An object possessing the ability to retain an applied magnetic field for a long period of time after the active power of the field has been removed.

permeability: (1) The ease with which a material can become magnetized. (2) The ratio of flux density to magnetizing force B/H.

permeability, μ: The ratio of the magnetic flux density B in a substance to the external (applied) field strength H. For example $\mu = B/H$.

permeability relative, μ_r: The ratio of the permeability of a substance to the permeability of free space, $\mu_r = \mu/\mu_0$.

permeability initial, μ_{int}: The permeability obtained from the ratio of the flux density B kept at <10 gauss, and the required field strength H. Material initially in a specified neutralized state.

pole: See *magnetic pole.*

powder: See *dry powder.*

powder blower: A compressed air device used to apply dry magnetic particles over the surface of a test object.

procedure: Usually a brief document that specifies the exact steps to perform magnetic particle testing on a particular part. The procedure is written by the agency performing the testing and is based on a specification or standard.

processing discontinuities: Discontinuities that occur during the forming or fabrication stage of making a part.

prod magnetization: See *current flow technique.*

prods: Handheld electrodes for transmitting magnetizing current from a generating source to a test object.

pulse magnetization: Direct or indirect application of a high field intensity, usually by the capacitor discharge method.

quick break: A sudden interruption of magnetizing current. Used in magnetic particle tests for materials with high residual longitudinal magnetism and limited to three phase full wave rectified alternating current.

rectified alternating current: A unidirectional electric current obtained by rectifying alternating current without the deliberate addition of smoothing to remove the inherent ripples.

reference standard: A specimen containing controlled artificial or natural discontinuities. Used for verifying the accuracy of discontinuity detection processes or equipment.

relevant indication: An indication caused by a condition or a type of discontinuity that requires evaluation.

remanence, *B*: The flux density remaining in a magnetic material when the applied magnetic field strength is reduced to 0.

remanent magnetism: See *residual magnetic field.*

residual magnetic field: The field remaining in a ferromagnetic material after the magnetizing force is reduced to 0.

residual technique: Ferromagnetic particles are applied to a test object after the magnetizing force has been discontinued.

retentivity: The capacity of a substance to retain magnetism after the magnetizing force has been reduced to 0.

saturation level: See *magnetic saturation.*

saturation point: The point at which a material is unable to be magnetized more strongly as all domains are oriented in the same direction.

sensitivity: The degree of capability of a magnetic particle test to indicate surface or near surface discontinuities in ferromagnetic materials.

settling test: A procedure used to determine the concentration of particles in a magnetic particle bath.

shot: A short energizing cycle in a magnetic particle test.

skin effect: The phenomenon that causes the magnetization produced by alternating current to be contained near the surface of a ferromagnetic object.

slurry: A free flowing pumpable suspension of a fine solid in a liquid.

specification: A specification is often written into a contractual agreement and places testing requirements on one or all parties to the agreement.

standard: A document that covers broad and general information on the testing method. It can usually be applied across a wide spectrum of materials or industries.

subsurface discontinuity: See *near surface discontinuity.*

suspension: A two phase system comprising finely divided magnetic particles dispersed in a vehicle, often a liquid petroleum distillate. See *vehicle.*

tesla: The SI unit of measure for magnetic flux density (T). One tesla is equivalent to 10^4 G.

test ring: A ring specimen typically made of tool steel, containing artificial subsurface discontinuities used to evaluate and compare the performance and sensitivity of magnetic particles.

ultraviolet light: Electromagnetic radiation with wavelengths between 200 and 400 nm (2000 and 4000 Å). The range of wavelengths used for fluorescent nondestructive testing is typically between 320 and 400 nm (3200 and 4000 Å), principally 365 nm (3650 Å). Shorter wavelengths are very hazardous.

ultraviolet light filter: A filter that transmits near ultraviolet radiation while absorbing other wavelengths.

vehicle: A liquid medium for the suspension of magnetic particles, often a light petroleum distillate or conditioned water. See *carrier fluid.*

visible light: Radiant energy generated in the 400 to 700 nm (4000 to 7000 Å) wavelength range.

wet method: A testing technique in which the magnetic particles are applied as a suspension in a liquid vehicle.

wet slurry technique: A magnetic particle test in which the particles are suspended in high viscosity vehicle.

yoke: A *U* shaped magnet that induces a field in the area of the test object that lies between its poles. Yokes may be permanent magnets, alternating current electromagnets or direct current electromagnets.

Appendix 2

Answer Sheet

Chapter 1

No Questions

Chapter 2

Q.2-1	a
Q.2-2	c
Q.2-3	c
Q.2-4	a
Q.2-5	a
Q.2-6	b
Q.2-7	d

Chapter 3

Q.3-1	b
Q.3-2	b
Q.3-3	b
Q.3-4	b
Q.3-5	b
Q.3-6	b
Q.3-7	c
Q.3-8	b

Chapter 4

Q.4-1	a
Q.4-2	a
Q.4-3	c
Q.4-4	a
Q.4-5	c
Q.4-6	c
Q.4-7	d
Q.4-8	c
Q.4-9	b
Q.4-10	d
Q.4-11	d
Q.4-12	b
Q.4-13	a
Q.4-14	c
Q.4-15	b
Q.4-16	c

Chapter 5

Q.5-1	b
Q.5-2	d
Q.5-3	d
Q.5-4	b
Q.5-5	b
Q.5-6	b
Q.5-7	c
Q.5-8	c
Q.5-9	d
Q.5-10	c

Chapter 6

Q.6-1	c
Q.6-2	b
Q.6-3	a
Q.6-4	d
Q.6-5	d
Q.6-6	a
Q.6-7	c

Chapter 7

Q.7-1	b
Q.7-2	c
Q.7-3	c
Q.7-4	b
Q.7-5	d
Q.7-6	d
Q.7-7	d

Chapter 8

Q.8-1	b
Q.8-2	a
Q.8-3	b
Q.8-4	d
Q.8-5	b
Q.8-6	c
Q.8-7	d
Q.8-8	c
Q.8-9	c
Q.8-10	a

Chapter 9

Q.9-1	a
Q.9-2	a
Q.9-3	d
Q.9-4	c
Q.9-5	c
Q.9-6	d