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Nondestructive Inspection Journeyman

Volume 2. Basic NDI Techniques

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NOW THAT YOU have completed volume 1 of the 2A752 *Nondestructive Inspection Journeyman* career development course (CDC) and have a basic understanding of general Air Force procedures and terminology, it is time to introduce you to the fundamentals of nondestructive inspection (NDI).

Volume 2 of this CDC, *Basic NDI Techniques*, focuses on the origins of NDI. In unit 1, we outline the principles of metallurgy and metallic structure. Without core knowledge of these principles, you will find the instruction presented later difficult to follow.

Unit 2 presents you with information on NDI techniques including what areas make up a technique, how to develop a technique, and how your technique is published.

Unit 3 introduces the simplest NDI method—optical inspections—and units 4 and 5 provide instructions on penetrant and magnetic particle inspection techniques, which are the two most basic NDI methods.

All together, these units begin to show you how NDI can be used to identify defects without harming equipment and improve safety for Air Force members around the world.

A glossary is included for your use.

Code numbers on figures are for preparing agency identification only.

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This volume is valued at 18 hours and 6 points.

NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

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Unit 1. Metallurgy

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IT WAS A COLD, windy March evening. The darkness and heavy drizzle obscured runway two-seven. Major Bill Jenkins, the aircraft commander, applied full throttle to execute a missed approach. Following a loud crunch, engine no. 4 pointed skyward and thrashed violently from side to side. The rear engine mount failed, dropping the back of the engine and jamming all controls. A bright flash followed by a dull, red glow in the sky off to the southwest concludes the story of Bill and his crew; however, this is where it starts for you—the nondestructive inspection (NDI) technician. This accident might have been prevented if the engine mount had been properly inspected using NDI methods during the aircraft's last-phase inspection.

This unit of instruction lays the foundation for every NDI method you will perform. Here we cover the general principles of metallurgy, including the identification and characteristics of metals. In addition, we also outline the types, causes, and characteristics of discontinuities causing component failures such as the one described.

1–1. Properties of Metallic Structure

This section describes metal properties and their classification so that you can identify them easily. Being able to identify a metal is extremely useful when you are determining the best inspection method to use when an aircraft component does not have a technical order (TO) that gives specific instructions. Begin by asking yourself whether the metal is ferrous (having an iron base) or nonferrous (having very little or no iron). If you cannot tell for sure by weight or appearance, use a magnet. An attraction between the metal and a magnet indicates the metal is ferrous and a magnetic particle inspection might be the best NDI method to use. You should know the general material composition for radiographic inspection of parts because all materials absorb radiation at different rates. Your mastery of a radiographic technique will greatly increase when you know the material's composition.

201. Metal classifications

Engineers use metal classifications, primarily, to determine the manufacturing process, chemical make-up, temper and thickness of a metal. When you think of it, even nature is make up of one or more chemical elements. While each element is composed of atoms, an *element* itself is a pure substance that cannot be decomposed by chemical change. An *atom* is the smallest particle into which an element can be divided, retain its identity, and enter into a chemical combination.

When two or more elements are combined, they form a *compound*. A compound may be either a chemical compound or a mixture. *Chemical compounds* are composed of two or more elements and can be decomposed by chemical change. Water, as an example, is a chemical compound designated

as H_20. It has two atoms of hydrogen and one atom of oxygen that may be decomposed, or separated, to form the separate elements of hydrogen and oxygen.

A *substance* is any variety of matter whose specimens have identical properties and composition. A *mixture* is composed of two or more substances, in any ratio, each of which retains its identity and specific properties. Examples of mixtures are sugar and water, salt and water, and concrete. As an NDI technician, you probably will not have to identify a metal as to its specific alloy. However, the closer you come to identifying the metal's composition, the better your inspection results will be.

Types of metals

Metals appear in two forms, of which the most basic form is pure metal such as copper, aluminum, or iron. This form contains only a single metallic element. The second, and most common form of metal, is an *alloy*, composed of two or more elements. Additionally, all metals may be classified as either ferrous or nonferrous. A *ferrous* metal is one that has iron as the major element. An alloy containing less than 50 percent iron is still considered ferrous, so long as it contains more iron than any other metal. For example, a metal comprised of 42 percent iron, 30 percent nickel, 22 percent tin, and six percent molybdenum is considered ferrous.

Ferrous metals

The term ferrous metals refers to the group of metals having iron as the principle component. These metals include cast iron, steel, and the various steel alloys. The only difference between cast iron and steel is the amount of carbon present in the metal. Cast iron contains *more than* two percent carbon, while steel contains *less than* two percent. Therefore, all steel is an alloy of iron and carbon. However, the term *alloy steel* normally refers to steel alloys containing one or more other metallic elements. For example, if the main alloying element is tungsten, the steel is a tungsten steel or a tungsten alloy. If no alloying material is used, the metal is called carbon steel.

Various types of alloy steels are developed to meet modern industrial needs. Simple carbon steels cannot provide the required toughness, strength, and hardness needed for advanced industrial applications. Alloying metals, such as nickel, chromium, tungsten, vanadium, manganese, and molybdenum, give distinct properties to steel; but in all cases, the principal aim is to increase toughness, strength, and hardness.

Nonferrous metals

Nonferrous metals refers to all metals where iron is not the principal component. These metals include those primarily used for metal plating or as alloying elements, such as tin, zinc, silver, and gold. Your primary interest in nonferrous metals is on those used in the manufacture of aerospace parts. These include aluminum, magnesium, titanium, nickel, copper, and their alloys. You can have a nonferrous alloy containing iron as long as it is *not* the major alloying element.

Composition of metals

The composition—both chemical and physical—of a metal determines its specific properties, which properties may be changed, and the amount of property change possible. Knowledge of a metal's composition is necessary to determine the type of metal to use for a specific application and the methods used to alter the metal to obtain the desired properties.

Chemical composition

Each element, and the exact percentage of each element, determines a metal's chemical composition. This is often referred to as the chemical analysis or, more simply, as the analysis of the metal. The chemical composition and the grain structure of a metal determine the properties that can be developed in the metal. When discussing chemical composition, a metal is said to be in the form of a pure metal, mechanical mixture, solid solution, or a combination of a mechanical mixture and a solid solution.

These are explained in the following table:

Form	Description
Pure metal	Is rarely used outside laboratories. A pure metal cannot be hardened by heat treatment because there is little change in its structure when it is heated.
Mechanical mixture	Can be compared to concrete. Just as the sand and gravel are visible and held in place by the cement, the elements and compounds in a mechanical mixture are clearly visible and are held together by a matrix of the base metal. An alloy in the form of a mechanical mixture at room temperature may change to a solid solution or to a partially solid solution when it is heated. When it is cooled to room temperature, the alloy may return to its original structure, remain a solid solution, or form a combination of a solid solution and a mechanical mixture.
Solid solution	When two or more metals are dissolved, one into the other, they form a solution. You are probably most familiar with liquid solutions, but solutions may also be gaseous or solid. When an alloy is in the form of a solid solution, the elements and compounds are absorbed into each other in much the same way that salt is dissolved in a glass of water. The separate elements cannot be identified even under a microscope.

The solubility of various metals often increases when the temperature is increased. Thus, a metal in the form of a mechanical mixture at room temperature often changes into solution when heated. When it is cooled, a metal can remain in solid solution, form a combination of solid solution and mechanical mixture, or return to a mechanical mixture.

Grain structure

The way atoms combine and build a solid mass determines the physical structure. In metals, this structure is called crystalline. One crystal of pure iron (or one unit cell) as an example, contains nine atoms in a body-centered cubic lattice network. Figure 1–1 is an illustration of an iron crystal.

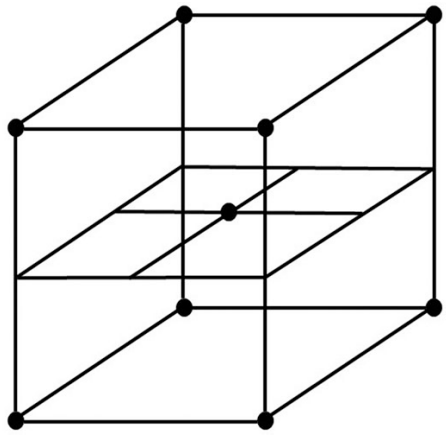


Figure 1–1. One iron crystal.

As the liquid metal cools to the recrystallization temperature, random crystals begin to form. As the metal cools further, other crystals form at each corner of these cubic structures. As crystals form, one to another, a solid mass develops from each of the original cells or crystals. As these masses spread and solidify, their outer boundaries contact adjacent masses and, thus, can spread no further. The boundaries around the masses are grain boundaries and are called *metal grains*. Figure 1–2 shows four grains of metal magnified many times. As you can see, crystals are built on each other in four areas of the liquid. Completely solid metals consist of grains of metal made up of thousands of crystals.

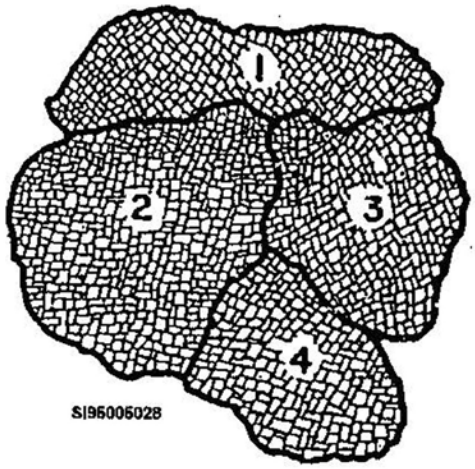


Figure 1–2. Four grains of metal.

In many metals, grain structure (not crystal structure) is controlled by heating and cooling the metal to specific temperatures within specific periods. When metals are heated, the grain boundaries prevent grains from expanding until the recrystallization temperature is reached (this is *not* the melting point). At this temperature, the grain boundaries collapse and small grains are formed from the original large grains. Sudden cooling (quenching) at this point produces a smaller than original grain size which is usually desirable. Recrystallization temperatures vary for different metals. The method of heating and cooling around the recrystallization temperature is called *heat-treating*. This process improves a metal's characteristics for specific applications by altering its grain structure.

202. Properties of metals

In the metals industry, it is customary to refer to metal characteristics as properties of metal. A list of groups for all metal properties includes thermal, electrical, optical, magnetic, mechanical, and chemical properties. To understand the characteristics of metals as they apply to NDI, our main focus will be to view their mechanical and physical properties. An in-depth study of all the other groups of metal properties would exceed the scope of this course. Therefore, for purposes of our discussion, we will group all properties that are *not mechanical* into the physical properties category.

Mechanical properties are those properties affecting the reaction of a material to an applied force or involving the relationship between stress and strain. All others classify as *physical properties.*

Mechanical properties of metal

A metal's mechanical properties reveal the metal's reaction to an applied force. Knowing the properties of a metal provides you with a means to predict how parts made from the metal will behave in service.

Manufacturers of metal components have known about the reaction of a metal to an applied force for many centuries. For example, look at this several centuries old test specification for a finished Damascus sword:

> "If with one stroke of the right arm of the master workman it severs the head of the man from his body, and displays not nick or crack along the edge, and the blade may be bent round about the body of the man and break not, it shall be accepted as a perfect weapon."

This was the Damascene way of checking a sword for hardness and toughness. Today's standards for precise metal characteristics require the use of specialized equipment and procedures to measure the specific properties of a metal.

Stress and strain

Stress is a more specific term for an applied force. Stress (expressed in pounds per square inch [psi]]), is found by dividing the load (force) by the original cross-sectional area. Stresses are forces that pull, compress, twist, or shear aircraft components and may result in fatigue or stress failures.

In figure 1–3, the cross sectional area is indicated by the lines A, B, C, and D. If the block is one inch by one inch and the load is 2000 psi, then the applied stress is 2000 psi. If the block were two inches by two inches, the stress is reduced to 500 psi.

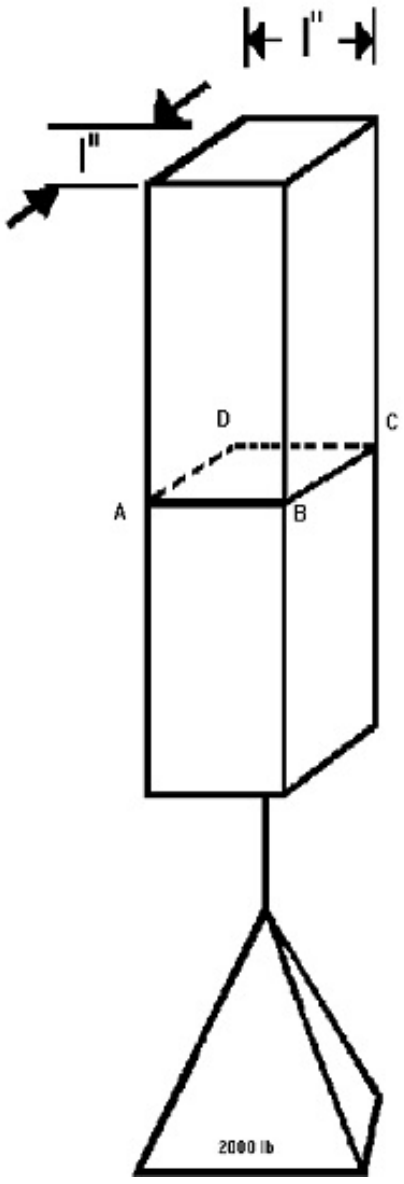


Figure 1–3. Example of stress.

Strain is the elongation or reaction to applied force per unit length. It is the change in dimension due to stress. Linear unit's measure strain, since area changes and volume is expressed in inches per inch. A two-inch length is as a standard length for strain. If a two-inch piece of material stretches one inch, the strain would be one half inch per inch. If the same part were to stretch two inches, the strain would be one inch per inch.

Types of mechanical properties

Mechanical properties include hardness, brittleness, elasticity, plasticity, strength, and toughness. They are defined in the following table:

Property	Description
Hardness	The ability of a metal to resist abrasion, penetration, indentation, or cutting action.
Brittleness	The tendency of a metal to fracture or break with little or no deformation. Brittleness is usually *not* a desirable mechanical property. Examples include cast iron or cast aluminum and very hard steel.
Elasticity	The property of a metal that allows it to recover its original size and shape after deformation. Each metal has a point known as elastic limit; if loading increases beyond this limit, the material will be permanently deformed.
Plasticity	Refers to the ability of a metal to deform nonelastically without rupture. In other words, when the metal is bent, stretched, or twisted, it remains bent, stretched, or twisted. Plastic properties of metals are usually referred to by the following more specific terms: • *Malleability* is a measure of a metal's ability to be deformed by compression, such as hammering, forging, or rolling. • *Ductility* is a measure of a metal's ability to be deformed by stretching and can be twisted into various shapes without breaking. Gold, silver, tin, and lead are example of metals exhibiting high malleability
Strength	The measure of a metal's ability to withstand a force or stress without deformation or fracture. The strength of a metal depends on the type of applied force or deformation observed in testing. Forces applied to a metal sample in testing are tensile, compressive, fatigue, shear, and torsional. Conditions observed while stressing a sample include whether it fractures (ultimate), deforms a specified amount (yield), or deforms at a specified rate (creep).
Toughness	The ability of a metal to absorb energy without fracturing. Maximum toughness obtains proper balance in hardness, elasticity, and plasticity.

Relationship of mechanical properties

There are definite relationships among the mechanical properties of metals. Obtaining perfection in one mechanical property normally requires that perfection in another must be sacrificed.

For example, if a metal is hard, it is also brittle and has high strength; if it is soft, it is also tough and has low strength. The ultimate shear strength is approximately equal to 60 percent of the ultimate tensile strength for most metals. The following table shows some of the common relationships between the different properties of metals:

Hardness	Tensile Strength	Brittleness	Toughness	Elasticity	Wear Resistance
As hardness increases	increases	increases	decreases	decreases	increases
As hardness decreases	decreases	decreases	increases	increases	decreases

The following items help to explain the preceding table further:

1. As hardness is increased by cold working or by heat treatment, the tensile strength will increase to a value as high as RC–53 (designation of tensile strength). Beyond this value, strength may decrease as hardness increases.

2. As hardness increases, brittleness also increases. Proper heat treatment brings about an increase in brittleness. Two steels may have the same approximate hardness with two different grain sizes. The steel with the coarser grain will be more brittle than the other steel.
3. As hardness increases, toughness decreases. Maximum toughness is obtained when all brittleness is removed; it is the opposite of hardness.
4. As hardness decreases, elasticity increases to a point about midway between maximum hardness and softness (RC–45). A heat-treated steel spring is a typical example of a material having excellent elastic properties.
5. As hardness increases, wear resistance increases.

Physical properties

The characteristics that enable us to distinguish one substance from another are known as chemical, mechanical, and physical properties. The physical properties of a substance are those that do not involve a change in composition of the material. Although we are mainly concerned with the mechanical properties of metal, physical properties are still important. They can have a direct impact on NDI methods, inspection techniques, and limitations. Physical properties are determined by the chemical composition of the metal and cannot be altered in the way mechanical properties are. Those properties involved in a transformation of one substance into another are known as chemical properties. Physical properties are helpful to you when you are identifying metals and alloys. Some of the more common physical properties are discussed in the following table.

Physical Property	Description
Melting point	The temperature at which a metal changes from a solid to a liquid.
Thermal Conductivity	The ability of a metal to conduct heat is called the metal's coefficient of thermal conductivity. A metal having a high coefficient of thermal conductivity transfers heat very rapidly through itself.
Thermal Expansion	The coefficient of thermal expansion indicates how much a metal expands when its temperature is raised a specific amount. Metals with a high coefficient of thermal expansion will expand a great deal when heated. Expansion of these metals can cause warpage and presents special problems for welders and heat treating personnel.
Electrical Conductivity	The coefficient of electrical conductivity is usually stated in percent of the International Annealed Copper Standard (IACS). Metals having a high coefficient of electrical conductivity are the better conductors of electricity. Copper and aluminum are examples of especially good conductors.
Density	Density is expressed as weight per unit volume. For example, a certain alloy can have a density of one-tenth of a pound (weight) per cubic inch (unit volume).
Color	The property of a metal that causes it to reflect light of a certain wavelength is the metal's color. Different wavelengths produce different sensations on our visual senses. This is what gives us our impression of color.
Luster	The shine or glitter a metal produces by means of reflecting light is the luster of the metal. Metals such as brass and stainless steel can be polished to a very bright luster. Others, such as gray cast iron, do not shine.
Magnetic Susceptibility	This refers to how a material reacts to a magnetic field. Metals may be diamagnetic, paramagnetic, or ferromagnetic. We will look at this later.

203. Identification of metals

A wide variety of materials are required in order to repair aircraft. Many manufacturers from around the world have different ways to identify these materials and metals produced. This lesson outlines the most common identification methods used. The prominent numbering systems that are encountered for ferrous metals are the Society of Automotive Engineers (SAE) and the American Iron

and Steel Institute (AISI) systems. The Aluminum Association (AA) and International Annealed Copper Standard (IACS) classify nonferrous metals, and are the main focus of this lesson. However, this lesson will also briefly touch on the SAE and AISI.

Society of Automotive Engineers identification numbers

The SAE numbering system is one method used to identify metals and concentrates on the identification of steel. The following table shows the numerical index system identifying the composition of SAE steels. This system uses numbers to partially describe the composition of material. This is done with a series of digits as follows:

- The *first digit* indicates the type of steel based on the primary alloying element or elements. For example, a 2 indicates a nickel steel and a 3 indicates a nickel-chromium steel.
- In the simple alloy steels, the *second digit* generally indicates the approximate percentage of the predominant alloying element.
- The *last two or three digits* indicate the approximate average carbon content in points or hundredths of one percent.

As an example, alloy number 2340 indicates a nickel steel of approximately three percent nickel and 0.40 percent carbon. To avoid confusion, in some instances it is necessary to deviate from the system of identifying the approximate alloy composition of a steel by varying the second and third digits of the number. Steel numbers selected for several of the corrosion and heat resisting are examples of such a deviation.

Type of Steel	Numerals (and Digits)
Carbon Steels	1xxx
Plain Carbon	10xx
Free Cutting (Screw Stock)	11xx
Manganese Steels	13xx
Nickel Steels	2xxx
Nickel Chromium Steels	3xxx
1.25 Percent Nickel; 0.65 Percent Chromium	31xx
Corrosion and Heat Resisting	303xx
Molybdenum Steels	4xxx
0.25 percent Molybdenum	40xx
Nickel-Chromium-Molybdenum Steels	
1.80% Nickel; 0.50 & 0.80% Chromium; 0.25% Molybdenum	43xx
0.55% Nickel; 0.50 & 0.65% Chromium; 0.20% Molybdenum	86xx
0.55% Nickel; 0.50% Chromium 0.25% Molybdenum	87xx

Type of Steel	Numerals (and Digits)
3.25% Nickel; 1.20 Chromium 0.12% Molybdenum	93xx
Nickel-Molybdenum Steels	
1.75 Percent Nickel; 0.25 Percent Molybdenum	46xx
3.50 Percent Nickel; 0.25 Percent Molybdenum	48xx
Chromium Steels	5xxx
Low Chromium	50xx
Medium Chromium	51xx
High Chromium	52xx
Corrosion and Heat Resisting	514xx and 515xx
Chromium-Vanadium Steel	6xxx
0.80 – 1.00 Percent Chromium, 0.10 – 0.15 Vanadium	61xx
Silicon Manganese Steels	9xxx
A Percent Silicon	92xx
Low Alloy, High Tensile	950
Boron Intensified	xxBx1
Leaded Steels	xxLxx

American Iron and Steel Institute

The AISI numbering system uses the same numerical system as SAE and adds a prefix alpha digit to identify the manufacturing process of the metal.

Aluminum Association identification numbers

The AA identifies aluminum and aluminum alloys based on metal composition. AA designates the material composition of wrought aluminum and wrought aluminum alloy using a four-digit index number. This system uses the digits as follows:

- In the 1xxx group, the *first digit* indicates a metal containing *at least* 99 percent pure aluminum.
- The *second digit* of the group indicates controls over the impurities in the metal. If the second number is zero, it indicates no special control over individual impurities.
- The *last two digits* indicate hundredths of 1 percent above the original 99 percent designated by the first digit; they are, in other words, the percentage above the original 99 percent of additional pure aluminum. For example, if the last two digits are 45, the metal contains not only 99 percent pure aluminum; it also contains an additional 0.45 percent of pure aluminum above the 99 percent (or 99.45 percent).

Aluminum alloys

For aluminum groups other than 1xxx, the AA numbering system is slightly different. The following table shows the major AA groups of aluminum alloys.

Composition	AA Group
Aluminum – 99.00% minimum and greater	1xxx
Aluminum Alloys, Grouped by Major Alloying Element	
Copper	2xxx
Manganese	3xxx
Silicon	4xxx
Magnesium	5xxx
Magnesium and Silicon	6xxx
Zinc	7xxx
Other element	8xxx
Unused Series	9xxx

NOTES:

1. In aluminum groups other than 1xxx, such as 2024 aluminum alloy, the *first digit* indicates its major alloying element; in this case copper.
2. The *second digit* indicates the special controls for impurities just as in group 1xxx.
3. The *last two digits* in the number identify the different alloys in the group. For example, the digits 24 tell us this is the 24th variation of the basic copper alloy group. It *does not*, however, indicate a specific purity or exact composition.

The specific chemical composition of an alloy is usually a well-guarded secret of the manufacturing industry.

It is important to note that the *last two digits* in the designation for aluminum alloys *do not* mean the same thing they do for 99 percent or greater pure aluminum. You can use TO 1–1A–9, *Aerospace Metals - General Data and Usage Factors,* to associate the AA number to the physical and mechanical characteristics for a particular aluminum alloy.

Aluminum hardening

Tempered (hardened) aluminum is produced by the following three methods:

1. Cold working (strain hardening).
2. Heat-treating.
3. A combination of cold working and heat-treating.

The various alloys of aluminum are classified as heat treatable or non-heat treatable. Alloys 1100, 3003, 3004, 5050, and 5052 *do not* harden by heat treatment. These alloys are work-hardened to increase their strength. H, F, and O symbols designate tempers of these alloys. A number to the right of the temper designation symbol indicates the degree of hardening; for example, 2 is ¼ hard, 4 is ½ hard, 6 is ¾ hard, and 8 is full hard.

Alloy groups such as 2xxx, 6xxx, and 7xxx can be hardened by heat treatment and are identified with the symbol T. Like work-hardened alloys, a number to the right of this symbol also indicates the

degree of hardening. The mechanical properties of these alloys improve with heat treatment or by a combination of strain hardening and heat treatment. The following table shows various temper codes used for aluminum alloys.

_____	F	As fabricated
_____	O	Annealed and recrystallized (wrought only)
_____	H	Strain Hardened (wrought only)
_____	H1,	plus one or more digits Strain Hardened only
_____	H2,	plus one or more digits Strain Hardened, then partially annealed
_____	H3,	plus one or more digits Strain Hardened, then stabilized
_____	W	Solution heat treated-unstable temper[1]
_____	T	Treated to produce stable tempers other than _____F, _____O or _____H
_____	T2	Annealed (cast only)
_____	T3	Solution heat treated, then cold worked
_____	T4	Solution heat treated and naturally aged to a substantially stable condition
_____	T5	Artificially aged only
_____	T6	Solution heat treated, then artificially aged
_____	T7	Solution heat treated, then stabilized
_____	T8	Solution heat treated, cold worked, then artificially aged
_____	T9	Solution heat treated, artificially aged, then cold worked
_____	T10	Artificially aged then cold worked

[1] This designation shall be used only for those alloys which age very slowly at room temperature and shall be followed by the length of the aging period; e.g., 7075-W (2 months).

Refer to TO 1–1A–9, Section III, Aluminum Alloys, for information on tempers, nominal composition, and characteristics of aluminum alloys.

Using a conductivity meter for metal identification

Identification numbers work well for known metals. How do you identify a piece of metal that has no number? A conductivity meter can help. The primary uses of the conductivity meter are metal sorting and heat damage detection. This instrument is covered in detail in a later unit on eddy current inspection methods. However, it is of some use in metal identification since different metals, and even the same metal with different tempers, have different electrical conductivity values. These values are read directly from the conductivity meter in percent of the IACS.

International Annealed Copper Standard

Metal sorting using the conductivity meter is simple, easy to do, and requires only a list of IACS values or samples of known alloys for comparison standards. As an example, you may measure a metal part of unknown composition and determine that it conducts electricity 50 percent as well as the

copper standard. You compare this value to readings from samples of known alloys or with an IACS value list, such as the list shown in the following table.

Alloy	Electrical Conductivity % IACS	Alloy	Electrical Conductivity % IACS
1100–0	59	5052–H38	35
1100–H18	57	5357–0	43
3003–0	50	5357–H38	43
3003–H12	42	6061–0	45
3003–H14	41	6061–T4, T6	40
3003–H18	40	7075–T6	30
3004–0	42	Brass	26–43
3004–H38	42	Copper	100
2014–0	40	Monel	4
2024–0	50	Nickel	16
2024–T3	30	Low Alloy Steel	3–15
5050–0	50	18.8 Stainless	2.4
5050–H38	50	Tin	15
5052–0	35	Zinc	30

In the preceding table, you see that 3003–0 aluminum conducts electricity 50 percent as well as the copper standard. You can now conclude unknown metal may be 3003–0 aluminum alloy. However, it could be any other metal with an IACS value of 50 such as 2024–0, 5050–0, or 5050–H38. If you are starting to think positive metal identification based solely on measured conductivity is *not* conclusive, you are correct. A conductivity meter can only eliminate certain alloys from consideration when the metal is completely unknown. It must be used in conjunction with some other method for precise metal identification.

Suppose you need to identify a piece of unknown metal plate. If at the end of the plate you find the number 3003–, it only tells you what the alloy is; however, the temper designation was cut off when the plate was last used. You measure its conductivity, and find it is 42 percent IACS. Refer to the preceding above. You can be reasonably sure that the metal is 3003–H12. The reasons for this include already knowing that the metal alloy is 3003, and that the conductivity of a metal varies consistently, or nearly consistently, with its temper. The softer a metal alloy is, the better it conducts electricity. As hardness increases, electrical conductivity decreases.

Identifying the hardness of a known metal alloy is probably the most useful function of a conductivity meter. Despite its limitations, it can be useful for metal identification.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

201. Metal classifications

1. What form of metal contains only one metallic element?

2. What form of metal contains two or more elements?

3. How much carbon is present in ferrous steel?

4. The text refers to tungsten steel. Using it as an example, what does the term *nickel steel* mean?

5. What is the principal reason for alloying steel?

6. Under what conditions are alloys containing iron termed *nonferrous*?

7. What do the physical and chemical compositions of a metal determine?

8. What determines a metal's chemical composition?

9. What characteristics will determine which metal properties can be developed?

10. What metal cannot be hardened by heat treatment because very little structural change occurs?

11. What are the characteristics of a mechanical mixture?

12. In a solid solution, what happens to metallic elements and compounds?

13. What is determined by the way atoms combine and build a solid mass?

14. What is the form of metallic structure?

15. What are the boundaries around masses of metal that spread and solidify called?

16. What is controlled by heating and cooling a metal within a specific temperature range and time period?

17. What do you call the heating point where grain boundaries collapse and smaller grains are formed?

18. What is heat-treating?

19. What does heat-treating do?

202. Properties of metals

1. What two physical properties are the main focus of NDI?

2. What properties are revealed by a metal’s reaction to an applied force?

3. What is stress?

4. What is strain?

5. List all the types of mechanical properties.

6. Match reporting authority in column B with their responsibilities from column A. Column B items may be used more than once.

Column A	*Column B*
____ (1) Defined by a metal's ability to resist abrasion, penetration, indention, or cutting action.	a. Toughness.
____ (2) Property of metal allows it to recover its original size and shape after deformation.	b. Plasticity.
____ (3) Ability in metal allows it to be bent, and remain bent without rupturing.	c. Hardness.
____ (4) Malleability and ductility are terms that are more specific for what metal property?	d. Elasticity
____ (5) A metal's ability to withstand stress without deformation or fracture.	e. Strength.
____ (6) Property describes a metal's ability to absorb energy without fracturing.	

7. As a metal's hardness is increased, what happens to the metal's brittleness?

8. As hardness is increased, what happens to a metal's toughness?

9. What determines a metal's physical properties?

10. List the physical properties of metal.

11. What is the physical property of a metal to conduct heat called?

12. What does it mean when a metal has a high coefficient of electrical conductivity?

13. What property is expressed as weight per unit volume?

14. What is magnetic susceptibility?

203. Identification of metals

1. What are the two ferrous metal identification systems, and the two nonferrous metals identification systems mentioned in this lesson?

2. What type of metal do SAE identification numbers center on?

3. What does the *first digit* of an SAE identification number indicate?

4. In an SAE identification number, what does the *second digit* generally indicate?

5. What do the *last two or three numbers* of an SAE identification number indicate?

6. What is the difference between the AISI systems and SAE?

7. How many digits are in an AA identification number?

8. What is indicated when aluminum falls into the 1xxx group?

9. What does the *second digit* of an AA identification number indicate?

10. In group 1xxx aluminum, what is indicated by the *last two digits* of the AA identification number?

11. For aluminum groups other than 1xxx, what does the *first digit* of the AA identification number indicate?

12. What do the *last two digits* of AA identification numbers mean for groups other than 1xxx?

13. What do numbers next to temper designation symbols indicate?

14. What symbol is used to indicate a heat-treated aluminum?

15. What TO and section can you refer to for information on tempers, nominal composition, and characteristics of aluminum alloys?

16. Why can measured electrical conductivity assist in metal identification?

17. What happens to electrical conductivity as hardness increases?

1–2. Discontinuities

An unfortunate reality of working with metal components is even a perfectly designed and properly used part may contain a flaw. This flaw can act as a stress-raiser forming the nucleus of a fatigue failure. Every defect you locate by using various NDI methods can be grouped into distinct classifications, according to their cause and their original formation. This section will provide you with information on identifying defects and classifying them as inherent, processing, or service and mechanical flaws. This section also presents an introduction to the welding process and probability of detection (POD).

204. Types of discontinuities

What is the difference between an indication, a discontinuity, and a defect? Normally, you do not judge the serviceability of a part. Most of the inspections you perform only require that you report your findings to the user of the part. Your *primary concern* is to *identify* and *describe* the discontinuity as completely as possible.

Indication

An *indication* is a response or evidence of a response that requires interpretation to determine its significance as the result of an NDI process and may be any of the following:

- Any magnetic particle patterns on the surface of a part being tested.
- The visible evidence of penetrant which has come out of a discontinuity, indicating to the inspector that some sort of surface opening is present.
- The signal displayed on ultrasonic, bond testing, or eddy current equipment.
- Contrasting densities on radiographic film.

An indication, requiring an interpretation, does not always mean that a discontinuity is present. Nonrelevant or false indications may be caused by conditions that have no bearing on the suitability of the part or its intended use. (The peculiarities of the indications obtained by the various NDI methods are included in the lessons for each method.)

Discontinuity

A discontinuity is an interruption in the normal physical structure or configuration of a part (e.g., cracks, laps, seams, inclusions, or porosity). A discontinuity may be fine or it may be quite large. This depends on the discontinuity's effect on the usefulness of a part. A discontinuity may or may not be a defect, or it may or may not affect the intended use of the part.

Defect

A defect is a discontinuity interfering with the usefulness of a part or is detrimental to its serviceability. You should understand that *not all* cracks, seams, laps, or other discontinuities are *necessarily* defects because they *may not affect serviceability* of the part in which they exist. Whether a discontinuity is a defect will be determined by the service history of the part, its stress loading, and the degree, location, and proximity to other discontinuities.

Nearly all technical data on aerospace components contains specific guidance outlining discontinuities *that are* or *are not* defects. As you progress in your career, you may be asked to assist the user of a part in determining whether a particular discontinuity constitutes a defect when no other guidance is available. Your knowledge and experience in this area will help you to give sound, educated advice when requested.

205. Types and origins of metal discontinuities

The two methods of forming raw ore into refined metal are classified as either casting or wrought. *Wrought* means the metal has been worked or shaped by force and includes processes such as rolling, forging, drawing, extruding, and piercing. A metal *casting* is obtained by pouring or forcing molten metal into a mold. The liquid metal solidifies in the shape of the mold and the mold is removed.

Discontinuities originating from metal-forming processes are classified as shown in the following short table:

Classification	Description
Inherent	Result of its initial metal solidification from a molten state.
Processing	Metal shaped by either casting or wrought.

Inherent discontinuities

Inherent discontinuities are caused by the melting and original solidification of a metal into a metal ingot. Most metals are not refined and poured into a working shape at one time. Usually, refined metal is poured into standard sized ingots for shipment to various manufacturers. As molten metal is poured, gas bubbles and impurities may be trapped in the ingot. If these are not removed, they weaken the metal structure of any parts made from it. Metal ingots are cropped with their tops removed since most gas bubbles and impurities tend to gather there. However, some discontinuities can be trapped lower in the ingot and find their way into a finished product, as shown in figure 1–4. Even when manufacturers melt the ingots down for castings, some discontinuities can remain. In other words, they can be trapped below the level normally cropped off the metal ingot. Let's look at the following table as we consider some of the most common inherent discontinuities found in metal parts.

Discontinuities	Description
Inclusions	Impurities present in the original ingot or present in a finished product cast in a mold. Incomplete refining of metal ore causes inclusions or the mixing of purification compounds with the metal as it solidifies.
Porosity	Gas holes of porosity form when insoluble gases are trapped in the molten metal as it solidifies. These gas holes are voids in the metal found individually, in small groups, or scattered throughout the ingot or casting. Porosity is nothing more than numerous, very small gas holes.
Pipes	Consist of large shrinkage cavities forming at the top of an ingot and extending down into the ingot for various distances. If they are not removed before subsequent wrought processing operations, they can form detrimental defects during these operations.
Segregation	Formed when the ingot solidifies and the distribution of the various elements or compounds is not uniform throughout the mass of the ingot. They can occur at or below the surface, may vary in size, and are normally irregular in shape. The most serious forms of segregation occur in castings where the basic condition of the metal remains unaltered in the finished part and any segregation remains as originally formed.

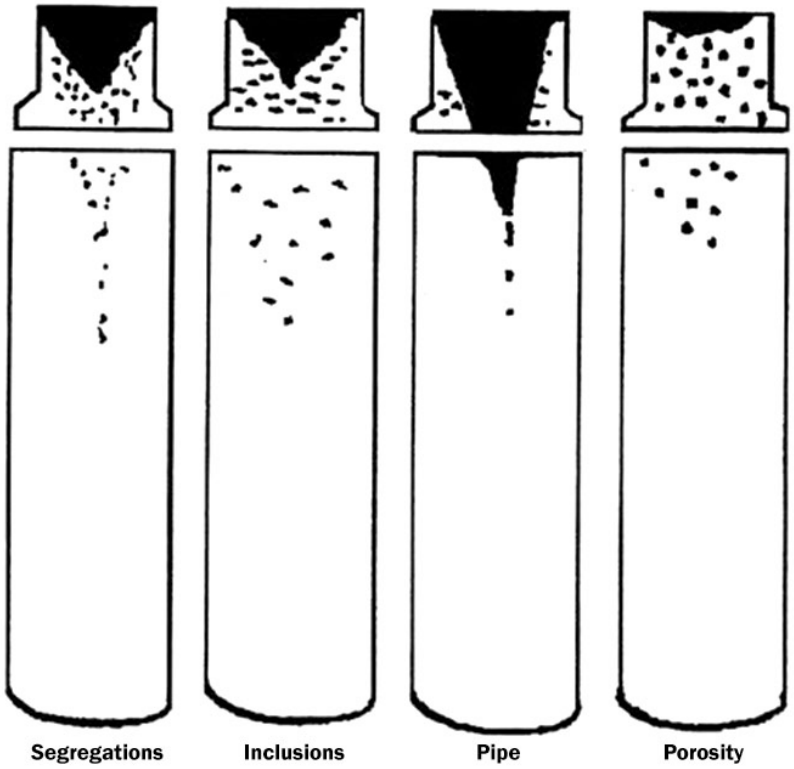


Figure 1–4. Inherent discontinuities.

Processing discontinuities

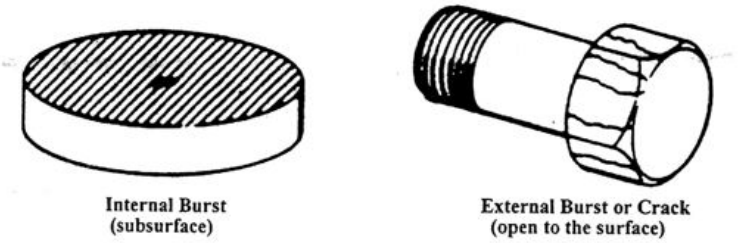
Processing discontinuities are caused by problems during various fabrication operations. They are divided into the two main categories, primary and secondary processing defects, and are discussed in more detail in the following paragraphs.

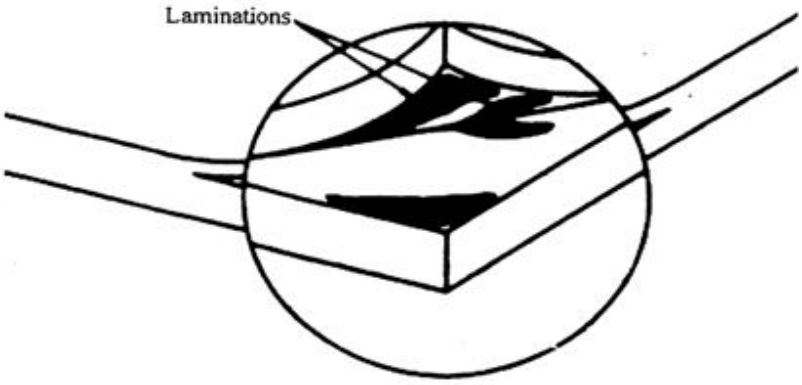
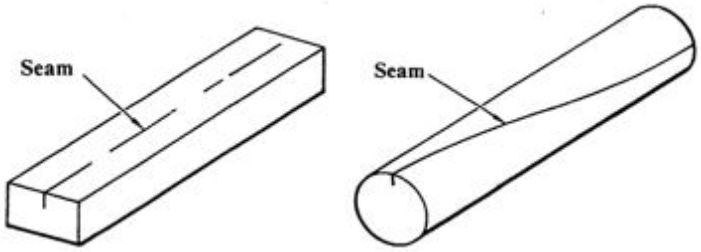
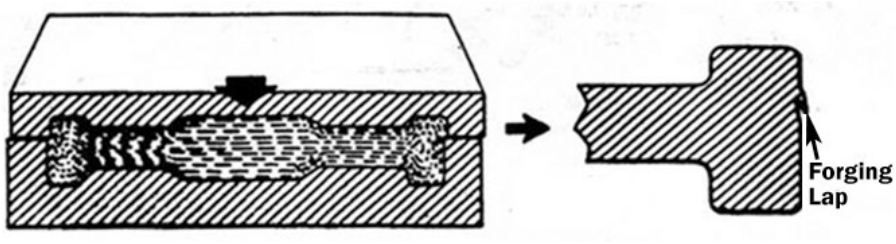
Primary processing defects

The improper rolling, forging, or drawing of the original metal ingot into the basic metal shapes causes primary processing defects. They can appear in a number of different forms. The previously described methods of wrought processing and casting are two means of shaping metals into usable forms during the primary stage of manufacturing; however, defects or discontinuities can occur even within these useful means.

Wrought processing

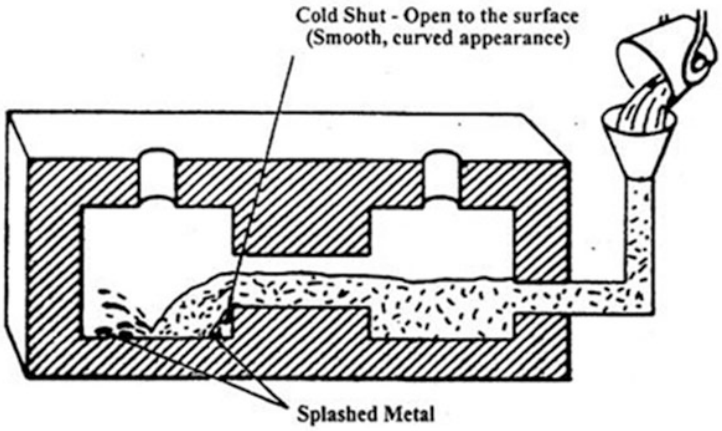
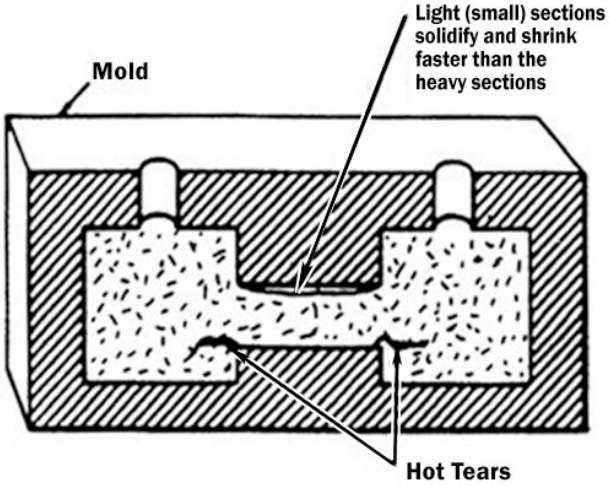
A wrought metal part is any metal part that has been shaped by force. Most metals may be worked into shape while hot or cold. The temperature of the metal that is worked directly affects the properties of the finished product. The following table shows defects of the wrought process.

Primary Processing Defects of Wrought Processing	
Defect	**Description**
Bursts	Ruptures occurring when forging operations are started before the material to be forged reaches an even temperature throughout. Hotter portions of the blank tend to flow around the colder, less plastic sections, causing them to tear or burst. Too rapid or too severe a reduction in a section can also cause bursts (fig. 1–5).  **Figure 1–5. Bursts.**
Flakes	Internal ruptures caused during cooling and are usually found only in alloyed steel forgings. In a fractured surface, flakes appear as bright silvery areas; on an etched surface they appear as short, discontinuous cracks called “shatter cracks and snowflakes.”
Laminations	Thin, flat discontinuities found most often in a steel plate or strip. They are the result of rolling gas inclusions or pipe in the original ingot (fig. 1–6).

Primary Processing Defects of Wrought Processing	
Defect	**Description**
	 **Figure 1–6 Laminations.**
Seams	Surface discontinuities, generally long, straight, and parallel to the longitudinal axis of a bar. They originate from blowholes, cracks, splits, and tears introduced earlier during fabrication operations or left over from the original ingot. The original discontinuity is closed by further processing until the distance between adjacent faces is very small. The process of rolling steel into bars and plates forms seams, stringers, laminations, and laps. Figure 1–7 shows how seams typically look:  **Figure 1–7. Seams.**
Laps	Similar to seams and can result from improper rolling processes. In working down the billet into a bar, corners may be folded over or small fins of metal may be forced out between the rolls. The folds and fins are flattened down into the bar forming laps. They are usually straight and parallel to the longitudinal axis. Laps are similar to seams, but extended into the bar at an angle to the surface. Figure 1–8 shows how typical laps form.  **Figure 1–8. Laps.**

Casting

Casting forms by pouring or forcing molten metal into a mold. The liquid metal solidifies in the shape of the mold, and is then removed. There are various types of casting discontinuities, as described in the following table.

Primary Processing Defects of casting discontinuities	
Defect	**Description**
Porosity	Gases, air bubbles, or voids may be trapped in the solidified metal and form random pits or holes. Porosity is usually round or nearly round.
Inclusions	Non-metallic foreign materials, such as oxides, sulphides, silicates and such that are retained during solidification. Inclusions may also be referred to as slag.
Cold Shut	Occur when metal fails to flow together because of interrupted pouring, uneven cooling, or pouring when the temperature of the metal is too cool. This is shown in figure 1–9.  **Figure 1–9. Cold shut.**
Hot Tears or Shrinkage Cracks	Caused by light sections cooling and solidifying faster than heavy sections, which results in a tearing action (fig. 1–10).  **Figure 1–10. Hot tears.**

Secondary processing defects

This is the final stage of metal manufacturing. Secondary processing defects, sometimes called finishing defects, are caused by improper machining, grinding, or heat-treating within a metal that form into a finished part. These defects are usually easier to detect because they nearly always appear on the surface of the finished part.

Machining tears

Machining tears are the result of working a part with a dull cutting tool or by cutting to a depth too great for the material being worked. The removed metal may not break away cleanly and the tool leaves a rough, torn surface. Close examination shows this rough surface contains numerous short discontinuities often misidentified as cracks. Machining tears can be too deep to be completely removed later by finish machining or by grinding. They may also be covered over and concealed by the burnishing action of finishing or polishing.

Grinding cracks

Grinding cracks are also called grinding checks because they often appear in a checkered network pattern (fig. 1–11). They frequently occur when hardened metal surfaces are ground. In actuality, grinding cracks are thermal cracks similar to heat-treating and hardening cracks. Over-heating, caused by a grinding wheel, produces these discontinuities.

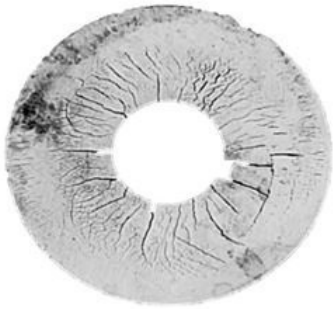


Figure 1–11. Grinding cracks.

Grinding wheels over-heat for several reasons:

- A wheel may become glazed, making it rub instead of cutting the surface.
- Too little coolant may be used.
- Attempting to take too heavy a cut.
- Feeding the material too rapidly.

Grinding cracks are generally at right angles to the direction of grinding. In severe cases, a complete network of cracks can appear. Grinding cracks usually appear as shallow separations of metal and are very sharp at their roots. Often, they are potential sources of fatigue failure. Hardened parts are very sensitive to improper grinding and readily develop cracks unless proper precautions are taken.

Heat-treating cracks

Heat-treating cracks are caused by stresses set up by uneven heating and cooling in certain areas of a part during heat-treating operations. They can occur during either the heating or cooling cycles. Heat-treating cracks are usually deep, seldom following a definite pattern, and appear in any direction on the part. Quenching cracks specifically occur during the rapid cooling of a part. They often start at a thin cross section where thicker and thinner areas of the part adjoin each other. They may also occur where a fillet or other sharp notch creates a perfect starting point for a crack.

206. Service-related discontinuities

The discontinuities of most concern to you as an NDI technician are those originating after a part is placed in service. These are service discontinuities divided into two general groups, resulting from *service induced* and *corrosion*. As an inspector, you also need to identify the relationship between a service defect and a manufacturing defect.

These groups sometimes overlap and compound the seriousness of both. Of the two groups, *fatigue discontinuities are the most serious.* Parts in service that develop discontinuities because of metal fatigue are extremely dangerous and you must give them close attention. Fatigue discontinuities usually consist of cracks developing during service. They normally take the form of fatigue cracks, originating from long-term successive applications of stress, or static cracks, originating from a single or relatively few applications of high stress. Cracks frequently originate from inherent or processing discontinuities and present the greatest hazard to personnel. For this discussion, we classify any service crack as a fatigue crack and will look at them more closely.

Manufacturing discontinuities

Many discontinuities result from manufacturing and repair processes. These are usually detected each time the part is reinspected. The NDI inspector must be familiar with their appearance and cause, in order to make valid call of inspection results. Examples of these were discussed in the previous lesson.

Service induced discontinuities

The most frequently encountered service discontinuities detected are fatigue cracks. Stress corrosion and overload cracking are also common. Overload fractures occur when the stress exceeds the tensile strength of the part. This is greater than the yield point, and the fracture is accompanied by some distortion. Cracks caused by overloading are relatively large and are enlarged by distortion, making them easy to detect visually.

Fatigue cracks

Fatigue cracks normally develop in, or adjacent to, areas of a part where stress is concentrated. These areas include oil holes, fillets, keyways, splines, and threads. Usually, these areas are designed to withstand the stresses imposed. Faulty design, such as oil holes with sharp edges and poorly finished or insufficient fillets, often results in a concentration of stress much higher than expected. Any discontinuity in an area of stress concentration greatly increases the possibility of fatigue failure.

A fatigue failure is progressive. It starts as a microscopic crack, or an accumulation of such cracks, and spreads under repeated stressing. This spread continues until the cross section of the part is reduced to the point where it fractures under low stress loads. Once a crack starts, its ability to progress or advance is greatly increased by the stress concentration caused by the crack itself. The rate of progress in fatigue cracks will vary, depending on the stress conditions. Figure 1–12 shows a fatigue crack and its progression. Cracks can spread slowly, as observed in some parts that apparently operate for many hours in a cracked condition. In instances where high stresses are continually applied, particularly to brittle materials, the progress of cracks can be practically instantaneous. Cracked parts are always a serious potential source of failure. Detecting them during inspection is of prime importance. In aircraft operation, the rapidly rotating and reciprocating parts in an engine and vibrations in the entire aircraft structure produce repeated stresses on components. The magnitude and rate of the stress can vary. There is relatively low stress during level flight, while high stress predominates during takeoffs, landings, dives, and at excessive speeds. High stress conditions invite fatigue failure.

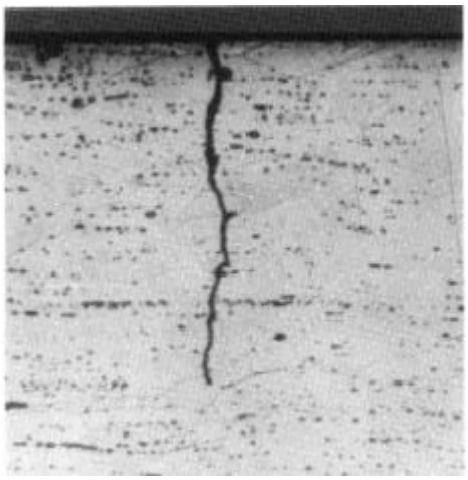


Figure 1–12. Fatigue crack.

Remember, fatigue cracks start as fine, microscopic cracks. For this reason, a small fatigue crack could be missed or confused with a much less significant discontinuity. Exercise care in evaluating all indications. Fatigue cracks, although very serious, are not necessarily cause to reject a part. In many instances, cracks under a specified length are allowed and a part can continue to be used. Using NDI as a maintenance tool, areas with existing cracks are inspected more frequently in order to make sure that the cracks do not grow past a rejectable limit. It is very important that you become familiar with the acceptance and rejection portion of the applicable –36 TO for your particular airframes. If no technical data is available for a part under inspection, the inspection findings are limited to a description of the size, location, and type of defect discovered. Responsible engineers for the affected weapon system will take your inspection data and make a determination of component serviceability.

Fortunately, a fatigue crack is often identified by its direction in relation to the applied stresses. For example, in a forged crankshaft, primary processing discontinuities such as seams and inclusions normally run parallel to the longitudinal axis. In contrast, fatigue cracks may run transverse to the longitudinal axis. Fatigue cracks usually run perpendicular to the direction of applied stress. This demonstrates the need for you to understand the characteristics of a part, whether it is forged or cast, and the direction of the principal stresses in it.

Stress-corrosion cracks

Stress-corrosion cracks are caused by corrosion buildup. Parts under residual or applied tensile stress (and are also exposed to a corrosive environment), may develop stress-corrosion cracking. The primary role of corrosion in this cracking mode is to produce hydrogen. The hydrogen migrates to the tip of a stress-corrosion crack where its presence increases the stresses at the tip, thus driving the crack even deeper into the part.

Overstressing

Parts stressed beyond the level of their limit can crack or break. Such overstressing may occur as the result of an accident; overloading due to an unusual emergency condition, not anticipated by the designer; or a part may be loaded beyond its strength, due to failure of a related member of the structure. It is important to check other parts of the assembly as well because they may appear undamaged until an NDI process is completed and you can determine whether any cracks have actually formed.

Corrosion

Corrosion is the deterioration of metal through reaction to the environment. It is an extremely critical service defect affecting both the life and serviceability of parts. Corrosion of components and primary structures can greatly affect the capability and structural integrity of an aircraft or missile. Depending

on your location, you may have to devote much of your time to the prevention and detection of corrosion.

Corrosion occurs because of the tendency of most metals to return to their natural state. Thus, over time, iron will revert to its natural state, iron oxide. Pure noble metals, such as gold and platinum, do not corrode, since they are chemically stable in their natural state. However, a metal can also corrode in reaction with a chemical.

Since corrosion often starts on the surface of a metal, it is frequently detected visually. NDI methods are used to detect corrosion, especially on aircraft areas having limited access. The following discussion covers the types of corrosion most commonly affecting aerospace weapon systems.

Pitting corrosion

This is the most common type of corrosion found on aluminum and magnesium. An indication of pitting corrosion is a white or gray powdery deposit on the surface. When the deposit is removed, small holes or pits are visible on the surface.

Intergranular corrosion

Intergranular corrosion (fig. 1–13) attacks at the grain boundaries of a metal. All metal alloys are composed of minute grains, each having a different composition at the center rather than at the grain boundary. A small corrosion cell is established when an electrolyte is in contact with the metal surface, causing rapid selective corrosion at the grain boundary.

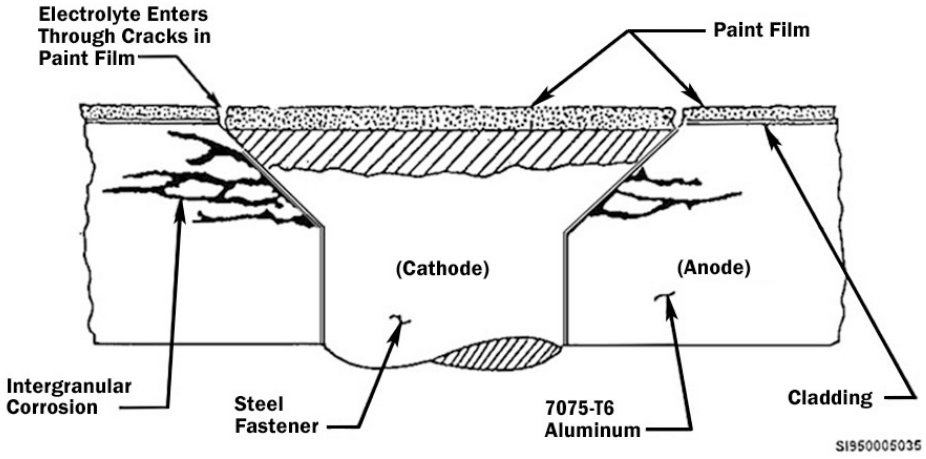


Figure 1–13. Intergranular corrosion.

Exfoliation corrosion

This is a form of intergranular corrosion. It starts at the surface and progresses along the grain boundaries under the surface of the metal. The formation of the expanding corrosion by-products causes the surface of the metal to lift up. Exfoliation is often seen in extruded sections of metal.

Galvanic corrosion

Galvanic corrosion is another common type of corrosion and occurs when dissimilar metals are in contact with each other in the presence of moisture. Each type of metal has unique physical properties and a specific electrical potential. The difference in electrical potential between two metals, in the presence of an electrolyte, establishes an electrochemical reaction and corrosion occurs. Galvanic corrosion is recognizable by a buildup of corrosion by-products between the dissimilar metals as shown in figure 1–14. Magnesium and aluminum skins on an aircraft wing with dissimilar rivets, or aluminum components attached with steel bolts, are prime examples of areas susceptible to this type

of corrosion. The greater the electrical potential difference in the metals, the more rapidly forming and resulting severity of the galvanic corrosion.

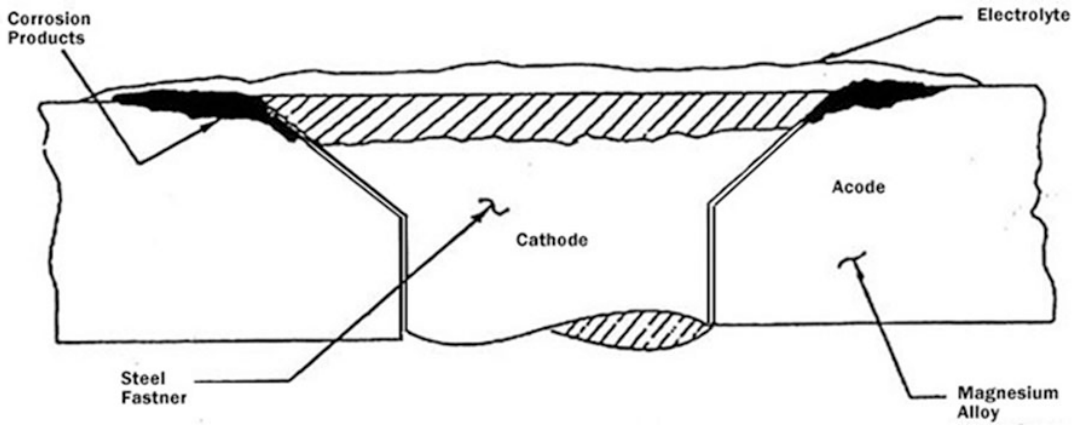


Figure 1–14. Galvanic corrosion of magnesium adjacent to a steel fastener.

Stress corrosion

The simultaneous effects of tensile stress and corrosion cause stress corrosion. When a metal is stressed to a certain point within the critical stress range for a particular metal, corrosion begins to occur at the point of stress concentration. During further stresses, the combination of the corrosion and the concentrated stress causes the metal to crack.

Although corrosion always starts on a surface of a metal, visual detection is not always possible. For example, it is not always possible to visually detect stress corrosion on the inside of wing skins, in areas between faying surfaces (where surfaces are in contact with a joints), or on the surfaces formed by cracks.

207. The welding process

One of the primary methods of attaching two pieces of metal together is welding. Welding inherently increases the potential for numerous discontinuities unique to the welding process. Additionally, you may be required to assist in the certification process for a welder. This means you must have a sound understanding of the welding process and any resulting discontinuities.

Welding process

The two basic processes by which metal parts are welded together are adhesion welding and fusion welding. Your basic understanding of these processes will enable you to identify defects common to welding processes. Welding defects are later discussed in radiation.

Adhesion welding

Adhesion welding refers to brazing, silver soldering, and lead soldering. In this process, only the bonding material reaches the melting point. The edges of the material to be joined are heated to the correct temperature below its melting point and the bonding material is applied. This method is used primarily to join two dissimilar metals.

Fusion welding

This process involves heating the edges of two pieces of metal to be joined by means of a torch or electric arc until they reach the melting point. Usually, this includes additional weld metal supplied in a welding rod melted by the torch flame or arc and flowed into the space between the edges of the parent metals. The part then to cools into a single, bonded piece.

208. Probability of detection

Ensuring that our equipment is capable of detecting critical defects and that NDI technicians are proficient enough to find defects with established procedures is the motivation behind the POD evaluation process. The process creates a measurement tool called a POD curve.

When an NDI journeyman or craftsman fails to find a defect while performing an inspection, human error is often the sole cause. Experience has shown, however, that human error is *not always* the only cause. Sometimes the failure is due to the inspection setup/calibration procedure not meeting engineering requirements, or from equipment that is not capable of detecting the defect that engineers want to find. POD focuses on the size of a crack that can be *found*, not the size of a crack that can be *missed*.

POD theories

Traditional flaw detection capability of an NDI technician performing an inspection procedure, using a specific piece of equipment, was determined by whether we were able to find specific sized cracks that match the indications from a reference standard. This was called the hit or miss theory; in other words, either you found the crack, or you did not. While this is effective for process control purposes, it does not always mean that we will find every naturally occurring defect in real aircraft parts.

Modern theories attempt to include many of the variables that may affect inspection results. Properties of both materials and defects, inspection conditions, instrumentation, sensors/transducers/probes, written inspection procedures, and human factors are all variables that can affect an inspection.

POD studies

A POD study is an experimentation and demonstration process designed by engineers to gather results from actual inspections. All theories call for experiments or demonstrations of the actual inspection using artificial or natural crack standards in order to obtain the required data. Some theories take the POD study information and predict the probability of detection by applying mathematical formulas while others rely more on statistical calculations.

The 90 percent POD value is an estimate of a defect size an inspector can find nine out of 10 times. This value is an assessment of individual capabilities, or a comparison of the abilities of inspection systems and procedures. POD is a training tool that you can use to build your confidence and capabilities as a trainee. The value associated with each POD curve links the aircraft design engineers, Air Force structural integrity engineers, and those of us performing NDI inspections on the flight line.

POD curve

All the information gathered from the experiment and demonstration process is put into a chart called a POD curve. The POD curve is a measurement tool that predicts in percentages how capable a specific NDI technique, piece of equipment, or technician is in finding a range of different size defects. The POD curve may also be used as a basis for the following:

- Establishing design acceptance requirements.
- Setting inspection and maintenance intervals.
- NDI procedure validation and acceptance.
- Personnel performance evaluation/qualification.
- Comparison of different NDI procedure performance capabilities.
- Selection of an applicable NDI procedure.
- Discovering needed improvements in NDI procedures.
- Evaluate and improve NDI process control procedures.

POD process goals

One goal of the POD process is to provide NDI technicians with the right equipment, correct inspection procedures and to ensure that the best on-the-job training is available. A second goal is to provide manufacturers with accurate information on NDI capabilities for use when designing aircraft.

A third goal is to enable Air Force structural integrity engineers to evaluate with confidence the indications NDI technicians find, and to enable them to make decisions that prolong the use of older aircraft, while protecting the men and women that fly them.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

204. Types of discontinuities

1. What is an NDI indication?

2. What is a discontinuity?

3. What is a defect?

4. What determines whether a particular discontinuity is a defect?

205. Types and origins of metal discontinuities

1. What classification of discontinuity results from initial metal solidification from a molten state?

2. What classification of discontinuity refers to metal shaped by either casting or wrought?

3. How can discontinuities in metal ingots find their way into finished parts?

4. What causes inclusions in metal?

5. How do gas holes of porosity form in metal?

6. What is porosity?

7. What are shrinkage cavities forming at the top of metal ingots called?

8. What causes segregation in metal ingots?

9. What are the two categories of processing discontinuities?

10. What causes primary processing defects?

11. What are two methods of shaping metals into usable forms during the primary stage of manufacturing?

12. What are ruptures occurring when forging operations are started before the material to be forged reaches an even temperature throughout called?

13. Flakes are usually found only in what type of metal?

14. Describe a lamination.

15. What are surface discontinuities that are generally long, straight, and parallel to the longitudinal axis of a bar called?

16. What results from metal that is folded over?

17. What is formed by pouring molten into a mold?

18. In what way does a metal fail, causing cold shuts to occur?

19. Hot tears are caused by light sections cooling and solidifying faster than heavy sections that result in what type of action?

20. What is another name for hot tear?

21. What are secondary processing defects sometimes called?

22. What is caused by cutting metal with a dull tool or by cutting to a depth too great for the material being worked?

23. What can the burnishing action of finishing or polishing operations accomplish?

24. What produces grinding cracks?

25. How do grinding cracks appear?

26. What parts are particularly sensitive to improper grinding?

27. What causes heat-treating cracks?

28. What defects often start where thinner and thicker areas adjoin each other during the rapid cooling of a part when performing heat-treating operations?

206. Service-related discontinuities

1. What defect often originates from inherent or processing discontinuities and presents the greatest hazard to personnel?

2. What are the most frequently encountered service discontinuities detected?

3. Where do fatigue cracks normally develop?

4. What does the word *progressive* describe?

5. What factor greatly increases a crack's progress in a part?

6. Under what circumstances can crack progress be practically instantaneous?

7. When is high stress predominant, inviting fatigue failure?

8. Why can small fatigue cracks be missed or confused with other discontinuities?

9. How can NDI be used as a maintenance tool regarding existing cracks in operational components?

10. Who determines component serviceability based on your inspection data when no other technical data is available?

11. In which direction to fatigue cracks normally run in relationship to the applied stress?

12. What may parts develop when they are under stress and are also exposed to a corrosive environment?

13. What happens when parts are stressed beyond their limit?

14. Why does corrosion occur?

15. Why can you suspect corrosion on the surface of metal?

16. What type of corrosion is indicated by a white or gray powdery deposit on metal surfaces?

17. What causes the surface of metals to lift up when subjected to exfoliation corrosion?

18. When does galvanic corrosion occur?

19. How can galvanic corrosion be identified?

20. What two simultaneous effects cause stress corrosion?

207. The welding process

1. Why must you have an understanding of the welding process and resulting discontinuities?

2. What are the two basic processes for welding metal parts together?

3. What are some examples of adhesion welding?

4. What flows between two pieces of parent metal during fusion welding?

208. Probability of detection

1. Along with ensuring that our equipment is capable of detecting critical defects, what else is the motivation behind the POD evaluation process?

2. What does POD focus on?

3. What is the POD value percentage?

4. What is described as a measurement tool that predicts in percentages how capable a specific NDI technique is in finding a range of different size defects?

5. The POD curve may also be used as a basis for setting what intervals?

6. What are three goals of the POD process?

Answers to Self-Test Questions

201

1. Pure metal.
2. An alloy.
3. Less than two percent.
4. Nickel is the major alloying element.
5. Increase toughness, strength, and hardness.
6. When iron is not the principal or major alloying element.
7. Specific properties, which properties may be changed, and the amount of property change possible.
8. Each element and the exact percentage of each element.
9. Chemical composition and grain structure.
10. Pure metal.
11. Elements and compounds are clearly visible and held together by a matrix of the base metal.
12. They are absorbed into each other and are no longer identifiable, even under a microscope.
13. Physical structure.
14. Crystalline.
15. Metal grains.
16. Grain structure.
17. Recrystallization temperature.
18. Heating and cooling a metal around the recrystallization temperature.
19. Improves metal characteristics for specific applications by altering the grain structure.

202

1. Mechanical and physical properties.
2. Mechanical properties.
3. An applied force.
4. Elongation or reaction to an applied force per unit length.
5. Hardness, brittleness, elasticity, plasticity, strength, toughness.
6. (1) c.
   (2) d.
   (3) b.
   (4) b.
   (5) e.
   (6) a.
7. It increases.
8. It decreases.
9. Chemical composition.
10. Melting point, thermal conductivity, thermal expansion, electrical conductivity, density, color, luster, and magnetic susceptibility.
11. Thermal conductivity.
12. That they are better conductors of electricity.
13. Density.
14. How a material reacts to a magnetic field.

203

1. SAE and AISI identify ferrous metals, while AA and IACS identify nonferrous metals.
2. Steels.

3. The type of steel based on the primary alloying element or elements.
4. The approximate percentage of the predominant alloying element.
5. The approximate average carbon content in points or hundredths of one percent.
6. AISI adds a prefix alpha digit to identify the manufacturing process of the metal.
7. Four.
8. The metal contains at least 99 percent pure aluminum.
9. The number of special controls over impurities in the alloy; for example, if the second number is zero, then it indicates no special control over individual impurities.
10. Hundredths of 1 percent above the original 99 percent designated by the first digit; they are, in other words, the percentage above the original 99 percent of additional pure aluminum.
11. The major alloying element.
12. The variation of the basic alloy, but not the specific purity or exact composition.
13. Degree of hardening.
14. T.
15. T.O. 1–1A–9, Section III.
16. Because different metals, and even the same metal with different tempers, have different conductivity values.
17. It decreases.

204

1. A response or evidence of a response that requires interpretation to determine its significance as the result of an NDI process.
2. An interruption in the normal physical structure or configuration of a part.
3. A discontinuity interfering with the usefulness or serviceability of a part or is detrimental to its serviceability.
4. The service history of the part, its stress loading, and the degree, location, and proximity to other discontinuities.

205

1. Inherent.
2. Processing.
3. At times, even when manufacturers melt the ingots down for castings, some discontinuities can remain. In other words, they can be trapped below the level normally cropped off the metal ingot.
4. Incomplete refining of the metal ore or the mixing of flux or purification compounds with the metal as it solidifies.
5. When insoluble gases are trapped in the molten metal as it solidifies.
6. Numerous, very small gas holes.
7. Pipes.
8. When the ingot solidifies and the distribution of the various elements or compounds is not uniform throughout the mass of the ingot.
9. Primary and secondary.
10. Improper rolling, forging, or drawing of the original metal ingot into the basic metal shapes.
11. Wrought processing.
12. Bursts.
13. Alloyed steel.
14. Thin, flat discontinuities.
15. Seams.
16. Laps.
17. Casting.

18. They fail to flow together because of interrupted pouring, uneven cooling, or pouring when the temperature of the metal is too cool.
19. A tearing action.
20. Shrinkage cracks.
21. Finishing defects.
22. Machining tears.
23. Either conceal or conceal over machining tears that may be too deep to be completely removed later by finish machining or by grinding.
24. Grinding wheels over-heating.
25. Shallow separations of metal with sharp roots.
26. Hardened parts.
27. Stresses set up by uneven heating and cooling in certain areas of a part during heat-treating operations.
28. Quenching cracks.

206

1. Cracks.
2. Fatigue cracks.
3. In or adjacent to areas where stress is concentrated.
4. Fatigue failures, which start as microscopic cracks, or accumulations of such cracks, and spread under repeated stressing. Once cracks begin, their ability to progress are greatly increased by the stress concentrations caused by the cracks themselves.
5. The stress concentration caused by the crack itself.
6. Brittle materials under continuous high stress.
7. During takeoffs, landings, dives, and at excessive speeds.
8. Because they start as fine, microscopic cracks.
9. By inspecting the cracks more often to ensure they do not exceed rejectable limits.
10. Responsible engineers for the affected weapon system.
11. Perpendicular.
12. Stress-corrosion cracks.
13. They can crack or break.
14. Because of the tendency of most metals to return to their natural state.
15. Because you can frequently detect it visually.
16. Pitting corrosion.
17. The formation of the expanding corrosion by-products.
18. When dissimilar metals are in contact with each other in the presence of moisture.
19. A build-up of corrosion by-products between the dissimilar metals.
20. Tensile stress and corrosion.

207

1. Because welding operations inherently increase the potential for unique discontinuities and NDI may be required to assist in a welder’s certification process.
2. Adhesion and fusion welding.
3. Brazing, silver soldering, and lead soldering.
4. Additional weld metal supplied by the welding rod.

208

1. NDI technicians are proficient enough to find defects using established procedures.
2. The size of the crack that can be found.
3. Ninety percent, which is an estimate of a defect size that can be found nine out of 10 times by an inspector.

4. POD curve.
5. Inspection and maintenance intervals.
6. First, providing NDI technicians with the right equipment, correct inspection procedures, and ensuring that the best on-the-job training may be obtained; secondly, to provide manufacturers with accurate information on NDI capabilities for use when designing aircraft; thirdly, to enable Air Force structural integrity engineers to evaluate with confidence the indications that NDI technicians find and to enable them to make decisions that prolong the use of older aircraft, while protecting the men and women that fly them.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field Scoring Answer Sheet.

Do not return your answer sheet to Air Force Career Development Academy (AFCDA).

1. (201) What form is the *physical structure* of metal?
   a. Crystalline.
   b. Solid solution.
   c. Mechanical mixture.
   d. Combination solid solution.

2. (201) The process of improving a metal's characteristics by altering its *grain structure* is known as
   a. casting.
   b. machining.
   c. heat-treating.
   d. cold working.

3. (202) Maximum toughness obtains proper balance in all of these properties *except*
   a. strength.
   b. hardness.
   c. elasticity.
   d. plasticity.

4. (202) Which of the following properly illustrates the relationship between mechanical properties in metal?
   a. As hardness increases, elasticity increases.
   b. As hardness increases, toughness increases.
   c. As hardness decreases, brittleness decreases.
   d. As hardness decreases, tensile strength increases.

5. (203) What does the does the *first digit* of an Aluminum Association identification number indicate?
   a. Aluminum group.
   b. Major alloying element.
   c. Special controls for impurities.
   d. Metal containing at least 99 percent pure aluminum.

6. (203) What three methods are used to produce tempered aluminum?
   a. Cold working, heat-treating, and a combination of both.
   b. Hardness, work-hardened alloys, and aluminum alloys.
   c. Cold working, work-hardened alloys, and aluminum alloys.
   d. Aluminum alloys, heat-treating, and a combination of both.

7. (204) The term nondestructive inspection (NDI) indication refers to
   a. a discontinuity.
   b. a defect in a part.
   c. changes in a parts mechanical properties.
   d. evidence of a response resulting from a process.

8. (204) In metallurgy, which of the following is *not* a discontinuity?
   a. Weld.
   b. Seam.
   c. Crack.
   d. Lap.

9. (205) Which discontinuity is created by the melting and original solidification of a metal into an ingot?
   a. Service.
   b. Inherent.
   c. Processing.
   d. Mechanical.

10. (205) Which of the following is *not* a defect of the wrought process?
    a. Laps.
    b. Bursts.
    c. Flakes.
    d. Inclusions.

11. (205) What is another name for slag?
    a. Porosity.
    b. Inclusion.
    c. Cold Shut.
    d. Lamination.

12. (205) Which defects are usually easier to detect because they nearly always appear on the surface of the finished part?
    a. Inherent.
    b. Segregation.
    c. Primary processing.
    d. Secondary processing.

13. (206) The reason *fatigue failure* is progressive is that when a crack begins,
    a. its ability to advance is increased by stress concentration, although the rate of stress can vary.
    b. its ability to advance is increased by stress dispersal, and the rate of stress remains the same.
    c. progression is relatively slow, even under repeated stress in concentrated areas.
    d. progression is usually instantaneous, even under varying conditions.

14. (206) Fatigue cracks form
    a. parallel to the direction of applied stress.
    b. parallel to the longitudinal axis of the part.
    c. perpendicular to the direction of applied stress.
    d. perpendicular to the longitudinal axis of the part.

15. (206) Stress corrosion is caused by
    a. an electrolyte.
    b. oxygen concentration.
    c. tensile stress and corrosion.
    d. dissimilar metals in contact.

16. (207) The potential for discontinuities is increased by the
    a. brittleness associated with very hard steel.
    b. composition of the metals used in manufacturing.
    c. stress applied across the load of a cross-sectional area.
    d. welding process used to attach two pieces of metals together.

17. (207) The two basic processes used to weld parts together are
    a. fusion and brazing.
    b. adhesion and fusion.
    c. fusion and soldering.
    d. adhesion and soldering.

18. (208) An experimentation and demonstration process designed by engineers to gather results from actual inspections is referred to as a probability of detection (POD)
    a. study.
    b. curve.
    c. policy.
    d. theory.

19. (208) The probability of detection (POD) curve may *not* be used for which basis?
    a. Selection of an applicable nondestructive inspection (NDI) procedure.
    b. Discovering needed supplements in NDI procedures.
    c. Personnel performance evaluation/qualification.
    d. Establishing design acceptance requirements.

Please read the unit menu for unit 2 and continue ➔

Unit 2. Inspection Techniques

2–1. Component Preparation 2–1
209. Contaminants and cleaning processes affecting NDI techniques 2–1
210. Pre-cleaning and post-cleaning 2–5
2–2. NDI Technique Development 2–10
211. NDI techniques 2–10
212. NDI technique development 2–12
213. Responsibilities for updating techniques 2–15

YOU SHOULD NOW feel confident in your knowledge of the types of metals aerospace components are made from and the types of discontinuities you can expect to find, but one question remains unanswered —"How do I inspect parts?" Like everything else in the Air Force, there is—or should be—written NDI guidance for every part you inspect. This written guidance is identified as an inspection or NDI technique.

NDI techniques tell you—the technician—everything you need to know to complete your assigned task. NDI techniques should not be confused with NDI methods.

- An NDI *method* is the specific tool used to inspect the part (e.g., x-rays or ultrasonics), and each of these methods is covered throughout the remainder of this career development course (CDC).
- An NDI *technique* describes the part you are inspecting, which NDI method to use, specific equipment settings or conditions, the defects you can expect to find, and your responsibilities for inspection documentation.

Every NDI technique has to start and stop somewhere. To start this unit, we cover general component preparation for NDI methods. We conclude this unit by looking at different techniques and show you how to submit information on new or revised procedures for publication.

2–1. Component Preparation

You may be asking yourself, "Why is cleaning a part that critical?" The answer is, in NDI the preparation of a part or material inspected *can be as critical as the actual inspection process*. Properly trained personnel should *only* accomplish cleaning Air Force equipment and parts. Contaminants affect how well NDI methods can detect defects varying in type, size, and shape. Therefore, it is important that you understand the types of contaminants and the cleaning methods used to remove them without harming the part or masking a defect.

209. Contaminants and cleaning processes affecting NDI techniques

NDI requirements for part preparation can involve a number of steps. Before you can apply an NDI method, a part may need paint removed, or disassembling. Additionally, many parts you inspect require cleaning after you have completed your inspection. Since paint removal and part disassembly are normally accomplished by the owning work center before you receive the part, we will concentrate on the one area where you may be directly involved—cleaning.

Pre-cleaning is the surface preparation performed by NDI personnel prior to an inspection. The purpose of pre-cleaning is to remove light soils and contaminates that have accumulated since major cleaning, such as bolt threads. Parts requiring more extensive cleaning will go to the appropriate cleaning shop or corrosion control facility. It is your responsibility to check for this prior to performing your inspection, because it will hinder your outcome and can cause false indications.

Contaminants and soils

Contaminants and soils are used interchangeably. They refer to any foreign matter on a part affecting the outcome of an NDI technique. Contaminants, such as lubricating grease, hydraulic oils, or corrosion prevention coatings, are intentionally applied to some parts. Other contaminants are unintentional, (e.g., corrosion, cleaning compound residues, or carbon deposits). The particular effect on your inspection depends on the NDI method and the type of contaminant present. You must be aware of the problems associated with inspecting uncleaned parts.

Improper preparation of a part can hide critical defects, harm the part, or contaminate your inspection materials. In some cases, NDI techniques specify the types of cleaning you may or may not use. When not specified by a technique, the degree and type of cleaning required depend largely on the type and location of suspected defects.

NOTE: Improper cleaning methods can cause severe damage or degradation of parts.

Light oils and soft films

Examples of light oils and soft films include hydraulic oils, light greases, and lubricating oils. These contaminants can adversely affect penetrant inspection materials by preventing or reducing proper penetrant entrapment in defects. They can also contaminate penetrant or magnetic inspection solutions. Also, many oils and greases fluoresce under a black light. When on a part surface, this fluorescence could obscure a discontinuity indication or produce a false indication. When surface oils contain dirt or other small particles, they can even affect ultrasonic inspections by disrupting sound transmission into the part. Oils and soft films are easy to remove by solvent washing, aqueous degreasing, or by ultrasonic cleaning with detergent or solvent.

Heavy oils and solid films

Heavy oils and solid films include thick greases, viscous oils, and particulate lubricants such as graphite. These contaminants can affect penetrant, magnetic, and ultrasonic processes in the same manner as light oils or soft films, but are more difficult to remove. Depending on their quantity and chemical properties, they can also produce images on radiographic film, obscuring or mimicking other defects. They are removed by using industrial solvents, chemicals, or strong mechanical action. A secondary problem is that strong mechanical action may scratch or even smear metal over surface discontinuities, which can hide defects or produce false indications.

Carbon, varnish, and other tightly held soils

These contaminants include partially burned petroleum by-products, residue from evaporated fuels or oils, and dry film lubricants. These contaminants can adversely affect most NDI inspection processes. Soils such as these are very adhesive and difficult to remove because parts may have been baked at elevated temperatures. They require special cleaning compounds and processes that break-up the deposits otherwise, the soils can bridgeover or partially fill the discontinuity. Strong mechanical action, such as scrubbing, pressure spray, or solution agitation may also be required. Care must be used, since many of the cleaning compounds will attack metals and alloys.

Scales, oxides, and corrosion

Since you are already familiar with corrosion, we will cover scale and oxides. These are generally caused by high temperatures such as those produced inside engines. These contaminants affect all NDI methods. Scale and oxides are usually very difficult to remove and may require aggressive cleaning methods. These are removed by only using acids, abrasives, or other metal removal that have the potential for covering or obscuring existing defects.

Water or moisture

We normally do not think of water or moisture as a contaminant, but it can be one. Moisture can occur from many sources, but the most common source is inadequate drying. Water can reduce the effectiveness of penetrant and magnetic inspection materials. It is essential that water be removed not

only from the part surface, but also from the inside of any discontinuities that may be present. Moisture in the form of condensation from high humidity or low temperatures may also occur and must be removed. Normally, additional drying of a part will sufficiently remove any excess moisture unless it is entrapped. Water entrapment in honeycomb structures is a defect we will cover in detail in the units on radiographic and ultrasonic NDI methods.

Residues from a cleaning process

Some cleaning chemical solutions contain strong alkalis or acids. If these are not properly removed or neutralized, they can react to penetrant inspection chemicals or contaminate magnetic inspection baths. Strong alkalis and acids can decompose or degrade dyes and other chemicals in the penetrant, causing weak or faint indications. Therefore, removal or neutralization of residual solution is always important and often imperative. The usual process to accomplish removal is with warm water and agitation, followed by repeated immersions in fresh water.

Residues from previous inspections

NDI materials themselves are considered contaminates and can affect serviceability of a part when they are not properly removed following an inspection. Frequently inspected parts are typically received while still containing dried, old penetrant oil. This old material can produce false indications, or dry inside existing defects, making future introduction of fresh penetrant impossible. If not properly removed, penetrant developers may corrode a part and also affect its serviceability, which will be discussed further later in this unit.

Cleaning processes for contamination and soil removal

There are no special cleaning processes or materials specifically dedicated to each method. Different materials and parts requiring cleaning must be evaluated individually. The selection of a particular cleaning method depends on a number of factors, including the following:

- Type of soils or contaminants to be removed.
- Type and amount of contaminants or soils to be removed.
- Part material – some cleaning methods will harm certain metals.
- Part surface condition – rougher surfaces tend to make cleaning more difficult.
- Surface accessibility (part geometry) –complex shapes make it hard to clean surfaces.
- Degree of cleanliness required for the NDI method or other part treatment.
- Availability and adequacy of cleaning facilities, materials, and trained personnel.

Effective cleaning methods to remove contaminants from surfaces, materials, and suspected defects are listed in TO 1–1–691, *Cleaning and Corrosion Prevention and Control, Aerospace and Non-Aerospace Equipment*. You should become familiar with the cleaning procedures used at your location and evaluate their effectiveness and effects for each NDI method you use. Let us look at some of the more common cleaning processes used in the Air Force.

Alkaline cleaning

Alkaline cleaners are water solutions of chemicals. They remove soils by a chemical action by converting chemicals into soap, or displacement, rather than dissolving the soils. Alkaline cleaning is usually immersed in tanks with the solution at or near its boiling point. The cleaning action occurs by agitation. The following are the four variables that affect the performance of an alkaline cleaning process:

1. Immersion time.
2. Agitation aggressiveness.
3. Solution concentration.
4. Solution temperature.

The cleaning process is more effective when each of these factors are increased.

Detergent cleaning

Detergents are water-based chemicals that surround and attach themselves to particles of soils. This is precisely the same action seen with hydrophilic removers in penetrant inspections. The particles and detergents are washed away using agitation, sprays, or hand wiping. Detergents may be alkaline, acidic, or neutral, but must be noncorrosive. They are normally effective on light soils, but may *not* effectively clean heavier soils.

Emulsion cleaning

Emulsion cleaners consist of an organic solvent and a detergent in a water-based solution. The organic solvent may be a petroleum-based liquid and may be removed through a combination of solvent and detergent action. The cleaner is lightly alkaline and is usually sprayed on the part. Emulsion cleaning may leave a light oil film (solvent residue) on the part surface; therefore, emulsion cleaned parts should be rinsed with hot water or wiped down adequately.

Solvent cleaning

Solvent cleaning involves the use of chemicals to dissolve soils. Solvents effectively remove oils, greases, waxes, paints, and other organic substances; however, this process may leave oily residues on parts. These residues must be cleaned using detergents or other cleaning methods prior to applying some NDI techniques. Solvents are available in liquid form for use in dip tanks and spray, paste, or gel form for use in smaller areas. When you use spray solvents, you must work in an adequately ventilated spray booth.

Paint strippers

Paint removers can be a solvent, bond release agent, softening agent, or a combination of both. Many paint removal operations leave a thin film of dissolved or softened paint and remover chemicals on the part surface or in discontinuities. This often occurs when local or spot paint removal is performed.

NOTE: Care must be taken to ensure the area inspected is free of paint residues since they interfere with the NDI inspection process.

Ultrasonic cleaning

High-frequency sound waves traveling through a liquid cleaning agent describes the ultrasonic cleaning process. This method utilizes ultrasonic agitation within a solvent detergent solution to accelerate the cleaning process as it subjects high and low pressures of ultrasonic waves. This provides a scrubbing action to the surface of the part and the agitation increases the action of the cleaning solution and decreases its cleaning time. Ultrasonic cleaning is effective in removing contaminants trapped in discontinuities, such as small holes or crevices, and this is why we use this often. It usually mixes with water and detergent on inorganic soils, such as rust, dirt, salts, and corrosion.

Salt baths

Molten salt baths are used to remove heavy, tightly held scale and oxides from low alloy steels, nickel, cobalt-base alloys, and some stainless steels. They cannot be used for aluminum, magnesium, or titanium alloys. Cleaning is accomplished by immersing parts in an extremely caustic (alkaline) soda solution at approximately 700 degrees Fahrenheit (°F). Differences in the thermal properties of the scale or oxides and the base metal tend to break them apart. The soda chemically reacts with these contaminants and further breaks their bond to the part. Once removed, parts are plunged into water, creating a thermal shock. The rapid change in temperature creates a shock and stream, which scours and blasts remaining scale from the part.

Acid cleaning

Acid solutions are used to clean inorganic contaminations such as rust, heat-treating scale, and corrosion. Any oil, grease, or other organic compounds must first be removed by another cleaning method or the acids will not properly react with the inorganic contamination. Because of their hazardous nature, use of these cleaners is highly controlled and only qualified personnel should accomplish the process.

NOTE: It is important to check with your local Bioenvironmental Engineering (BE) personnel and state laws for approval of these types of cleaners before use.

Mechanical cleaning

Various types of mechanical cleaning methods are used to remove surface contaminants. However, they should be used only to remove contaminants *not* readily removed by chemical means. Mechanical methods, such as wire brushing or abrasive blasting, can be used to remove rust or other corrosion deposits. These methods, if used improperly, can damage parts and conceal discontinuities. They are effective, but result in longer work times, and increased metal loss. Be advised that they also obscure small cracks and other discontinuities.

Chemical etching

Chemical etching removes base metal surfaces using an etching solution specifically formulated for a particular part material and condition. There are strict controls on this process and deviations can lead to adverse effects such as the following:

- Excessive metal removal.
- Etching of critical surfaces.
- Increased susceptibility to stress corrosion.
- Reduced surface area with a corresponding reduction in fatigue life.

NOTE: NDI personnel are not qualified to perform chemical etching unless they train and certify in this process.

Mechanical removal

Mechanical working removes soils and contaminates by physical action. This physical action may also remove or deform the part surface. Mechanical removal methods are divided into two general categories: (1) abrasive blast and (2) grinding/sanding/brushing.

210. Pre-cleaning and post-cleaning

Extensive chemical or mechanical cleaning of parts is not always necessary. However, each method affects various surface contaminants in specific ways. Before selecting a cleaning method, you need to know the particular requirements of each method. You also need to be able to select the right cleaning process for different parts. Pre-cleaning will properly prepare parts for your NDI inspection process. Once NDI inspection process is completed, post-cleaning may be required to ensure serviceability. Within this lesson, we will examine both pre- and post-cleaning processes.

Pre-cleaning

Pre-cleaning is the surface preparation performed by NDI personnel prior to an inspection. The purpose of pre-cleaning is to remove light soils and contaminates that have accumulated since major cleaning, touch-up critical areas (e.g., bolt threads), and remove residue from other cleaning processes. Parts requiring more extensive cleaning will be sent to the appropriate cleaning shop or corrosion control facility. There is no single cleaning agent or process to clean *all* parts for *all* NDI methods. Cleaning agents may work on one part and fail to clean another. Some cleaning agents may even attack the alloys composing a part. If you are unsure of the cleaning requirements for the part inspected, consult the –36, *Preparation of Part* section, of the specific NDI TO.

The following table lists all the NDI methods and their pre-cleaning requirements.

Method	Pre-cleaning Requirements
Radiographic	Normally, no preparation of the part is necessary for radiographic inspection.
Eddy current	Except for the removal of loose paint and thick or loose scale, an eddy current inspection requires no surface treatment. Severe surface roughness or large variations in coating thickness can give inaccurate readings.
Ultrasonic	Ultrasonic inspection of parts requires good contact between the part and the search unit. Although paint removal is desirable, it is not necessary if the paint surface is smooth and the bond between the paint and the part inspected is secure.
Magnetic particle	Magnetic particle inspections require a high degree of cleanliness. Any organic soils left on the part may dissolve and contaminate the inspection solution. Soils may trap fluorescent particles and produce irrelevant indications or cover defects, making them difficult or impossible to detect.
Liquid penetrant	Penetrant inspections require absolute cleanliness of parts for dependable results. Inorganic soil, such as rust, will absorb penetrant and produce a fluorescent background (in the case of fluorescent penetrant), masking actual defects beyond detection. Indications of defects by penetrant depend upon the flow of the penetrant into what may only be a microscopic crack. Flow cannot take place when a crack fills with oil, paint, engine varnish, dirt, water, plating, or similar coatings.

Post-cleaning

As the name implies, post-cleaning takes place after the NDI process is completed. The purpose of this operation is to remove residue left by the inspection process and return the part to the owning organization as clean as possible. Post-cleaning also removes any residue that could corrode or damage the part and render it unserviceable. It is important to know that post-cleaning methods that use water can cause corrosion of the test surfaces if water is not promptly removed and should be thoroughly dried off by wiping, heating, or blowing with compressed air.

Only the three NDI methods described in the following table require post-cleaning operations.

Method	Post-cleaning Operations
Ultrasonic	Residue left by an ultrasonic inspection is the medium used to couple the search unit to the part. Usually, this is oil or light grease with a petroleum or water base. In a shop environment, the same method used to pre-clean oil, grease, or water contaminants are usually used to remove this residue. When inspections are accomplished in place on an aircraft, suitable post-cleaning may be accomplished by wiping with a dry cloth or one moistened with a suitable cleaning solvent.
Magnetic particle	Remove particle residue (after the part is demagnetized) by rinsing in clean solvent of the same type that is used for mixing the bath. Remove excess vehicle by wiping with a rag or cloth.
Penetrant	Residue from the penetrant inspection process consists of developer and penetrant residue. Remove aqueous wet and dry developers by rinsing with water. This process may be expedited by using a soft brush and suitable detergent. When nonaqueous developer is used in a field situation, hand-wipe with a dry cloth or paper towel to remove most of the residue. A rag or paper towel moistened with water or alcohol will remove the remaining traces. Solvent spraying may be used as a final step, when water use is not practical. Remove penetrant residue after the developer removal process. Remove penetrant with liquid solvents, detergent, or alkaline cleaning.

Post-cleaning precautions

Some post-cleaning operations, particularly those using solvents, can leave a part completely clean and dry. Be aware that you may need to take additional steps beyond post-cleaning.

For example, steel parts post-cleaned with solvents that are not immediately scheduled for further processing will corrode or rust very rapidly. To prevent this, you should promptly treat them with light oil or other approved prevention methods, especially if they are to be stored in a warm and humid atmosphere.

Parts cleaned with water-based solutions must be adequately dried to prevent potential water damage. They may also require corrosion preventive treatment. Check the applicable maintenance TOs for guidance.

Parts condemned because of an inspection may not require post-cleaning, depending upon their disposition. If there are doubts, go ahead and post-clean the parts. In all cases where you have used chemicals during the NDI process, you must post-clean. Chemical residue may present a potential health hazard to personnel who will handle the parts later and do not have training in NDI chemical dangers and precautions.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

209. Contaminants and cleaning processes affecting NDI techniques

1. What are contaminants and soils referred to as?

2. What variable determines the effect contaminants and soils have on an inspection?

3. What are some of the consequences of improperly preparing a part for NDI?

4. What factors determine the degree of part cleaning required when no guidance is available?

5. What can improper cleaning methods cause?

6. List the examples of light oils and soft films.

7. How can strong mechanical action become a problem when removing heavy soils?

8. What are included within carbon and varnish soil contaminants?

9. What types of surface conditions are caused by high temperatures, such as those in aircraft engines?

10. What is the most common reason for water or moisture contamination?

11. What effects can alkali or acid residues have on NDI?

12. When are NDI materials considered contaminants?

13. Identify some of the factors cleaning selection methods depend upon.

14. Which type of cleaner *displaces* rather than dissolves contaminants?

15. What are the four variables affecting alkaline cleaning performance?

16. What category of cleaner acts in the same way as hydrophilic removers?

17. Which type of cleaner maybe petroleum-based?

18. What class of cleaners uses chemicals to dissolve soils?

19. What type of cleaning method heats a solution to near 700°F?

20. When should mechanical removal method be used before performing NDI?

21. What is *not* authorized for NDI personnel unless they are qualified?

22. How is mechanical working removed?

210. Pre-cleaning and post-cleaning

1. What is the purpose of pre-cleaning?

2. What section of –36 NDI TO tells you the cleaning requirements for a part?

3. What part preparation is normally required for radiographic inspections?

4. Which NDI method requires the highest degree of cleanliness?

5. What is the purpose for post cleaning parts?

6. What are the three NDI methods requiring post-cleaning?

7. How do you remove magnetic inspection particle residues during post-cleaning?

8. How can you remove penetrant after you have inspected it?

9. What problem can develop when cleaning steel parts with solvents?

10. What do you do to prevent damage to parts cleaned with water?

2–2. NDI Technique Development

NDI is the inspection of a structure or component, accomplished in any manner that will not impair the usefulness of the part. The purpose of the inspection may be to detect flaws, measure geometric characteristics, determine material structure or composition, and characterize physical, electrical, or thermal properties without causing any changes in the part.

Nondestructive inspection techniques are the single most important set of instructions you will use throughout your Air Force career. However, NDI techniques do not appear out of thin air. Someone has spent a great deal of time and expertise developing, testing, and reporting his or her technique for publication. New technique development can be expensive and time-consuming. Part of your job, as a qualified NDI technician, will be the development or modification of techniques. This section covers the information you need to accomplish this task. We will explain NDI techniques, technique development, and reporting and updating procedures.

211. NDI techniques

NDI techniques are defined as specific instructions for evaluating the quality, integrity, properties, and dimensions of materials and components with approved NDI methods and without damaging or impairing their serviceability in any way. NDI techniques are directives, and deviation from their instructions without approval is extremely limited. Your responsibility for following NDI techniques can be summed up in the following three steps:

1. Follow the authorized NDI technique – *to the letter!*
2. If you have no technique, look for one—it may be in a different manual or at another base.
3. If no technique exists, develop one—*before* you inspect the part or material.

NDI technique

As previously stated, an NDI technique is a directive set of instructions. It provides a roadmap to follow in order to complete your inspection. Well-written techniques include everything you, and anyone supporting you, need to know from start to finish. Let’s breakdown a technique and look at what it contains.

Composition of a TO NDI technique

The following areas outline each of the components of TO NDI techniques. Some TOs may vary slightly from this format, but variations will be minor.

Part description

NDI techniques normally start with a precise description of the part you are about to inspect. This description starts by listing the name of the part, part number, and location on the aircraft.

Example 1

An upper bulkhead possesses the part number 16C5261, fuselage station (FS) 357.80. The description may further breakdown the exact location of the part on the aircraft. It also provides the exact material or materials of which the part is made.

Example 2

The part is fully machined from 2124–T851 aluminum alloy. All surfaces are chromic acid anodized and finished with a urethane corrosion protection coating except the aft side, which is finished with two coats of epoxy primer.

Defect or condition

Every NDI technique is developed to detect specific defects or conditions. Penetrant inspection techniques detecting surface cracks will not reveal subsurface discontinuities. Radiographic techniques to inspect engine bays for foreign objects will not normally reveal fine cracks in

components. Each TO NDI technique will specify the defects or conditions you are seeking, whether they are cracks, corrosion, or some other condition.

Primary and backup NDI methods

Each NDI technique will specify a primary NDI method used. Some techniques may specify more than one primary NDI method. In such cases, you may use any specified primary method listed in the TO to inspect the component. You don't need to perform all primary methods. Some techniques will specify one or more backup NDI methods. Backup methods *do not* replace primary methods. They are normally accomplished after the primary NDI method is complete and are used to verify findings, more precisely assess a discovered defect, or detect secondary defects or conditions. Both primary and backup methods are listed in the TO with a title line, including the NDI method to be used, and are further broken down into specific procedures. A summary of these can be seen in the following table.

NDI Method Specific Procedures	
Procedure	**Description**
Equipment requirements	This section of the NDI technique within the applicable TO lists all of the equipment and materials needed to perform the inspection. It should contain the equipment name, model, and part number used to develop the technique; any supplemental equipment required (e.g., chemicals, probes, cables, or transducers); and reference standards if applicable.
Preparation of aircraft	The NDI technique completely outlines all preparations needed to perform the inspection. This includes all steps needed to make the aircraft safe for maintenance.
Access	This area includes all of the instructions for opening, disconnecting, or removing of any aircraft panels, or parts. Either this area or the *preparation of aircraft* area also specifies any equipment or parts required to be installed *before* inspection.
Preparation of part	This section lists any requirements for disassembly of the part itself and any surface preparation needed. The surface preparation should specify whether pre-cleaning or coating removal is required and which methods for pre-cleaning or paint stripping are authorized.
Equipment settings or setup	This area of the NDI technique can vary quite drastically. The applicable TO may simply tell you to setup your equipment in accordance with another reference, such as "Setup eddy current equipment in accordance with section I." The instructions may require you to setup equipment in accordance with another reference and then make specific changes for this particular inspection, such as "Once calibrated, make the following adjustments to the equipment settings." For some ultrasonic, eddy current, and radiographic inspections, this section of the technique may be several pages long and involve many steps and illustrations. You must ensure you follow all of these instructions exactly. Any deviation on your part could result in a substandard inspection and missed defects. You may also be quite embarrassed when you call a part unserviceable when it is, in fact, perfectly serviceable.
Inspection procedure	Like the equipment setup, the inspection procedures can be short or very extensive. The key is you must follow them exactly. Your integrity as an inspector and as a military member will be questioned if you fail to follow these procedures as written, unless you have received approval from an authorized agency for deviations. Inspection procedures consist of things such as dwell times for penetrant, scanning speeds for probes or transducers, time of x-ray film exposures, or other information directly related to your actual inspection of the part.
Defect marking and recording	This section outlines your responsibilities regarding marking and recording your inspection results. They may be as simple as marking the end of a crack or as complex as documenting every single setting on your equipment and precise measurements of the defect you located. You may also be required to contact engineering agencies if certain defects or conditions were noted during your inspection.

System securing

Finally, the NDI technique in the aircraft specific TO will outline all post-cleaning requirements as well as finish restoration, replacement of sealants, and reinstallation of parts and panels. These steps enable you and other support personnel to return the aircraft to its owning unit in the same condition as before the inspection.

212. NDI technique development

Now that we have looked at techniques that are already developed, let's look at what happens when there is not an NDI inspection for the part that you are inspecting. Whenever you must inspect a part that does not have a current NDI technique, you need to develop one. This may seem like a difficult process, but it is relatively simple. By following the steps in this lesson, you can easily develop an NDI technique in no time at all.

Select inspection method

Your first step upon receiving a part for inspection is to select the correct NDI method to perform. Selection of an inspection method depends on the type of material, the criticality of the equipment or part, and the suspected defects. It does no good to use magnetic particles on an aluminum part. Likewise, using radiography on a part suspected of surface defects would be costly and time consuming. Use common sense, the NDI theories you have learned, and the information provided in this CDC in determining the correct NDI method to use.

Modify existing techniques

If an existing inspection does not make sense, or you believe there is a better inspection method, do your research. Come up with a safer, quicker, or more cost efficient NDI method to do the job and document it. Then, using the procedures for changing TOs, submit your inspection technique, waiting to use it until it is officially approved and instituted. The bottom line is this: until you change the existing technical data, you *must* follow it.

Develop inspection method

Once you have determined the NDI method best suited for the part under inspection, the second step is to start developing your technique. Simply knowing that you are going to perform a penetrant or ultrasonic inspection is not enough. You need to outline your procedures in much the same way as –36 techniques. Let's go through some of the areas you will need to address in your technique.

Technique variables and limitations

Every current NDI technique, or a new technique you may develop, has variables and limitations that you must consider. Variables and limitations are any uncontrolled factors relating to your inspection that affect the way subsequent inspections are accomplished. Here are a few of the more important considerations.

Parts

When you develop a technique, consider the part itself; then, ask yourself the following questions:

- Is the part always made from the same material?
- Does the part always have the same hardness and temper condition?
- Is the part always finished with the same coatings across the Air Force?
- Flight controls frequently undergo depot modification. If there have been modifications to some components, can they still be inspected using your technique?

If there are two or more versions of the part, you need to consider including these in your technique, or specify the version of your technique. Again, the best way to limit part variables is researching your part.

Equipment

One of your most important considerations is the type of equipment used with each NDI method. Not every base or installation has the exactly same equipment on hand. You need to consider how to address inspecting parts at these locations. Perhaps you could use a method everyone has on hand such as penetrant instead of an eddy current inspection. You be the judge.

Another factor is nonstandard equipment. You *do not* develop or submit an NDI inspection technique that requires using equipment not listed in allowance standard (AS)455. Techniques for such non-standard equipment are not authorized; as a result, you must ensure the equipment is listed within the AS455 before you can consider developing an NDI inspection technique. Technicians need to use the same or equivalent equipment in order to properly duplicate an inspection. For example in radiography, the x-ray unit manufacturer, film type, kilovoltage (kV) and milliamperage (mA) settings, time, and screens can all affect inspection results and may make duplication of your technique difficult. If you develop a technique using a non-standard piece of equipment, it may be impossible for others in the NDI community to perform your technique.

The best way of reducing variables or limitations with equipment is to include as much information as possible in your technique. You can do this in a number of ways, including the following:

1. Include a sketch or photograph showing critical inspection areas, location and orientation of defects, and nonrelevant indications. If sizes are critical, include a ruler or scale to indicate sizes in your photographs.
2. For ultrasonic and eddy current inspections, include detailed information on equipment manufacturer, transducer or probe descriptions and part numbers, and all applicable switch or dial settings. If available, include sketches or photos of cathode ray tube (CRT) presentations in support of your technique.
3. Magnetic particle inspections should include all data pertaining to amperages, central bar conductor (CBC) sizes, and method of particle application.
4. Liquid penetrant inspections should include information on any special pre-cleaning problems, dwell times, and type of developer.

Personnel

Normally, you need not worry about personnel limitations. Most NDI laboratories have sufficiently experienced and qualified personnel to perform any inspection. However, if your technique requires more than one person, it may be difficult for other bases to accomplish. Ask yourself if there is a technique that allows the inspection to be accomplished with a single person.

Facilities

Imagine working at a small, four-room NDI laboratory supporting deployed F–15s. You have a bay area with a short penetrant line and magnetic inspection unit, a room for your spectrometer, an office, and a storage room doubling as your composite tool kit (CTK). How would you react upon receiving a new NDI technique that begins, “After positioning the F–15 aircraft in the NDI x-ray facility, secure all entrances and position the x-ray equipment?” Your technique *should not* include anything that would restrict or prevent its completion because facilities are not available. Consider such factors as overhead hoists, large doors accessing the NDI laboratory, and oversized exposure vaults when writing your technique.

Documenting your technique

Nothing is quite as frustrating as finishing an inspection on a part than having your supervisor ask you, “So, what was the amperage setting you used?” and not being able to answer. Even better yet, you shoot a radiograph and process the film to see how it turned out, and you can’t remember how long the exposure was. You can avoid these situations by simply documenting everything associated with your technique as you develop it. If you try to remember everything you did after the fact, you

more than likely will find that you are missing steps or documenting incorrect settings. The most important thing you need to remember when documenting is to record each step in your technique before completion.

Testing your technique

Testing your NDI technique is simple and will ensure procedures are repeatable, valid, and show comprehensive results. These terms are described in the following table.

NDI Technique Testing Terminology	
Term	**Description**
Repeatability	Repeatability is another way of saying consistency. Does your technique provide the same results regardless of who performs the inspection and with different makes or models of equipment? You can test your technique's repeatability by asking several other NDI personnel to perform the inspection and by trying the inspection with different pieces of equipment. This may mean that you need to send your technique to several other bases and get feedback. If your technique produces the same results in all cases, it is repeatable.
Validity	Validity relates to whether your technique finds or measures what it is designed to find or measure. Does your technique clearly detect the defects you are looking for every time? If your technique produces nonrelevant indications due to part geometry or from noncritical discontinuities, the technique is not valid. If it only produces relevant indications from 80 percent of critical defects, can the technique really be valid? You can test your technique for validity by testing numerous parts, if available, with various relevant defects.
Comprehensiveness	A comprehensive technique is one capable of detecting the entire range of defects it is designed to detect. If you develop a technique to detect surface cracks larger than a certain size, does the technique work on each size crack above your minimum? For example, if the technique works when detecting cracks between .001" and .025" yet fails to detect cracks between .026" and .030", then detects all cracks larger, you have a comprehensiveness problem. Your technique misses cracks in this small, yet critical range. Comprehensiveness can only be tested by inspecting parts containing the full range of defects you are interested in finding.

The best thing you can do when you develop a new technique is to use your resources for testing. Rely on your coworkers, trainers, and supervisors. Ask questions and have them test your technique. You might even consider consulting with engineers responsible for the component you are inspecting for input and guidance. Do not hesitate to use the resources available to you. Having said that, we will take a look at technique recording responsibilities.

Recording inspection technique

Technique recording is an essential step in technique development. Air Force Technical Order (AFTO) Form 242 is the standardized method you use to develop, record, and submit your technique for approval and publication. Refer to TO 33B–1–1, *Nondestructive Inspection Methods, Basic Theory* for detailed explanations of this form and submission procedures.

AFTO Form 242, Nondestructive Inspection Data, is the approved form you use to submit your new technique for review and publication. The form can also be beneficial in providing guidance as you develop your technique.

The first 12 blocks of this form identify the submitting command, organization, and initiator. Additional information includes the system, subsystem, next higher assembly, actual part or component inspected, and a description of the defect/condition or reason for the inspection. Blocks 13

through 22 contain information for your NDI method or methods. Blocks 23 through 25 outline your inspection procedure, a sketch or photo of the part, inspection area, and any post inspection procedures required. TO 33B–1–1 has complete step-by-step procedures on how to fill out the form. If you fully evaluate your technique, and include documentation on the evaluation with your AFTO Form 242, you can feel confident that you have provided a sound inspection technique for approval.

213. Responsibilities for updating techniques

After you have developed your technique and completed the AFTO Form 242, you need to complete an AFTO Form 22, Technical Manual (TM) Change Recommendation and Reply, which serves as a processing document. The AFTO Form 22 should cite the specific manual in which you want the technique added. Submit one copy of your AFTO Form 242 along with the AFTO Form 22, and forward this package on to your supervisor.

Reporting responsibility

Your supervisor reviews all of your completed forms to ensure that all required information is included and is accurate. Your supervisor also witnesses a demonstration of the technique following the instructions on the AFTO Form 242 to verify the capability of performing the inspection and its repeatability described, and then signs the AFTO Form 242. The supervisor then forwards the package for approval. The processes all begins with the initiator.

Initiator

The initiator should initiate and complete the applicable sections of the AFTO Form 242, as discussed in the preceding lesson 212. The initiator is any NDI technician who accomplishes the following:

- Develop an NDI technique or procedure not presently contained in the existing NDI applications manuals or other applicable TO manuals.
- Improve an existing NDI procedure.
- Determine an area or condition where an NDI procedure would be advantageous.

The initiator also prepares an AFTO Form 22 in accordance with TO 00–5–1, *AF Technical Order System*, to serve as a processing document for the AFTO Form 242. The AFTO Form 22 should cite the NDI applications manual (–9, –36, etc.) for the applicable weapon system or other manual that should be included. One copy of the AFTO Form 242 attaches to each copy of an AFTO Form 22.

Initiator supervisor

The supervisor of the person submitting a recommended AFTO 22 will ensure that it is valid and warrants submittal. A fully certified NDI technician other than the originator should witness the demonstration of the complete procedure to ensure its technical accuracy.

If there are no inspection procedures available, the laboratory supervisor should request immediate engineering disposition from the responsible weapon system authority and forward the AFTO Forms 22 and 242 to the responsible System Program Office (SPO) and the Air Logistics Center (ALC) NDI manager. The supervisor ensures the AFTO Form 242 inspections *will not* be used to perform inspections on aircraft until approved by the appropriate SPO.

NOTE: Support equipment inspection techniques are approved locally by the NDI laboratory supervisor and need not be sent to an ALC.

System Program Office

The SPO coordinates efforts with the responsible ALC NDI manager to ensure all AFTO Forms 22 and 242 are reviewed for technical accuracy. Upon approval, the SPO provides immediate guidance to all users of the affected manual by issuing a message that incorporates the change until the affected TO is updated.

Air Logistics Center NDI program manager

The ALC NDI program manager is responsible for ensuring the technical accuracy of your technique (to include adding, revising, or supplementing the technique as required in order to produce a workable procedure). The program manager will validate the final technique submitted and act to incorporate it into the applicable technical manual, along with forwarding the information to the SPO to take action. The ALC NDI program manager can also provide you with a reproducible copy of the ALC approved technique.

As you can see, when you submit an AFTO Form 242, along with an AFTO Form 22, many actions take place. It is only through your initiative that this happens. If you know a better way to perform NDI on a part, or you can improve a technique, submit the necessary paperwork and get the ball rolling.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

211. NDI techniques

1. What is the definition of an NDI technique?

2. In an NDI inspection technique, where do you find the exact material of a part?

3. Why are NDI techniques developed?

4. What do you do when two or more primary NDI methods are listed in a technique?

5. Why are backup NDI methods listed in an NDI technique?

6. Within the applicable TO, where do you find a list of the cables, transducers, and probes you need for an NDI technique?

7. What could be the result of deviations from equipment settings or setups?

8. When marking and recording defects, what may require you to contact engineering agencies?

9. Why is there a *system securing* section in an inspection technique?

212. NDI technique development

1. What is your first step after receiving a part for inspection when no technique is available?

2. What factors determine the selection of an NDI method?

3. If you are changing an existing NDI technique, what must you do concerning the current data?

4. What is the second step in the technique development process?

5. What are technique variables and limitations?

6. How do you develop a technique for nonstandard equipment?

7. What factors should you consider when documenting facilities in your technique?

8. What is the most important thing you should remember when documenting you technique?

9. What three characteristics will be ensured by testing your technique?

10. What form is used to record your inspection technique?

11. Which blocks in an AFTO Form 242 include photos, inspection area, and post inspection procedures?

213. Responsibilities for updating techniques

1. What form serves as a processing document for an AFTO Form 242?

2. How many copies of your AFTO Form 242 accompany your technique package?

3. What must your supervisor do prior to signing the AFTO Form 242?

4. Match the reporting authorities in column B with their responsibilities in column A. Items in Column B may be used more than once.

Column A	*Column B*
____ (1) Coordinates with ALC NDI program manager to ensure all documents are reviewed for technical accuracy.	a. Initiator.
____ (2) Prepares the AFTO Form 242.	b. Initiator supervisor.
____ (3) Is responsible for technical accuracy of your technique.	c. System Program Office.
____ (4) Makes sure that the AFTO Form 242 will not be used until it is approved.	d. ALC NDI program manager.
____ (5) Determines an area or condition where an NDI procedure would be advantageous.	
____ (6) Validates the final technique.	
____ (7) Provides immediate guidance by issuing a message with affected changes and updates.	
____ (8) Validates the AFTO Form 242.	

Answers to Self-Test Questions

209

1. Any foreign matter on a part affecting the outcome of an NDI technique.
2. NDI method and type of contaminant.
3. Hiding critical defects, harming the part, or contaminating inspection materials.
4. The type and location of suspected defects.
5. Severe damage or degradation of parts.
6. Hydraulic oils, light greases, and lubricating oils.
7. It may scratch or smear metal over surface discontinuities, which can hide defects or produce false indications.
8. Partially burned petroleum by-products, residue from evaporated fuels, and dry film lubricants.
9. Scale and oxides.
10. Inadequate drying.
11. They can react with penetrant inspection chemicals or contaminate magnetic inspection baths.
12. When they are not properly removed following an inspection.
13. The type of soils or contaminants to be removed; type and amount of contaminants or soils to be removed; part material; part surface condition; surface accessibility; degree of cleanliness; availability and adequacy of cleaning facilities, materials, and trained personnel.
14. Alkaline cleaners.
15. Immersion time, agitation aggressiveness, solution concentration, and solution temperature.
16. Detergent cleaners.
17. Emulsion cleaners.
18. Solvent cleaners.
19. Salt baths.
20. Only to remove contaminants not readily removed by chemical means.
21. Chemical etching.
22. By physical action.

210

1. To remove light soils and contaminates that have accumulated since major cleaning, touch-up critical areas, and remove residue from other cleaning processes.
2. Preparation of part.
3. None.
4. Liquid penetrant.
5. To remove residue left by the inspection process and return the part to the owning organization as clean as possible.
6. Liquid penetrant, magnetic particle, and ultrasonic inspections.
7. By rinsing the part in clean solvent of the same type used to mix the bath.
8. With liquid solvents, detergents, or alkaline cleaning.
9. They can corrode or rust very rapidly if not immediately scheduled for further processing.
10. Dry them adequately.

211

1. Specific instructions for evaluating the quality, integrity, properties, and dimensions of materials and components with approved NDI methods and without damaging or impairing their serviceability in any way.
2. Part description.
3. To detect specific defects or conditions.
4. Use any specified primary method listed in the TO to inspect the component.
5. To verify findings, more precisely assess a defect, or detect secondary defects or conditions.
6. Equipment requirements.
7. A substandard inspection and missed detects.
8. If certain defects or conditions are noted during your inspection.
9. To return the aircraft to its unit in the same condition as before the inspection.

212

1. Select the correct NDI method to perform.
2. The type of material, the criticality of the equipment or part, and the suspected defects.
3. Follow it until the change is approved and instituted.
4. Develop your technique.
5. Uncontrolled factors relating to your inspection that affect the way subsequent inspections are accomplished.
6. You do not; nonstandard equipment techniques are not authorized.
7. Overhead hoists, large doors accessing the NDI laboratory, and oversized exposure vaults.
8. To record each step in your technique before completion.
9. Repeatability, validity, and comprehensiveness.
10. AFTO Form 242.
11. Blocks 23–25.

213

1. AFTO Form 22.
2. One.
3. Witness a demonstration of your technique to verify it.
4. (1) c.
   (2) a.
   (3) d.
   (4) b.

(5) a.
(6) d.
(7) c.
(8) b.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field Scoring Answer Sheet.

Do not return your answer sheet to AFCDA.

20. (209) The purpose of pre-cleaning parts is to remove
    a. light soils and contaminates.
    b. all chemical agents.
    c. paint.
    d. rust.

21. (209) Light oil contamination on a part being inspected can cause
    a. uncontrollable glare during visual inspections.
    b. reduced wear of eddy current inspection probe tips.
    c. contamination and damage to ultrasonic transducers.
    d. contamination of penetrant or magnetic inspection solutions.

22. (209) One characteristic of a *detergent cleaner* is that it *must* be
    a. acidic.
    b. alkaline.
    c. nonabrasive.
    d. noncorrosive.

23. (209) Paint removers can be a
    a. bond release agent, solvent, dissolving solution, or a combination.
    b. solvent, bond release agent, softening agent, or a combination.
    c. water-based chemical, softening agent, and organic solvent.
    d. solvent and bond release agentonly.

24. (209) Which of the following is *not* a result of *mechanical cleaning* methods?
    a. Longer work times.
    b. Increased metal loss.
    c. Obscuring small cracks.
    d. Etching of critical surfaces.

25. (210) Which of the following identifies nondestructive inspection (NDI) requirements from *least* to *most* cleanliness required?
    a. Eddy current, ultrasonic, magnetic particle, liquid penetrant.
    b. Ultrasonic, eddy current, magnetic particle, liquid penetrant.
    c. Liquid penetrant, magnetic particle, ultrasonic, eddy current.
    d. Liquid penetrant, magnetic particle, eddy current, ultrasonic.

26. (211) Nondestructive inspection (NDI) techniques are defined as specific instructions for evaluating
    a. techniques, discontinuities, manufacturer flaws, and serviceability.
    b. techniques, integrity, manufacturer flaws, and dimensions.
    c. quality, properties, discontinuities, and serviceability.
    d. quality, integrity, properties, and dimensions.

27. (211) Which of the following is *not* a reason for a backup nondestructive inspection (NDI) method in a technical order?
    a. Verify findings.
    b. Detect secondary defects.
    c. Replace primary methods.
    d. More precisely assess a defect.

28. (212) When considering non-standard equipment for your new inspection technique, what must you ensure?
    a. It is listed on the AS455.
    b. It is the correct manufacturer.
    c. The response from the unit is accurate.
    d. All nondestructive inspection (NDI) labs have the same unit.

29. (212) Which form do you use to submit your new nondestructive inspection (NDI) technique for review and publication?
    a. AF Form 22.
    b. AF Form 242.
    c. AFTO Form 22.
    d. AFTO Form 242.

30. (213) Which nondestructive inspection (NDI) techniques are approved by the laboratory supervisor?
    a. Visual inspections.
    b. Support equipment inspections.
    c. Nonaircraft equipment inspections.
    d. Techniques using nonstandard equipment.

31. (213) Who adds, revises, or supplements your submitted technique in order to produce a workable procedure?
    a. Air Force Nondestructive Inspection (NDI) program manager.
    b. Office of primary responsibility for the technical orders (TO).
    c. Air Logistics Center (ALC) NDI program managers.
    d. Major command NDI program manager.

Please read the unit menu for unit 3 and continue ➔

Unit 3. Optical Inspections

214. Optical evaluation 3–1
215. Optical operator maintenance 3–5

OPTICAL OR VISUAL INSPECTION is an essential link in almost every NDI procedure. Yet, amidst all the sophisticated NDI equipment currently used, the simple art of an optical inspection is often times ignored or neglected. You will use optical inspection aids to enhance the findings of other nondestructive inspection methods. In this unit, we present a discussion of the principles, operation, and maintenance of optical inspection aids.

This unit also explains the constitution and structure of metals and alloys as revealed by the unaided eye or by such tools as low-powered magnification, optical microscope, and other optical devices. Visual inspections are not a technique used for crack finding but is used for crack verification. Many times an NDI technique will produce an indication and it is up to the inspector to verify that it is an actual discontinuity.

214. Optical evaluation

Discontinuities unseen by the unaided eye may be magnified utilizing optical aids. They also permit visual inspection areas that are not accessible to the unaided eye. The three optical aids we discuss in this lesson are magnifiers, microscopes, and borescopes.

Magnifier

You will see hand-held magnifiers throughout the maintenance community. The most common magnifiers are rated at 10X (10 power) and below. Ten power means objects appear 10 times larger than normal. Use a magnifier for interpretation when inspecting small discontinuities.

As a rule, you will only use magnifiers to examine discontinuities already discovered by an NDI technique, *not for locating them*. There is a reason for this. Although higher power magnifiers provide the sensitivity to see specific discontinuities better, the higher power reduces the effectiveness of the magnifier to cover a large area. Additionally, magnifiers are not as sensitive at detecting microscopic defects as other NDI methods. Your eye can see nearly everything significant about an indication obtained from an NDI process with the help of a magnifier.

To get the best possible performance from a magnifier, perform the following:

- Always hold the magnifier as close to your eye as possible.
- Move the magnifier and your head toward and away from the specimen to focus the image. The distance a magnifier can be moved toward or away from the specimen and retain a good image called *depth of field*.

Stereo-zoom microscope

In the NDI laboratory, a typical stereo-zoom microscope (fig. 3–1) is used for viewing discontinuities when more magnification than is available from the hand-held magnifier is required. You can vary the magnification between 3.5X and 150.0X on this microscope by using various accessories. With the standard 10X eyepieces installed, you can adjust magnification between 0.7X and 3.0X.

All optical aids increase sensitivity and decrease the area of coverage. It is critical to position the light source at an angle that properly illuminates the indication and prevents shadows.

Possible indications are described in the following table.

Possible Types of Indications	
Type	**Description**
Crack	A crack will have sharp and jagged lines that follow the grain boundaries. The bottom may not be visible.
Scratch	A scratch is usually uniform in pattern with a shallow depth. The bottom is usually visible.
Corrosion	Corrosion may appear as shallow pits on the surface of the part and the bottom may be visible.

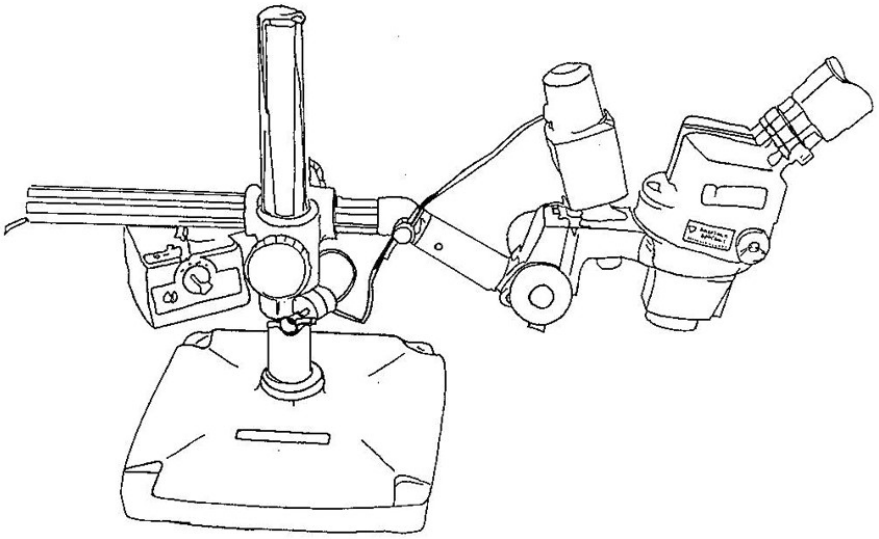


Figure 3–1. Stereo-zoom microscope.

Initial focusing

Initial focusing of the microscope eyepieces is necessary to match the eyepieces to your eyes. Follow this procedure each time the operators change.

1. Make sure eyepieces are seated inside the eyepiece tubes. Eye shields made from plastic or rubber slip over the top of eyepieces to reduce stray light. If you wear glasses, remove the eye shields if they get in your way.
2. Set the calibrated zoom knob to the highest power (3X). The zoom knob is located on the right side or the top of the zoom body depending on the model of microscope (fig. 3–2).
3. With you left eye closed, look through the right eyepiece. Using the focus knob located on the microscope stand, lower the power body until the surface of the object you are viewing is in sharp focus.
4. Reset the calibrated zoom knob to the lowest power setting (0.7X). Without disturbing the focusing knob and with your right eye closed, look through the left eyepiece. Turn the focusing sleeve (*not the focus knob*) on the left eyepiece tube counterclockwise until the object is out of focus. Now, turn the sleeve clockwise until sharp focus is obtained.

The microscope is now correctly adjusted for viewing of both eyes. You can also adjust the instrument to any magnification within the range of the zoom power body without having to refocus. If you add auxiliary lenses or eyepieces with different magnification ratings, you will need to reaccomplish initial focusing.

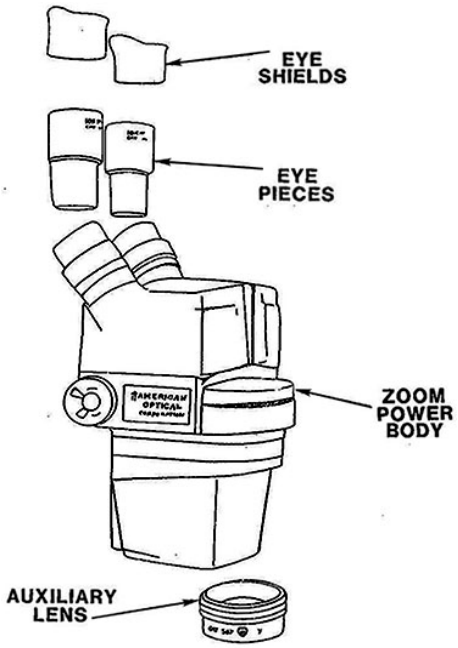


Figure 3–2. Stereo-zoom power body.

Operation

Initial magnification ratings are engraved on auxiliary lenses, eyepieces, and calibrated zoom control knobs. *Total magnification* is the product of the magnification rating of auxiliary lens (if used), setting on the zoom control, and magnification of the eyepieces. If your zoom control setting is on "2" and you are using 10X eyepieces with no auxiliary lens, the *total magnification* is 20X (2 times 10 = 20). Adding one 2X auxiliary lens increases magnification to 40X (2 times 10 times 2 = 40).

To examine a discontinuity, center the suspected area under the viewing window, or auxiliary lens if used, and adjust the initial focus. Illuminate the area in question by using the starlight illuminator and adjusting the light-intensity control to the position that gives best illumination. Adjust the height and angle of the light to reduce any glare. Scan the area beginning with lower zoom settings and increase magnification as needed to concentrate on details. As you vary magnification, your point of interest is constantly in view and always in focus—only slight adjustments may be necessary. You may use auxiliary lenses, alternate eyepieces, or both, if you want more magnification. Keep in mind, as magnification increases your field of view—or area you can see at one time—and the depth of focus, decreases. Any jarring or movement of the focus mechanism will quickly take your work out of focus at higher magnifications.

Measurement

The stereo-zoom microscope can measure discontinuities or objects by inserting a micrometer disc into an eyepiece. Since the field of view varies with the magnification setting, micrometer discs are precalibrated to match specific power body magnification settings. Assuming the zoom power body setting is correct; these discs are accurate for most routine measurements. When extreme accuracy is required, the discs can be calibrated precisely.

Borescopes

A borescope is an optical instrument designed to enable an inspector to look inside narrow tubes, bores, chambers, deep holes, or other limited access areas. Borescopes are an arrangement of prisms and lenses through which light passes to your eye with maximum efficiency. Light emanates from a lens window, located near the objective lens, illuminating the area examined. The image of the inspection area passes back through the objective and ocular lenses to your eye. The basic construction of a typical borescope is shown in figure 3–3.

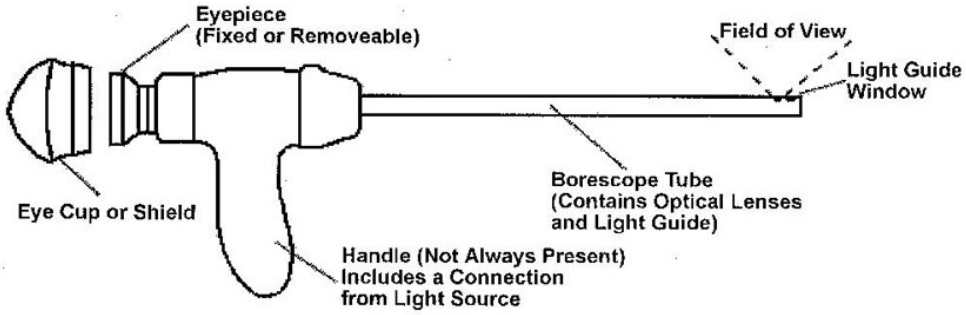


Figure 3–3. Typical borescope construction.

Careful handling of borescopes

Borescopes have optical systems designed to provide direct, right angle, retrospective, and fore-oblique vision (fig. 3–4). They are available in many different types, sizes, and shapes. Borescopes are very fragile, expensive scientific instruments; lenses in the borescope tube, eyepiece, and light guide cable can be easily broken if they are mishandled in any way. You must take care to avoid dropping or bumping any borescope components.

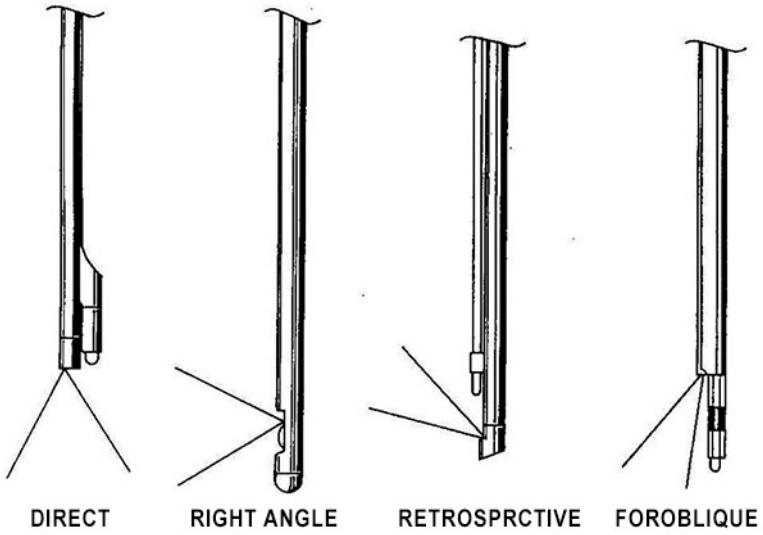


Figure 3–4. Borescope tips showing various viewing angles.

Applications resulting in advances in borescopes

Recent advances in borescope design now align specific instruments to specific job applications. When engine manufacturers have a need to look at something inside an engine, they contact a borescope manufacturer, and together they develop the most suitable borescope possible. For this reason, specific weapon systems, aircraft engines, or missiles determine the type of borescopes you have in your laboratory.

Types of borescopes

Over the years, manufacturers have designed and adapted borescopes for specific applications. Some designs have even crossed the boundary between industrial and medical applications. Let’s look at some of the most common types of specialized borescopes in the following paragraphs.

NOTE: Borescopes equipped with black light illumination sources are authorized by AS455 for NDI to use for specific penetrant inspections.

Rigid borescopes

The *most common* type of borescopes used in the Air Force are *rigid borescopes*. Although designs may vary somewhat, a basic borescope system consists of the following:

1. A high-intensity light source to provide illumination.
2. Rigid borescope tubes of varying lengths, diameters, and viewing angles containing ocular and objective lenses. These tubes transmit the light to your area of interest and return an image of the inspection area to you through a fixed or removable eyepiece.
3. A flexible reinforced fiberoptic cable, called a light guide cable, transmits light from the light source to the borescope tubes.

Operating a borescope is not difficult; however, before you use it, you should refer to the equipment manual, TO, or even attend a class on how to use the specific borescope model in your shop.

Typically, you select a borescope of the appropriate length, diameter, and viewing angle for your inspection. Next, attach the light guide cable to the borescope and the light source. Finally, turn on the light source and insert the borescope into your work area. After a little practice, you will get comfortable with viewing things through the eyepiece, as well as and become familiar with the way parts appear.

Chamberscopes

Chamberscopes are specialized borescopes having a large diameter and capacity for greater illumination intensity. They use a high-resolution optical system geared to inspect certain diesel, pipeline compressor, or aircraft engines internally.

Video inspection systems

Video inspection systems can use many basic borescope concepts or can be coupled directly to rigid or flexible borescopes and display images on a monitor. Video systems can also use a small TV camera as a viewing head that sends the image directly to a monitor. Video systems are expensive, but they are authorized for special applications and have the advantage of allowing you to videotape images for later review.

Waterproof and vaporproof systems

Waterproof borescopes are available for use in submerged applications and vaporproof borescopes are available for gaseous or vaporous atmospheres like those in confined spaces of fuel systems.

215. Optical operator maintenance

While there are several incorrect ways of trying to maintain optical aids, there is also the right way. In the following paragraphs, we discuss the correct maintenance practices for magnifiers, microscopes, and borescopes. Proper operator maintenance will ensure the equipment operates as required.

General maintenance

Although most optical equipment maintenance is minor, it should still be treated as vitally important. In order to maintain the equipment in an operational condition, you must learn basic information for maintenance and care. Your optical equipment will be only as good as you maintain it.

Visual inspections

Prior to using the equipment, check the exterior for cleanliness, corrosion, or damage. Check the lenses for cracks, scratches, and dust. Check electrical cables for fraying or other damage.

Storing

Always store optical equipment in its storage case when it is not in use. Also, keep dust covers and lens covers in place when the equipment is not in use. The most important rule to remember about optical equipment maintenance is to keep the equipment clean and dry.

Cleaning

Never clean lenses unnecessarily such as by a calendar schedule. When cleaning is required, use a soft, lint-free cloth, lens paper, or cotton swab moistened with distilled water, xylene, or alcohol. Use only water on lenses with protective coatings.

It is very important to avoid the excessive use of solvent. The cleaning material should only be moist and not wet enough for the solvent to run inside and around lenses. Too much solvent may loosen cemented components or transfer soils to internal surfaces and cause irreparable damage. Promptly wipe all surfaces dry without allowing them to air dry.

Never touch lenses with your fingers because they leave behind oils and corrosive salts. When optical surfaces are coated with dust or dirt, the first step to clean the debris from the surface is to blow it off with a syringe or dust it off with a soft brush (such as a brush made of camel’s hair). Secondly, once

the loose dirt and dust is removed, wipe the surface with a soft, lint-free linen cloth, lens paper, or cotton swab moistened in xylene, alcohol, or distilled water.

NOTE: Never clean the lens with a dry cloth because it can scratch the lens, causing false indications during evaluations.

Microscope maintenance

Keep the plastic dust cover in place when the stereo-zoom microscope is not in use. Eyepieces should always be kept installed on the power body to keep dust from collecting in the eyepieces and the power body.

NOTE: Do NOT attempt to disassemble the power body for cleaning.

Lubricate gears if necessary. However, do NOT use oil or grease on plastic gears. Occasionally, the focusing slideway should be wiped clean, using alcohol or xylene; and then it should be lightly lubricated. When rack teeth or pinion gears require cleaning, use a small stiff brush; do not apply lubrication.

Borescope maintenance

Like any other fine optical equipment, exercise normal care in storing and cleaning the borescope. The black light borescope has coated optical surfaces; therefore, use only distilled water to clean these surfaces.

Borescope lamps may be exposed or enclosed, depending on their design and direction of vision. *Exposed lamps* may be replaced simply by unscrewing them and screwing in new ones. *Enclosed lamps* may require some disassembly before you can replace them. Closely follow your technical guidance in order to avoid damaging the equipment.

Qualified technicians, who are experienced in soldering delicate instruments and who understand the insulation techniques involved in high voltage, should probably replace defective black light bulbs in borescopes. Black light current controller output voltage is in the 400 to 1000 volt alternating-current (VAC) range. If you attempt to replace the black light bulb, follow the directions in the technical order precisely.

NOTE: Borescope lamps can generate very high temperatures. If the lamp has been operating for even a short time, the lamp itself and surrounding components can remain hot long after it has blown or been turned off. Follow the manufacturers' guidelines and allow the instrument to cool completely before performing any disassembly or attempting lamp replacement.

Repair of optical equipment

Components having optics in them have been matched at the factory for optimum optical performance. Whenever any optical component is damaged or is not operating properly, *return the entire kit to the factory for repair*. This way, new parts can be properly joined with undamaged parts in the instrument.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

214. Optical evaluation

1. What are the three typical optical inspection aids used in NDI?

2. What is the power of the most common hand-held magnifier?

3. What types of discontinuities are examined with magnifiers?

4. What is the magnification range of a stereo-zoom microscope?

5. Which type of indication is usually uniform in pattern with a shallow depth?

6. What procedure must be accomplished each time a new operator uses a stereo-zoom microscope?

7. How do you reduce glare from the starlight illuminator when using a stereo-zoom microscope?

8. What accessory can be used to measure defect sizes when using a stereo-zoom microscope?

9. Which optical inspection aid has systems designed for direct, right angle, retrospective, and fore-oblique vision?

10. What component of a rigid borescope system provides illumination?

11. What is the advantage of a video borescope system?

215. Optical operator maintenance

1. What is the most important rule to remember about optical equipment maintenance?

2. How is optical equipment cleaned?

3. What should be used to clean lenses with protective coatings?

4. What is the first step when cleaning optical surfaces badly coated with dirt or dust?

5. How do you disassemble the stereo-zoom power body for maintenance?

6. How do you clean the stereo-zoom rack teeth and pinion gears?

7. Which borescope lamps should only be replaced by qualified technicians?

8. When optical equipment is damaged, what should you do with it?

Answers to Self-Test Questions

214

1. Magnifiers, microscopes, and borescopes.
2. 10 power.
3. Discontinuities already discovered by an NDI technique.
4. Between 3.5X and 150X.
5. A scratch.
6. Initial focusing.
7. Adjust the height and angle of the light.
8. Micrometer discs inserted in the eyepieces.
9. Borescopes.
10. A high-intensity light source.
11. Videotaping images for later review.

215

1. Keep the equipment clean and dry.
2. By using a soft, lint-free cloth, lens paper, or cotton swab moistened with distilled water, xylene, or alcohol.
3. Water.
4. The debris should be blown off with a syringe or dusted with a soft brush.
5. Never disassemble the power body.
6. Use a small stiff brush.
7. Defective black light bulbs in borescopes.
8. Return the entire kit to the factory for repair.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field Scoring Answer Sheet.

Do not return your answer sheet to AFCDA.

32. (214) What is the distance a magnifier can be moved toward or away from the specimen and retain a good image called?
    a. Zoom angle.
    b. Optical depth.
    c. Depth of field.
    d. Magnification field.

33. (214) What type of indication has sharp and jagged lines that follow the grain boundaries?
    a. Crack.
    b. Scratch.
    c. Corrosion.
    d. Weld crack.

34. (214) What ratings are engraved on auxiliary lenses, eyepieces, and calibrated zoom control knobs?
    a. Total magnification.
    b. Initial magnification.
    c. Auxiliary magnification.
    d. Operating magnification.

35. (214) Which *does not* determine the type of borescope you will need for your lab?
    a. Aerospace ground equipment (AGE) equipment.
    b. Specific weapon systems.
    c. Aircraft engines.
    d. Missiles.

36. (214) Which type of borescopes are the most commonly used in the Air Force?
    a. Chamberscopes.
    b. Rigid borescopes.
    c. Waterproof borescopes.
    d. Video inspection borescopes.

37. (215) What do you use to clean optical lenses that have a protective coating?
    a. Water.
    b. Zylene.
    c. Alcohol.
    d. Lens paper.

38. (215) When the stereo-microscope is not in use, its eyepieces should always be kept installed
    a. under a cover.
    b. on the power body.
    c. in a protective case.
    d. next to the microscope.

Please read the unit menu for unit 4 and continue ➔

Student Notes

Unit 4. Penetrant Inspection Method

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PENETRANT INSPECTION is one of the oldest NDI inspection methods and was originally used in the railroad maintenance shops in the late 1800s. Parts were immersed in a used machine oil and then coated with powdered chalk; this was known as the oil and whiting test. As the oil seeped out of the openings, dark stains formed on the white background. This process was used for many years and undoubtedly identified many defects otherwise unnoticed. It certainly did not detect discontinuities considered “gross defects” by today’s modern aircraft industry. In 1941, fluorescent dye materials were added to highly penetrating oil to make a penetrant material. Today, penetrant inspection is still highly used not only on aircraft but also on bridges, railroads, pipes, and other nonmagnetic metals.

In this unit, we present the basic principles of the liquid penetrant inspection method. We will also discuss different equipment types and safety considerations that you will use in the field. Next, we look at various penetrant selections for particular inspections, and the determination of dwell times. Finally, we cover inspection processes and how to interpret defect indications along with process controls.

4–1. Principles of Penetrant Inspection

The basic purpose of penetrant inspection is to increase the visible contrast between a discontinuity and the background. There are many desirable properties in a good penetrant system. As the name of the process indicates, one of the most important properties is the penetrant’s ability to penetrate a part’s surface. Then, a compatible developer must be available to enhance the visibility of discontinuities. Within this section, we identify the physical properties of penetrants, the principles of the basic types of penetrants and methods you will use, as well as the classifications of solvents removers and developers.

216. Penetrant properties

In order to understand how liquid penetrants work the way they do, it is necessary for you to understand the various physical properties affecting these materials. As a result, let’s begin by going over some of the important characteristics of penetrant.

Characteristics of penetrant action

There are a number of characteristics desired in a material for it to function as a penetrant. First, it should be capable of entering and filling entire surface openings within an area of inspection. It should also resist washing out during the rinsing processes so that defects are not missed. When

inspecting parts, each inspector should look for penetrant exiting from defects after the surface penetrant is removed. Finally, penetrant should reveal visible indications.

Physical principles in the inspection process require a liquid that can flow over and wet a surface. The ability of a liquid to cover the surface of a part and enter any surface opening depends on the following: surface tension, wetting, and capillary action.

Surface tension

If you could look closely at small insects walking on the surface of water, you would note their feet making small depressions in the water surface. The surface is tough enough to support these insects because water molecules have a strong attraction for each other. This attraction is known as *cohesion*. The tendency of the surface of a liquid to act as a tough elastic membrane is called *surface tension*, which is demonstrated in the following table.

Examples of Surface Tension	
Example 1	Fill a glass completely full of water. Drop paper clips one at a time into the water. The surface of the water will rise appreciably above the rim of the glass before any actually spills over the rim. Surface tension is what holds the water together until it has risen high enough to be overcome by the force of gravity.
Example 2	Use a dinner fork to lay a paper clip, needle, or razor blade gently on the surface of a pan of cold water. If you are careful, you can make the objects float because of the cohesive force of the water molecules. If you try this experiment using hot water, you will find it is quite difficult to make the objects float. This is because *surface tension is reduced as temperature rises.*

Although water has high surface tension, it makes a poor penetrant because it does not have other required characteristics.

Wetting ability

Attraction of molecules of different substances for one another is called *adhesion*. Wetting agents, such as detergents or soaps, added to water increase its adhesive force. These agents can also decrease the cohesive force. If you add a few drops of detergent in the water near the floating objects in the experiment just discussed, they would sink immediately. This is because the adhesive force of the water increased while the cohesive force decreased. Generally, high surface tension and good wetting ability are desirable penetrant qualities.

Wetting happens when a liquid is in contact with a solid surface; the cohesive force competes with the adhesive force between the liquid molecules and the solid surface. These forces determine the contact angle the liquid forms with the surface. The contact angle (fig. 4–1) is measured by the angle a drop of liquid makes with a solid surface. If the contact angle is zero, the liquid will “wet” and spread. If the contact angle is 90-degrees or more, the liquid will not “wet” the surface and will remain as a rounded drop.

Capillary action

As we consider how a good penetrant finds or forces its way into fine openings, we can begin with the knowledge that forces generated by capillary action are involved in the entry of a liquid into cracks. Consequently, *capillary action* is defined as the tendency for a liquid to penetrate or migrate into small openings, such as cracks, pits, or fissures. Due to this characteristic, capillary action is associated with wetting ability.

For example, when a tube with a small inside diameter is inserted into a liquid, the liquid level inside the tubing may rise above, remain even, or be lower than the outside liquid level. If the contact angle between the liquid and the tubing wall is less than 90-degrees (the liquid wets the tube wall), the liquid will be higher in the tube than on the outside. When the contact angle is 90-degrees or greater (poor wetting and high surface tension), the liquid will not rise above the outside level and may even

be depressed. Capillary rise occurs when a liquid wets the inside of a tube and the surface tension draws additional liquid into the wetted area. The effects of contact angles and capillary action are illustrated in figure 4–2.

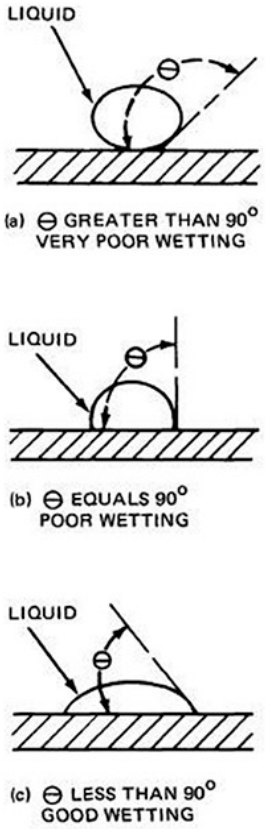

Figure 4–1. Contact angle of wetting ability.

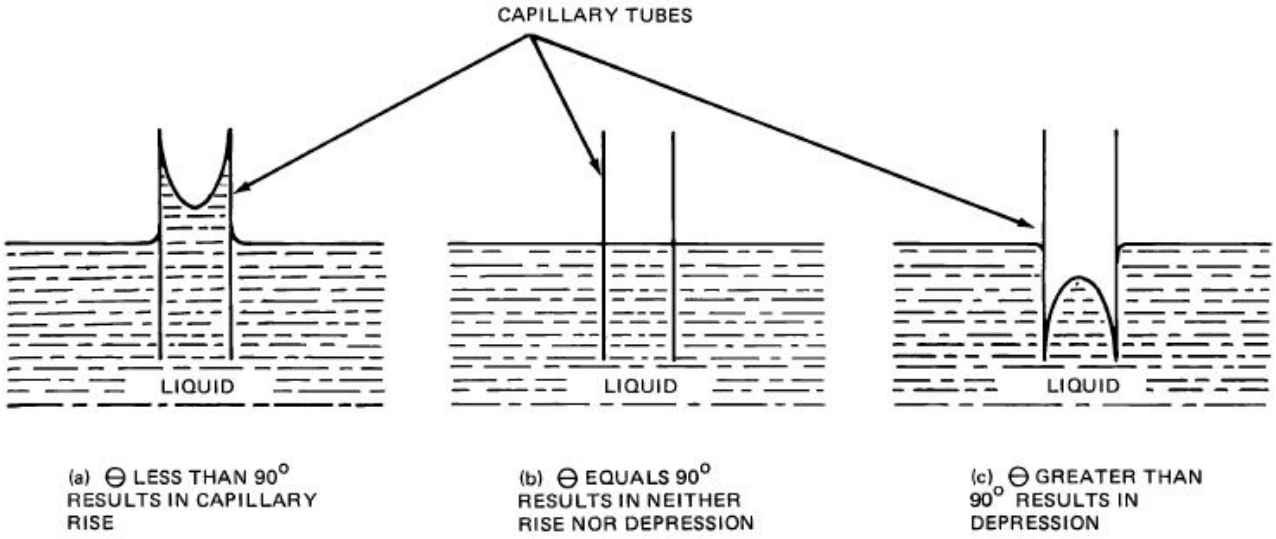

Figure 4–2. Liquid in a capillary tube.

Physical properties

Formulation, selection, and application of penetrant materials requires consideration of many physical and chemical properties. The properties associated with its physical condition are viscosity, specific gravity, flash point, volatility, thermal temperature and storage temperature. These are discussed in depth in the following paragraphs.

Viscosity

When applied to penetrants, viscosity is defined as the "property of a liquid opposing flow." If you dip an object into a liquid of high viscosity—such as heavy oil—and lift it out, you will notice a thick surface film draining off and moving very slowly. On the other hand, a similar object dipped in water, which has a low viscosity, will have a thin surface film draining off and moving very rapidly.

The property of viscosity is important in selection of a liquid penetrant inspection because viscosity indirectly affects the speed with which penetration occurs. Viscosity also determines how much penetrant will remain on a part surface. High viscosity penetrants cling to the surface, requiring increased effort for removal. Very thin penetrants (low viscosity) may drain from the part surface so quickly insufficient penetrant remains to enter into discontinuities.

Viscosity has no effect on penetrating ability but it can affect the time required for penetration. The reason this happens in viscosity is that liquid decreases as temperature rises and viscosity increases as temperature drops.

Specific gravity

Specific gravity is the ratio of weight of a substance to an equal volume of water. It has no direct effect on the performance of a penetrant, and most penetrants have a specific gravity of less than one. This is due to the organic materials within the penetrant that has low specific gravities. For example, if water were to contaminate a penetrant tank, it would sink to the bottom. Specific gravity measures the concentration of a single solution.

Flash point

This is the lowest temperature at which vapors of a substance ignite in air when exposed to a flame. The flash point does not affect the performance of a penetrant; however, high flash points are desirable to reduce the hazards of fire. The minimum flash point of the most commonly used penetrants is 200 °F.

Volatility

The vapor pressure or boiling point of a liquid characterizes its volatility. It is associated with evaporation of liquids and requires a low volatility rate. High volatility results in a loss of penetrant in open tanks and can result in penetrant drying on a part during the penetrant development time called "dwell" (discussed in greater detail in the next lesson), leaving a coated film on the part, which is difficult to remove. Low volatility provides the following four advantages:

1. Low economic loss due to low evaporation loss.
2. Low fire hazard because few flammable vapors form above the liquid.
3. Low toxicity because of low hazardous vapor concentrations in the test area.
4. Uniform removal and fluorescent properties because of minimal evaporation.

Fluorescent dye thermal stability

Over time, dyes used in fluorescent-dye penetrants lose their brightness when subjected to elevated temperatures; this is called "heat fade." Thermal stability is an important consideration when a part stays in the dryer for too long, either before or after the developer application. The temperature increases to where it is too hot to handle the part and reprocessing must take place.

Storage temperature stability

When storing penetrant, it is extremely important to keep it out of sunlight or subjected to temperatures above 130 °F or below 32 °F. Storage temperature stability is the ability of a penetrant to resist physical and chemical changes when stored in sealed containers at appropriate temperatures. Most liquid penetrant materials are not affected over time as long as they are kept in closed storage containers.

Chemical properties

Chemical properties of penetrants are ways in which particular chemicals may deteriorate, damage, or react with penetrant materials. In the next several paragraphs, we will look specifically at toxicity, solvent ability, removability, water tolerance, brightness, and penetrant sensitivity.

Toxicity

Toxicity measures adverse effects on humans resulting from contact with the material. It applies to any abnormal effects ranging from nausea and dermatitis through dysfunction of major organs, such as the liver or kidneys. It is essential for penetrant materials to be nontoxic.

Solvent ability

The visibility of indications depends on the fluorescent or visible dye dissolved in the penetrating oil. Oils used in penetrants must have good solvent properties to dissolve and hold the dyes in solution. Large quantities of dye, especially in the visible penetrants, must hold in a solutionover a wide range of temperatures. Even a small amount of separation can decrease penetrant performance.

Removability

To complete a penetrant inspection, it is necessary for you to remove the excess penetrant from the surface of the part. Solvents, removers, and emulsifiers are normally used to accomplish this step. Water-washable penetrants contain built-in emulsifiers that enable penetrant removal without additional processing. In all cases, a penetrant is easily removed to obtain a clean background surface without removing penetrant trapped in discontinuities.

This term describes the following two requirements for a penetrant:

- The ability to remove penetrant from a surface, leaving little or no residual background.
- Resistance of removing penetrant from discontinuities.

Water tolerance

Water contamination is avoidable by closing the penetrant tanks.

Post-emulsifiable penetrants

Since post-emulsifiable penetrants are oil base materials, and are inherently tolerant to water intrusion, any extra water will settle to the bottom of the tank. Although their performance does not degrade, corrosion of the tank itself can occur.

Water-washable penetrants

Because they contain emulsifiers and can combine with water, water-washable penetrants can tolerate the addition of small amounts of water without losing their properties.

Brightness

One of the more important factors responsible for the effectiveness of the penetrant process is the visibility of the indication. Penetrants containing fluorescent dyes are not especially visible under white light. However, when subjected to a black light, the dyes emit visible light. In addition, the amount of light given off is proportional to the amount of dye in the penetrant.

Penetrant sensitivity

The term “sensitivity,” when used to describe a penetrant performance characteristic, is the ability to produce indications from very small, tight cracks. This characteristic involves the combined properties of penetrating ability and brightness. The flaw opening in discontinuities is usually restricted, and the void volume is such that only a very small amount of penetrant is entrapped. The penetrant must enter and exit the flaw with enough dye to produce a noticeable indication.

The different types of sensitivity levels are shown in the following table:

Level	Sensitivity
Level ½	Very low
Level 1	Low sensitivity
Level 2	Medium sensitivity
Level 3	High sensitivity
Level 4	Ultra-high sensitivity

The term “low,” when used to describe sensitivity levels ½ and 1 penetrant systems, is a contradiction; the sensitivity of levels ½ and 1 systems are low only when compared to higher sensitivity penetrant systems. The low sensitivity level is actually much higher than visual inspections, and is acceptable for a large number of applications.

217. Penetrant types and methods

Selection of an inspection process to obtain the best possible result is not always easy because of the many factors involved in an inspection. The proper inspection process you should use is the one listed in the appropriate technical manual. If no specified inspection technique is available, you should select the process satisfying the majority of the factors involved. In this case, you will need to know and understand the different penetrant, remover, and developer types and methods.

Penetrant types

There are the two types of penetrant processes: type I process employs fluorescent penetrant materials, and type II process uses visible dye materials.

Type I: Fluorescent penetrant

Some chemical compounds have the capability of emitting visible light when exposed to near-ultraviolet radiation or black light. Type I penetrants are made with a dye that exhibits the property of fluorescence when exposed to a black light. These penetrants provide excellent detection sensitivity to small surface discontinuities as very small quantities of fluorescent penetrant will emit highly visible indications when exposed to black light. Further, type I will be the penetrant used for all Air Force applications and the focus of our information in this CDC.

Type II: Visible penetrant

Visible-dye or color-contrast penetrants contain a red dye dissolved in the penetrating oil. The visibility enhances during the penetrant process by the application of a white developer. The white developer provides a high contrast background for the bright red penetrant when viewed under natural or white light.

NOTE: DOD prohibits the use of visible penetrant on aircraft, engines, and missiles (and is not normally used for Air Force applications), except for those parts with specific engineering approval.

Penetrant methods

The following table lists four type I standard methods of processing penetrant inspections:

Inspection	Description
Method A	Water-washable penetrant
Method B	Post –emulsifiable penetrant (lipophilic)
Method C	Solvent removable penetrant
Method D	Post-emulsifiable penetrant (hydrophilic)

Method A: Water-washable penetrant

Water-washable penetrants use petroleum oil, which is insoluble in water. This means the penetrant cannot be removed with water; however, there are chemical compounds that, when mixed with the oil vehicle, form a mixture that can be removed with water. This is the *least* sensitive of the fluorescent inspection methods. Water-washable penetrants are formulated with an emulsifier as an integral component of the penetrant vehicle. This permits direct removal by water immediately after the penetrant dwell time.

Method B: Post-emulsifiable (lipophilic) penetrant

Post-emulsifiable materials are similar to those used for method A, except the penetrants are not self-emulsifiable. Since the penetrant does not contain an emulsifier, it is more sensitive and has the ability to seep into very fine surface discontinuities. Lipophilic emulsifiers are oil-based products, which are applied with the sole purpose to convert the excess surface penetrant into an emulsifiable mixture that can be removed with water.

In addition to detecting the finest of the deep cracks, you can detect shallow scratches, tool marks, and shallow imperfections wider than they are deep.

Method C: Solvent removable penetrant

The solvent-removable method is most often used with spray cans. This method utilizes a solvent wipe to remove excess surface penetrant. Method C penetrants are used when spot inspections are required and when water rinsing is not feasible.

Method D: Post-emulsifiable (hydrophilic) penetrant

Post-emulsifiable, hydrophilic penetrant uses the same type penetrants as Method B. The difference lies in the removal steps. Hydrophilic removers allow more control over this very important step as compared to lipophilic emulsifiers.

System concept

All four methods are applied with each type of process. Each type and method of inspection uses a specific family group of materials. The use of family groups from the same manufacturer is called the *system concept*. The system concept applies to all penetrants and emulsifiers or removers; it *does not*, however, apply to developers or solvents.

Developers and solvent removers for fluorescent penetrants are not subject to the system concept. This means you may use any authorized developer with any fluorescent penetrant and expect good results. This exception does not apply to visible dye and dual-mode penetrants. At present, the developers for visible penetrants are limited to nonaqueous wet and water-suspendable. Dual mode penetrant in the visible mode is limited to nonaqueous wet, while in the fluorescent mode, it requires dry developers.

Dwell times

Dwell time is a somewhat a catchall term used to indicate how long a particular action is allowed to continue during penetrant inspection processing. Depending on the process you are using, you will have two or three dwell times. The post-emulsifiable process includes the following three:

- Penetrant dwell.
- Emulsifier dwell.
- Developer dwell.

The following table breaks down the process of how you determine dwell times for penetrant, emulsifier, and developer.

Dwell Time	The Process
Penetrant	The length of time you allow the part to dwell after you apply the penetrant is an extremely important factor for a reliable penetrant inspection. The length of penetration dwell time depends on the type of discontinuity you are looking for and the method used to manufacture the part you are inspecting. The purpose of dwell time is to allow the penetrant to seep into and fill any surface openings. In all types of materials, penetrant dwell time is broken down by defect type. • *Manufacturing induced defects* – The minimum dwell time is specified by an inspection procedure. • S*ervice induced defects* (fatigue cracks) – The minimum dwell time should not be less than 30-minutes, unless otherwise specified by a specific part procedure. • *Stress corrosion cracks* – The minimum dwell time is 8 times the dwell time for service induced defects and should dwell for 240 minutes. Penetrant on the surface of the part should never be allowed to dry during the dwell time.
Emulsifier	After the emulsifier has been applied and the part is draining, a period of time is allowed for diffusion of the materials. During diffusion, a water removable mixture is formed. This is the emulsifier dwell time and is one of the most critical factors in this process. If the dwell time is too long, the emulsifier will diffuse, easily causing loss of sensitivity and missed flaws. • Dwell times may range from 10-seconds to 5-minutes; however, typical dwell times of less than 1-minute are adequate. • Emulsifier dwell times should not exceed 5-minutes.
Developer	Sufficient time should be allowed for an indication to form, but the penetrant should not be allowed to bleed into the developer in sufficient quantities to cause loss of definition. A good rule of thumb is to allow for development time on any material being about one-half of the penetrant dwell time. However, the use of special application penetrants and developers may result in a shorter dwell. The following are the *maximum* dwell times for *service induced defects* for different types of developers, unless specified in a written inspection procedure. • Nonaqueous developer – 30 minutes. • Aqueous developer – 1 hour. • Dry developer – 2 hours. Developer dwell time SHALL NOT begin until the part is completely free of moisture.

218. Classifications of solvent removers and developers

The most important part of any penetrant inspection is the removal of surface or background penetrant before application of the developer. Once you are sure the penetrant has dwelt long enough to penetrate the defect, remove the excess penetrant so it does not interfere with the interpretation of indications. An important consideration with penetrant removal is to remove just enough penetrant to ensure no background interference, but not enough to remove the penetrant from a defect.

Since the Air Force does not allow the use of method A and B penetrant inspections, we will only look at methods C and D.

Method C solvent

All oil-base penetrants are soluble in a large number of organic liquids. However, solvents are most frequently used to remove penetrants in method C.

For almost all solvent removers, removal of excess penetrant is accomplished through dissolving and dilution. The exception to this is when an aqueous based detergent mixture is used as a solvent remover. Furthermore, when higher boiling point solvents are used, care is needed to control the amount of solvent applied to the surface. Excess solvent can strip penetrant from defects or dilute it in a defect, which will in turn produce dim, fuzzy indications. The following table shows three classes of solvent removers.

Class	Solvent Remover Type
1	Halogenated
2	Nonhalogenated
3	Special Application

Most class 2 removers are excellent solvents because of their high boiling point; they will not rapidly evaporate at room temperature. Consequently, when used as a pre-cleaner, you should take precautions to make sure no residual solvent remover is left on the part surface prior to the application of penetrant. This can be accomplished by thoroughly drying the surface with a lint free cloth or rag, dry the part in an oven, or alternatively, use a more volatile solvent such as Isopropyl Alcohol to remove the less volatile solvent remover.

The solvent remover is used in the following three ways.

1. It serves as a pre-cleaner before penetrant application.
2. It removes the last of the excess penetrant after completion of the penetrant dwell.
3. It serves as a post-cleaner to remove residual penetrant materials when the inspection is complete.

Method D hydrophilic remover

The word “hydro” means “water.” Thus, hydrophilic is a water-based solution. Hydrophilic removers consist of water-soluble chemicals. They are concentrated liquids mixed with water either before or during the removal process. The active agent in hydrophilic remover displaces a small quantity of penetrant at the surface and prevents it from recombining with remaining penetrant. All penetrant removal action takes place at the surface, and penetrant just below the surface is not displaced until it is exposed to remover. Agitation of hydrophilic remover during immersion of a part removes displaced penetrant at the surface and allows fresh remover to contact the remaining penetrant layers. Figure 4–3 shows the basic method D inspection process.

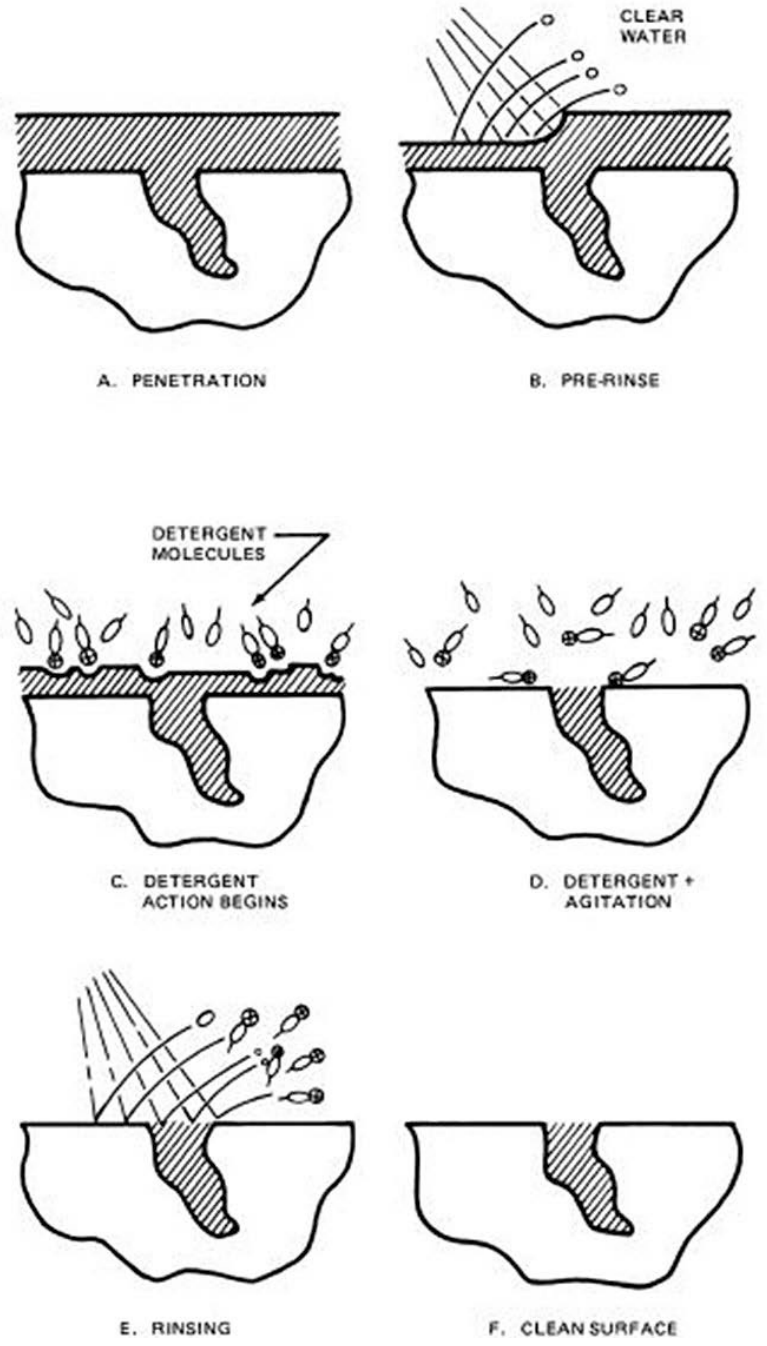

Figure 4–3: The penetrant inspection process.

Remover appearance

A freshly mixed remover bath is a transparent pink solution. As the remover is used and penetrant is removed from parts, the bath becomes cloudy and will start to change color. When additional parts are processed, globs of penetrant will rise to the surface, and then slowly disperse back into the mixture. This effect is not usually noticed when the bath is agitated, but is visible when the agitation is shut off. The excess penetrant does not spread across the surface of the bath, but collects at the sides. The remover will continue to function, but at a reduced rate. This is why it is important to test the quality of our materials.

Penetrant tolerance point

One of the disadvantages of the hydrophilic immersion technique is the remover's limited tolerance to penetrant contamination. As parts are processed, the amount of penetrant in the remover gradually increases. If the removal process is monitored, penetrant contamination will reach a point where a distinct performance change occurs. The amount of penetrant causing this performance change is called the remover's penetrant tolerance point. The amount of penetrant tolerated directly relates to the concentration of the remover and sensitivity level of the penetrant.

Each penetrant manufacturer has its own formulation that varies in aggressiveness. The concentrations of hydrophilic remover (in water) can range from 5 to 35 percent. Typical tolerance levels for a remover concentration of 33 percent is 5 to 6 percent for a sensitivity level 3 penetrant, and 3 to 4 percent for a sensitivity level 2 penetrant.

Pre-rinse and post-rinse

Rinsing parts either after applying penetrant or after immersion is an important factor in the penetrant process and should be controlled. We will focus on the following three main areas: water pressure, water temperature, and spray angle.

Water pressure during pre- and post-rinse

Increased water pressure increases the speed of removal; however, excessive pressure can atomize the water into a fog that is useless for removal. The normal penetrant line pressure is 10 to 40 psi; this should not exceed 40 psi.

Water temperature

Temperature of the rinse water will affect washability. Some penetrant-emulsifier combinations may form a gel with water temperatures of 50 °F or less. This gel can be removed during post-rinse, but requires longer wash times. Other penetrant emulsifier combinations have reduced removability at elevated temperatures, above 110 °F. The effect of temperature on washability depends upon the penetrant formulation, which varies between suppliers. The rinse water temperature shall be maintained between 50 °F to 100 °F.

Spray angle

The angle of spray may be varied over a wide range with only slight effects on the removal time. When the angle is close to perpendicular (80 to 90 degrees), the droplets will rebound into the oncoming water, diverting the fresh droplets, which reduces the scrubbing action. The scrubbing action is also reduced when the spray is close to parallel with the part surface (10 to 20 degrees), since there is little energy transfer at the point of impact. Generally, an angle of 45 to 70 degrees is most effective when washing remover from a part.

Principles of developers

The basic function of all developers is to improve the visibility of the entrapped penetrant indication. The improvement in visibility is achieved through a number of means, including the following:

- Assisting in extracting the entrapped penetrant from discontinuities.
- Spreading or dispersing the extracted penetrant on the surface, thus increasing the apparent size of the indication.
- Improving the contrast between the indication and the background.

When developers improve visibility of indications by providing a contrasting background, they reduce reflections from a part surface that appear blue-black under ultraviolet (UV) black light (UV-A). The blue-black color provides a high contrast with the fluorescent yellow-green penetrant indication, thus making it easy for the inspector to find cracks and other defects.

Fluorescent penetrant indications improve as developer is applied by as much as 600 times over the undeveloped indications. Developer application is a critical part of the penetrant inspection process. It

may make borderline indications visible which otherwise could be missed. In all cases, it cuts inspection time significantly by hastening the appearance of indications. The following are the four types of developers in common use in the Air Force:

1. Dry powder.
2. Water-soluble (dissolved or liquefied in water).
3. Water suspended (insoluble particles suspended in water).
4. Nonaqueous wet (usually supplied as an aerosol packaged product).

Dry powder

Dry developer is fluffy in nature with low bulk density. Dry developers loosely hold on to the surface of the part by adhesion and the coating layer is very thin and uniform. In fact, dry developers leave very little visible trace, but their presence becomes readily obvious when a finger or rag wipes the surface. You may use dry developers with any fluorescent penetrant method.

NOTE: Dry developers will not be used with visible-dye penetrants since they do not provide adequate contrast.

Water-soluble

Water-soluble developers are developer particles (dry powder) dissolved in a water solution. They contain wetting agents, corrosion inhibitors, and biocides. During the drying process, the developer particles crystallize out of the solution as the water evaporates. The resulting coating is thick, bright white and readily visible. The dry layer is much thicker than a dry developer coating is.

Water-suspended

Water-suspended developers consist of inert particles in a water suspension. The developers are supplied either as a concentrated liquid or as a bulk, dry-powder. If the developers are in the bulk, dry powder form, they must be mixed with water prior to use. In addition, they contain chemical dispersing agents to reduce the tendency of the developer particles to stick together or form clumps. Wetting agents are added to provide complete and thorough coverage of the parts. Corrosion inhibitors protect the part from corrosion and biocides are added to provide a reasonable tank life by delaying bacterial growth. When applied, water suspended developers evaporate very slowly at room temperature and require a hot air oven for proper drying.

NOTE: Developing action in wet suspended developers will not start until all the moisture is absorbed. Developer dwell time should not begin until the part is completely free of moisture.

Nonaqueous wet

Nonaqueous solvent-based developers are composed of particles suspended in a mixture of volatile solvents. These developers are packaged as ready-to-use aerosol cans and are used with the Method C process. The penetrant materials specification qualified products list (QPL) SAE Aerospace Materials Specification (AMS) 2644 classifies nonaqueous solvent-based developers into the following two categories:

1. Form d – formulated for Type I fluorescent penetrant systems.
2. Form e – formulated for Type II visible penetrant systems.

Many nonaqueous developers are formulated to perform as both (Form d and Form e) developers. Solvent developers also contain surfactants and dispersants whose functions are to coat the particles and reduce their tendency to clump together. Solvent developers are the most sensitive form of developers. In many cases where tight, small flaws occur, the dry and aqueous developers do not contact the entrapped penetrant. This results in the failure of the developer to create the necessary capillary and surface tension forces that serve to pull the penetrant from the flaw. The nonaqueous developer solvents enter the flaw and dissolve into the penetrant. This action increases the volume and reduces the viscosity of the penetrant.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

216. Penetrant properties

1. List the three physical principles of the penetrant inspection process.

2. What is the term for the strong attraction of a material's molecules to each other?

3. What is the term for the strong attraction of one material's molecules to another material's molecules?

4. What is wetting?

5. What force explains how liquid penetrants into small openings, such as cracks?

6. What physical property of penetrant describes liquid opposing flow?

7. What happens to the viscosity of a liquid when temperatures increase?

8. What is the ratio of specific gravity?

9. What is the minimum flash point of most commonly used penetrants?

10. What is it called during thermal stability when dyes lose their brightness when subjected to heat?

11. What is a good temperature for storing penetrant?

12. List the specific chemical properties of penetrants addressed in this lesson.

13. Why is it essential for penetrant materials to be nontoxic?

14. Why must penetrants have a solvent ability?

15. What does a built-in emulsifier in a washable penetrant aid in?

16. How is water contamination avoidable?

17. Explain the term sensitivity as it is used in reference to a penetrant performance characteristic.

217. Penetrant types and methods

1. What are the two types of penetrant processes?

2. What type of penetrant is not normally used for Air Force applications?

3. What is a method D penetrant process?

4. What is the least sensitive of the fluorescent inspection methods?

5. Which penetrant is most often used with spray cans?

6. What is the term used to identify family groups of materials from the same manufacturer?

7. What is dwell time?

8. What is the purpose of dwell time?

9. What is the minimum penetrant dwell time when inspecting parts for service induced defects?

10. What are the dwell times for emulsifiers?

11. What is a good rule of thumb for development dwell time on any material?

12. What is the maximum dwell time for a dry developer?

13. When should developer dwell time started?

218. Classifications of solvent removers and developers

1. Air Force allows what two types of penetrant inspection methods?

2. What can excess solvent do to your inspection process?

3. What is the consistency of hydrophilic removers?

4. What does a freshly mixed remover bath look like?

5. Define the penetrant tolerance point.

6. What is the tolerance level when the remover concentration is 33-percent for a sensitivity level 3 penetrant?

7. What should the water pressure be when rinsing off a part after the penetrant dwell time?

8. What should the water temperature be during the post-rinse process?

9. When washing remover from a part, what general spray angle is most effective?

10. How much do fluorescent penetrant indications improve by when developer is applied?

11. List the four types of developers commonly used in the Air Force.

12. Which type of developer crystallizes out of the solution as water evaporates?

4–2. Penetrant Equipment and Hazards

Equipment for penetrant inspections is generally classified as either portable or stationary. We cover both types in this section, starting with portable equipment.

219. Portable penetrant equipment

Portable penetrant inspection kits are for inspecting parts too large for a standard NDI lab, or for laboratories that only process a minimum number of parts. Penetrant materials are in small lightweight kits that can be easily transported to any location. Such kits are available for both visible and fluorescent penetrant processes and usually contain aerosol spray cans of penetrant, solvent remover, and developer. Penetrants may also be provided in small containers with a brush for penetrant application. Generally, portable penetrant applications are limited to a localized area or spot inspections rather than entire part surfaces.

Portable penetrant kit

The portable penetrant kit, illustrated in figure 4–4, contains several items, including those just discussed. We strongly suggest the following items be included in your kit.

- One or more cans of penetrant, remover, and developer.
- A black light.
- Clean, lint-free rags and/or soft paper towels.
- Cotton swabs.
- 10X magnifier.
- Inspection mirror.
- Flashlight.
- Marking device cited in the equipment technical manual.
- Approved carrying case.

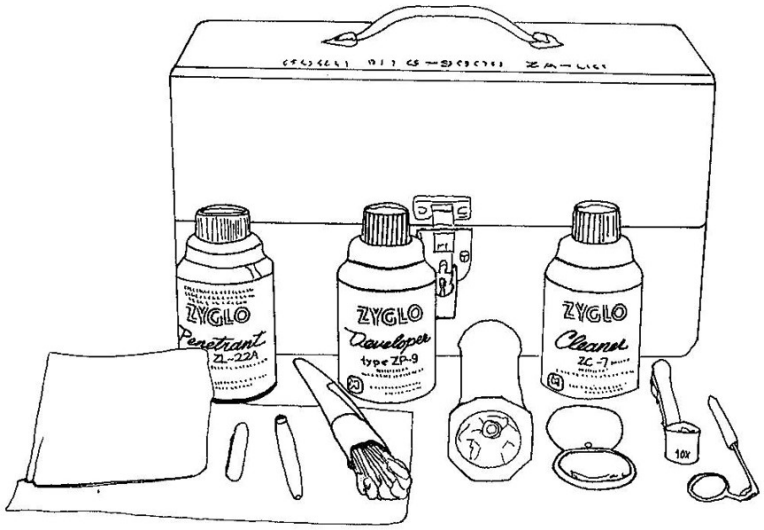

Figure 4–4. Portable penetrant inspection kit.

You will find that a kit equipped as outlined in the preceding paragraphs and list will be sufficient to meet most inspection needs for dispatches away from your laboratory.

Portable equipment hazards

You are not likely to find an NDI process with simpler operating procedures than portable penetrant inspections. Penetrant, remover, and developer are applied by pressing the spray nozzle on top of the aerosol can—it is that simple. However, even such a simple process still has potential hazards.

Tightly closed areas

Repeated spraying of penetrant materials in a tightly enclosed area, such as jet engine intakes or exhaust tubes, can quickly produce high concentrations of these materials in the air you breathe. Although they are not normally considered highly toxic, penetrant materials can cause irritation and considerable discomfort to your respiratory system.

Wear a respirator if you cannot avoid situations in which there are high concentrations of sprayed materials. One way to reduce the vapor concentration in a tightly enclosed area is to spray penetrant on cotton swabs or acid brushes while outside the area and use them to apply the penetrant to enclosed inspection areas. This procedure also saves time and effort by avoiding penetrant over spray that must be removed later. Remover is always applied to the towels or rags used to remove penetrant. You should apply remover to your wiping materials outside closed areas when practical. This will also reduce the amount of vapors you breathe.

Hazards of aerosols

Aerosol cans are a convenient method of packaging a wide variety of materials; however, their wide use, in both industry and the home, has led to complacency and mishandling. Haste or inattention has caused individuals to press the aerosol can’s spray nozzle with the opening pointing toward their faces instead of turned away. While this type of hazard should never occur, eye protection must *always* be worn by NDI personnel. A good pair of chemical goggles or a face shield is a welcome piece of protective equipment in these cases.

Aerosol cans are gas-pressured vessels; when heated to temperatures above 120 °F, the resulting gas pressure may potentially burst the container. Any combustible material, regardless of flash point, can ignite with explosive force when it divides and disperses into the air. Penetrant materials should be stored in a cool dry area, protected from direct sunlight. Always place your aerosol materials off to the side in a shaded area when working in sunlit, hot conditions.

Maintaining portable equipment

Maintenance on the portable penetrant kit is simple. At the beginning of each shift, take time to inventory the kit for sufficient materials to prevent an unnecessary return trip to the laboratory for materials when you dispatch. This is also a good time to inspect the kit for cleanliness, if necessary. Keeping your kit clean, and supplied with serviceable equipment and materials, fulfills your maintenance obligation for portable penetrant kits.

220. Stationary penetrant equipment

When high production, high level of sensitivity, or 100-percent inspection of a part is required, proper facilities and equipment are necessary to ensure optimum and uniform conditions. Depending upon the needs of a particular base, such conditions typically necessitate the use of stationary equipment, in the form of penetrant lines.. The type of equipment most frequently used in NDI labs consists of a series of modular workstations. At each station, an inspector performs a specific task. The number of stations in a processing line varies with the type of penetrant method used. A penetrant line will typically look like figure 4–5 and will have the following stations:

- Penetrant dip tank.
- Emulsifier/remover (methods B and D) dip tank. (Method D systems should include a rinse station prior to the remover tank).
- Rinse station with black light.
- Developer tank for liquid or dry-powder.
- Drying oven.
- Inspection booth with black light.

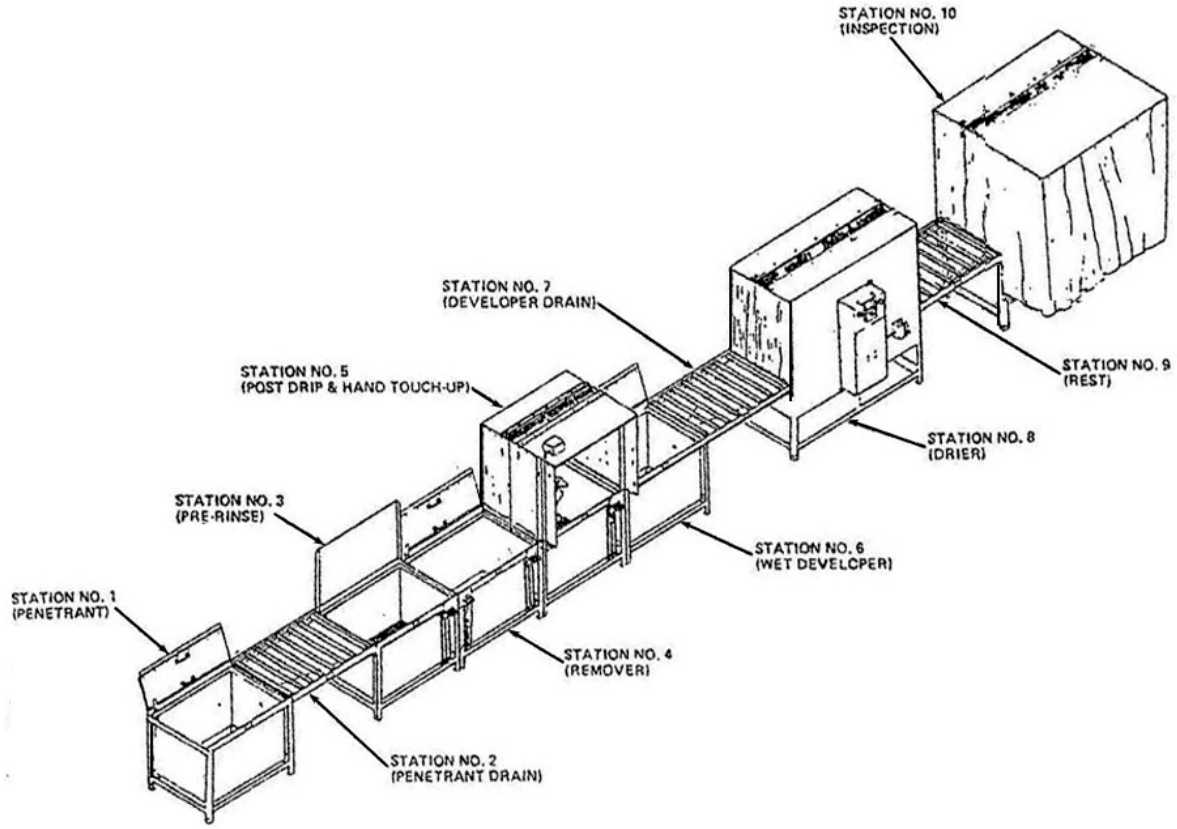

Figure 4–5. Hydrophilic penetrant line.

Liquid penetrant lines

A penetrant line is flexible and can be adapted to the requirements of different inspection processes. This flexibility is possible due to construction features allowing for the addition or subtraction of stations, as needed. Each penetrant line is composed of an arrangement of separate units described in the following table.

Liquid Penetrant Line	
Unit	**Description**
Holding tanks	These tanks provide a reservoir for penetrant, emulsifier, or developer storage in sufficient quantities to submerge most parts processed. They may also be equipped with electric circulating pumps having attached hoses and nozzles to spray penetrant materials onto parts. Hydrophilic remover should never be put in tanks of plain carbon steel or other material easily corroded. It has a water base and will eventually attack this type of material.
Drain stations	A typical drain station consists of conveyor type rollers with an integral drip pan on the bottom side. The drip pan has a drain fitting attached to its lowest point and may be connected to the holding tank preceding the drain station or a suitable waste container.
Rinse station	The rinse station tank is similar to the holding tank in size and shape. It should have a rack installed to prevent the operator from having to work with parts on the bottom of the tank. Water is provided at pressures determined by an in-line pressure gauge. A suitable drain and a black light are provided at this station.
Dryer station	The typical dryer oven is an electrically heated, circulating-air type with a temperature gauge and thermostat. Conveyor-type rollers in the floor of the dryer provide an easy means for moving heavy parts through the dryer.
Inspection station	This is the last station in the penetrant inspection line. It provides an area of subdued light where parts are examined thoroughly under black light illumination. Normally, this station is equipped with two, 100-watt mercury vapor black lights.

Equipment selection

Selection of the stationary penetrant line equipment needed for optimum results at your laboratory is based on the following factors: production requirements, size of inspection items, and inspection method used.

Each of the five penetrant line components is available in three sizes. They are assembled together to form small, medium, or large fluorescent penetrant inspection units. The only significant difference in these units is the size of the parts they can accommodate. The following table outlines each unit, their Air Force designation, and their normal uses.

Penetrant equipment types

Commercial units used by the Air Force include two different types of fluorescent penetrant inspection units which are explained in the following table.

Penetrant Stationary Equipment Types	
Type	**Uses**
Type I	Integrally assembled single unit (Applicable to size one).
Type II	Separate modular stations (Applicable to size two – six).

Penetrant equipment sizes

Units conform by the following sizes and are used with their particular unit type.

Penetrant Stationary Equipment sizes		
Size	**Designation**	**Tank Size**
1	PT-18	17” long x 29” wide x 14” deep
2	PT-24	22” long x 29” wide x 20” deep
3	PT-36	33” long x 29” wide x 26” deep
4	PT-48S (Short)	43” long x 29” wide x 26” deep
5	PT-18	43” long x 29” wide x 26” deep
6	PT-72	67” long x 44” wide x 26” deep

NOTE: Type 1, Size 1 (PT-18) was formerly known as MA-1. Type II, size 5 (PT-48) was formerly known as MA-2. Type II, size 6 (PT-72) was formerly MA-3.

Maintaining stationary equipment

The operating controls on stationary equipment are simple. However, they should be checked for familiarization and proper operation before starting your penetrant inspection. The following table describes the equipment check procedures.

Stationary Equipment Checks	
Procedure	**Description**
Preliminary check	The recommended level of tanks on the penetrant line is ¾ full. If a tank that you plan to use is empty, make sure that the drain valve is closed, and fill the tank to the recommended level. Refer to the TO for your equipment to find the amount of materials required. Medium tanks require approximately 105 gallons. A normal preliminary check will consist of the following: 1. Turn on the breaker or fuse boxes that supply 115 and 220 volts AC electrical power to the inspection unit. 2. Turn on the pump motors at the penetrant, emulsifier or remover, and developer stations. Check for pump operation and illumination of the pump ON indicating lamps. Shut off the pump after checking it. 3. Check the water supply at the rinse station for the correct pressure and sufficient volume of water. Ensure the rinse tank drains properly. Turn on the black light at the rinse station. Check its operation and the switch ON indicator. Preliminary black light operation is verified by noting a light purple glow through the filter. 4. Turn on the dryer station heater and fan switches. Check for heater and fan operation and illumination of the heater and fan ON indicating lamps. Leave heaters and fans on and close dryer curtains. Set the thermostat control to the desired temperature and check its operation by noting the temperature indicated when the heater ON lamp extinguishes. It will normally take 20 to 30 minutes for operating temperature to be reached. 5. Turn on the two black lights, white lights, and fan in the inspection booth. Check the operation of the fan and lights and ensure the switch ON indicating lamps illuminate. You may turn off the fan and white lights, unless you plan to use them directly. 6. The penetrant line is now ready for use.

Stationary Equipment Checks	
Procedure	**Description**
Operating precautions	Observe the following precautions when handling cleaners, emulsifiers, penetrants, or developers. 1. Provide adequate ventilation. 2. Avoid skin contact by wearing neoprene gloves and keep the inside of your gloves clean. 3. Use a black light to periodically check for traces of fluorescent penetrant on your skin, clothes, and gloves. Wash areas of your skin exposed to penetrant materials with soap and water. Exposure to penetrant materials may cause skin irritation.

Black light safety

Ultraviolet radiation below 320 nanometers (nm) can be hazardous and may cause permanent effects. The output of a black light bulb is 365 nm and is ideal for penetrant inspections. The amount of radiation emitted at or below 320 nm is typically less than 1-percent; however, this quantity is enough to require a filter. Germicidal, sun tanning, and mineral light bulbs that emit short and medium wavelength ultraviolet light shall not be used for penetrant inspection. Ultraviolet light filtering safety eyewear and gloves will be used to minimize potential detrimental health effects.

High-pressure mercury vapor bulbs are the most common source of black lights. They are preferred because they have an acceptable output at a reasonable distance from the bulb. The 100-watt bulb is the most frequently used size because it can be mounted in a variety of fixtures or housings. Since the output range of these bulbs is from 320 to 440 nm, a filtering lens over the bulb is used to remove the undesired wavelengths.

Observe the following cautions when using ultraviolet black lights:

CAUTION: Before use, check black light filters for cracks, breaks, and chips. Replace any damaged lenses before use. Use battery-powered lights only when it is impossible to use the 110/220 volt-powered light.

CAUTION: Install ultraviolet filters on all mercury vapor lamps before turning them on or you will injure your eyes and skin.

CAUTION: Black light bulbs can reach an operating temperature of 750 °F. Do not lay hot black lights on or near combustible items. Brackets or hinges are provided in the areas of black light use to prevent having to set them down. Exercise care when using hot black lights to avoid burns to your hands, arms, or face. Additionally, do not handle black lights at the penetrant rinse stations when washing parts because of the electrical shock hazard. Black lights at the wash station should be permanently mounted to avoid hazards.

CAUTION: Before using portable ultraviolet equipment inside hangers, coordinate such action with the base fire department. Ultraviolet sources may activate automatic fire suppression systems and cause massive water or foam damage.

NOTE: For UV light, UV filtering safety glass, goggles or face shields are sufficient.

Equipment maintenance requirements

You will not need to disassemble any penetrant line components for routine maintenance. When parts or assemblies are defective, they need replacement in accordance with the applicable TO or manual. In every case, refer to the inspection and maintenance section of the applicable TO for your equipment or ask a supervisor. Actual servicing of equipment is based on the use it receives. Your equipment may require servicing at shorter intervals or at intervals shorter than the maximum recommended by the TO for the equipment. This is discussed in a later section when we cover process controls.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

219. Portable penetrant equipment

1. List materials recommended in a portable penetrant kit.

2. What should you wear to avoid high concentrations of spray materials?

3. What should be done to reduce penetrant over spray?

4. What must always be worn by NDI personnel when working around aerosols?

5. What precaution can you take with your aerosol materials when working in sunlit, hot conditions?

6. What are the maintenance requirements for portable penetrant kits?

220. Stationary penetrant equipment

1. When is a stationary line typically used?

2. What three factors are used in the selection size of stationary penetrant equipment?

3. What is the penetrant equipment type of a separate modular station?

4. How long does it usually take penetrant line ovens to reach their operating temperatures?

5. What is the most common source of black light bulbs?

6. What is the highest temperature a black light can reach?

4–3. Penetrant Inspection Process

Your success with the application, interpretation, and evaluation of penetrant inspections depends on your thoroughness of the part preparation—from pre-cleaning, all of the way through to your final interpretation of the indications. You must carefully process the part and search out indications before you can judge the seriousness of defects and determine the part disposition. In this section, we will take a look at both of these aspects to help you gain a greater knowledge to complete the inspection process.

221. Penetrant processing sequence

The fundamentals of the penetrant process has not changed from the oil-and whiting days. This lesson provides a simplified description of the penetrant process steps. Because Method A and Method B penetrants are not used in the Air Force, we will focus our attention on Methods C and Method D processing.

Application of method C penetrant inspection

As stated previously, when using portable equipment, the inspection materials are brought to the aircraft or part to be inspected. See figure 4–6
for the entire method C process.

Figure 4–6: Method C process.

Pre-cleaning

Remember, pre-cleaning is the surface preparation performed by NDI personnel prior to an inspection. The purpose of pre-cleaning is to remove light soils and contaminates that have accumulated since major cleaning, touch-up critical areas, and remove residue from other cleaning processes.

Apply solvent to a dry clean lint free cloth and wipe all dirt, grease and soils from the part or area of inspection. There should be no dirt on the end of your brush or swab when applying penetrant if accomplished correctly.

Penetrant application

Penetrant is applied by spraying, brushing or swabbing. The method you will use depends on several factors, including the following:

- Size, shape, and configuration of the part inspected.
- Accessibility of the area.
- Availability of the inspection equipment.

All methods of application are acceptable, providing the surface and inspection area is completely coated with penetrant.

Spraying

Penetrant, emulsifiers or removers, and wet developers may be applied by any of several manual or automated spray methods. Spray application is especially suitable for parts too large to be immersed in a tank. It is also applicable for on-equipment inspections and a portion or local area of a large part. In applying penetrant by the spray method, the requirement is to apply a thin layer covering the inspection area.

Spray application of penetrant is usually more economical than stationary equipment and reduces pooling of penetrant in part cavities.

Brushing or swabbing

Penetrant may also be applied to large parts by brushing, wiping, or even pouring from a container. The brush or swab method is most frequently used to coat small areas of a surface. Brushing or swabbing provides control over the placement of penetrant on the desired area, improves the ability to regulate the quantity or thickness of the penetrant layer, and eliminates overspray. Any brush, swab, rag, or even sponge may be used, provided the applicator material will not react with the penetrant. The size of the brush may vary from large paintbrushes down to small acid or artist brushes. Any type of clean container may also be used to hold penetrant.

Solvent removal process

Method C solvents are normally available in aerosol or pressure containers because of their high evaporation rate. Penetrant removal is accomplished through dissolving and dilution. Most removers may be used both to pre-clean the part surface before inspection and to remove excess penetrant during the inspection. The use of excess solvent will remove or dilute entrapped penetrant resulting in a failure to produce a visible indication. The following table outlines the recommended practice for the method C process:

Penetrant Removal with Solvent	
Step	**Description**
Initial Wipe	Following the penetrant dwell period, wipe the surface with a clean, dry rag or paper towel to remove the major portion of surface penetrant. The proper procedure is to make only a single pass, and then to fold the rag or towel over to provide a fresh surface for each succeeding wipe.
Final Wipe	When the surface penetrant has been reduced to a minimum, any remaining residual penetrant is removed with a fresh lint-free rag or towel moistened with an approved solvent. The amount of solvent applied to the rag or towel is critical. The cloth or towel should *only* be lightly moistened with the application of a fine spray of solvent to the cloth. The cloth must not be saturated by either pouring, immersion or excessive spraying. **NOTE:** NEVER spray or pour solvent directly on a part surface before you have inspected it. Once your inspection is finished, it is permissible to do this for post -cleaning.
Testing	Use a black light to examine the part surface and the rag or cloth during the initial and final wiping stages. Once you are finished wiping the part, check it with a black light and ensure you remove all surface penetrant before applying developer. This procedure is repeated until the rag shows little or no trace of penetrant.

NOTE: Solvent should not be sprayed directly on the surface of parts *even when removing excess surface penetrant* during a penetrant inspection process.

Developer process

Nonaqueous solvent-based developers are *always* applied by spraying. Proper spraying produces a thin, uniform layer that is very sensitive in producing indications. In this case, developers should be applied only as a fine spray or mist. Spraying of nonaqueous developer is most often done with

pressurized, aerosol containers and will be used with method C. Spray developer is applied in the following manner:

1. Prior to spray application, the developer spray container should be agitated.
2. Hold the spray can far enough from the surface to produce a light, moist film. The recommended technique is to apply a very thin, dry layer and build up the thickness with several passes rather than applying a single, wet pass.

NOTE: If the metallic luster cannot be seen, the developer layer is too thick, and small indications may be masked or too widely spread or blurred. Developer coatings that are too thin, may not extract a sufficient amount of entrapped penetrant to form an indication. Also, too thin of a coat does not allow the penetrant to spread and magnify the indication.

3. Let the developer dwell for the recommended time.

Refer back to figure 4–6 to view a quick and easy flowchart process when using method C.

Application of method D penetrant inspection

Immersing or dipping is the preferred method of applying penetrant when the entire surface of a part must be inspected utilizing Method D. This method is limited by the size of the tank or penetrant container. Parts can be immersed one at a time or, if small enough, can be batch processed by placing them in a basket or rack.

Certain part configurations require special attention when immersed. Parts containing concave or recessed surfaces can trap air bubbles or pockets. Air bubbles or pockets will prevent the penetrant from contacting the part surface. Complex shaped parts should be inverted or turned over while immersed. This helps to dislodge entrapped air. Precautions must also be taken with air-cooling or oil passages and blind holes. Passages and holes will fill in with penetrant that will continuously bleed out during development and obscure any discontinuities in the area. Air cooling passages and blind holes should be plugged prior to immersion.

Refer to figure 4–7 for a quick and easy flowchart process for Method D.

Pre-cleaning

There is no pre-cleaning station normally attached to a penetrant line and you will normally accomplish this step elsewhere. Spray and wipe parts repeatedly with an approved solvent until they are clean and no dirt is seen on a clean dry cloth. Use a drying oven if part is still wet before processing. After you determine the part is ready, process the parts as described in the following paragraphs.

Penetrant application and dwell

You can apply penetrants by dipping, flowing-on, spraying, brushing, or any other method that completely covers the area of inspection. In stationary line operations, you will dip parts completely into the penetrant, making certain the penetrant reaches all surfaces. Spray, flow, or brush penetrant on all parts not completely submerged.

Remove parts from the penetrant and allow time to drain on the drain station. While parts remain at this station, the penetrant enters discontinuities open to the surface. The amount of time spent at this station is determined by recommended dwell time.

Pre-rinse

Following the penetrant dwell, the part must be pre-rinsed as previously outlined before remover can be applied. The pre-rinse step removes over 80 percent of the excess surface penetrant.

Spray the part for 30 to 120 seconds at as low a pressure as practical, but not exceeding 40 psi. The mechanical action of the pre-rinse improves the efficiency of the process by reducing the amount of remover used, and cuts the remover contact time by about 50 percent.

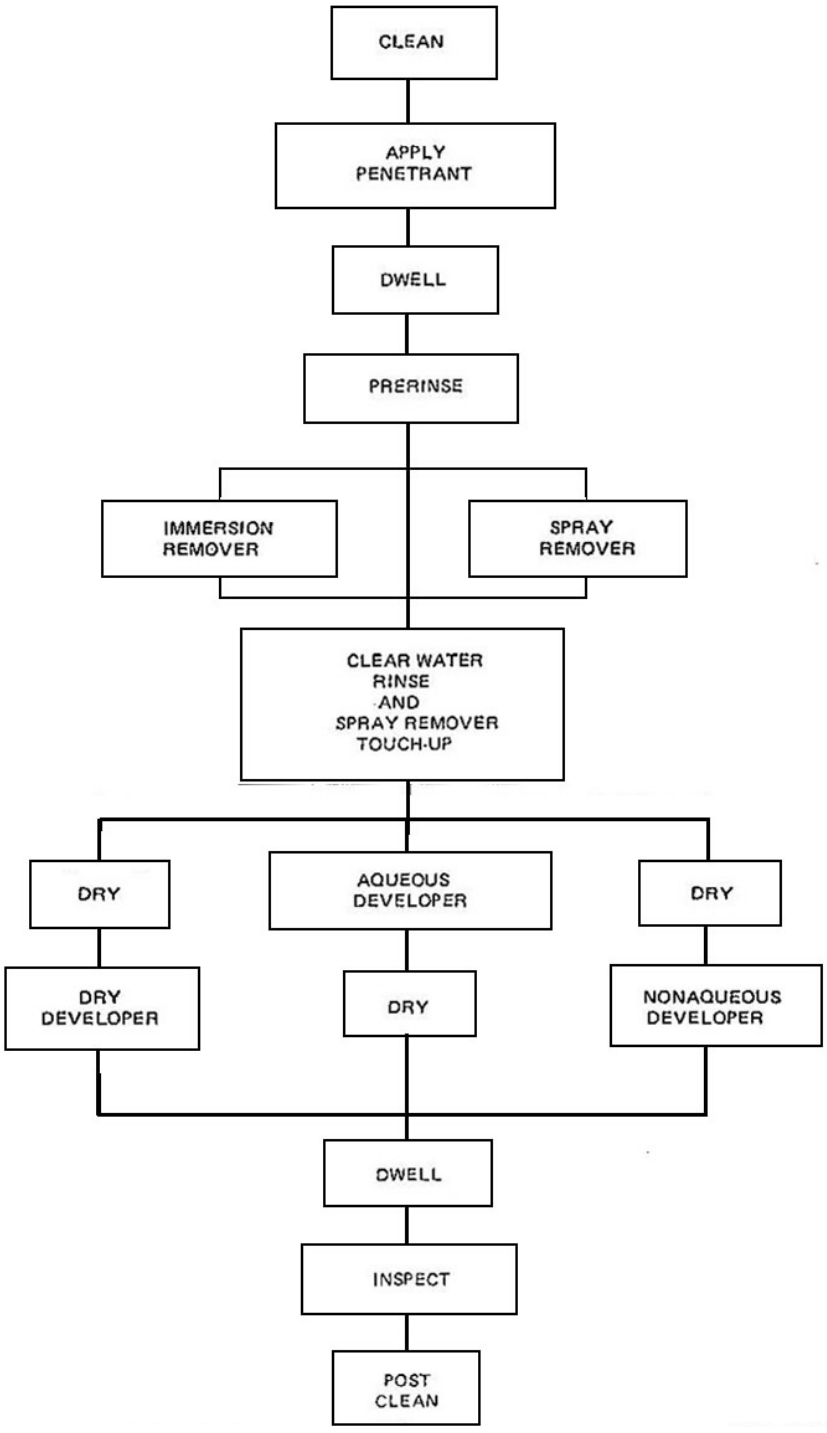

Figure 4–7. Method D processing flowchart.

Emulsifier or remover application

Hydrophilic remover must be applied over the penetrant before it can be washed off. You will use either the immersion or the spray technique (or both), to apply remover to the penetrant surface. In both cases, the remover attacks and removes just the surface of the penetrant using agents called *surfactants* to displace penetrant.

- With the immersion technique, submerge the part in a bath for a period of 30 seconds to minutes. Agitation is required to provide fresh remover to the surface.

- For the spray technique, apply to the part a concentration range of 1 to 5 percent of remover to water volume. The procedures and equipment used for the spray technique are the same as those used in spray rinsing water-washable penetrants.

Emulsifier or remover removal

Water rinsing is required for removal of method D penetrants. Conduct water rinsing of type I penetrants and emulsifiers in a darkened area with the aid of a black light to ensure the penetrant is completely removed from the surface without over-washing.

For best washing results, you should hold the spray nozzle approximately 12 inches from the surface of the part. Direct the spray at the surface of the part at an angle of about 45° to roll the penetrant and remover off the surface and decrease the tendency to wash penetrant out of discontinuities.

Following the penetrant removal step, the part is rinsed with plain water. This rinse washes away remover residues and prevents contamination of the developer. Spray the part for 30 to 60 seconds using a pressure between 10 and 35 psi and 55 °F to 100 °F water temperature. If surface penetrant removal is not complete, you can touch up the areas with additional immersion or spray remover.

Developer application

Developers may be applied by spraying, flowing or immersion. When the immersion process is used, parts should not remain in the solution any longer than required to provide complete coverage. The developer may be applied to parts while they are still wet from the water wash after penetrant removal. Immerse the part into the developer tank and remove immediately after the solution covers the entire part. Try to prevent entrapment of soluble developer in part cavities or concave surfaces (pooling). The developer should wet the part surface with no water break areas after application. Let developer drain no more than 30-seconds before placing into the dryer.

Drying

The most frequently used method of drying parts is with a recirculating hot air oven. It provides a rapid means of properly drying parts, is adaptable to production, and permits control of the temperature.

It is easy to monitor and control oven temperature, but almost impossible to monitor test part temperatures. The rate at which the part undergoing the test is heated is another complicating factor. Thin sections will reach oven temperature and dry before thick sections become warm. The recommended procedure for proper drying is to set the oven temperature between 120 °F and 140 °F and check the part every 5–10 minutes. Remove the part as soon as it is dry.

NOTE: Parts should be separated with a space between them. If the part temperature reaches and remains at 140 °F for over ten minutes, the inspection sensitivity can be reduced. As a guideline, remove the parts before they become too hot to handle with bare hands. Refer back to figure 4–7 to once again view a quick and easy flowchart process when using method D.

Inspecting

This is the last station in the penetrant inspection line where parts are thoroughly examined. It normally includes both black light and white lights. When inspecting parts, you should accomplish the following:

1. Start from one end or side of the part.
2. Systematically scan to the other side.
3. Rotate the part.
4. Repeat the procedure until the complete surface is examined.

Before starting the actual inspection with fluorescent materials, stay in the darkened inspection booth so that your eyes become accustomed to the lighting. Allow at least five minutes for dark adaptation

before examining parts. Pay special attention to areas where defects are likely to occur. These areas of special interest are determined by your experience in inspecting the part or by the TO technique you are following. Usually, areas where defects are likely to occur are junctions of thin and thick cross-sections, sharp fillets, keyways, roots of gear teeth, fastener holes, or any other places of stress concentration.

Post-cleaning

Developer and penetrant residues left on the test part have detrimental effects on the application of surface finishes such a painting and plating. Penetrant residues, if not removed from discontinuities, will dry, forming a varnish-like material in the flaw. This entrapped residue may not fluoresce and will reduce or prohibit entry of penetrant during future tests of the part.

The form of developer applied (dry-powder, nonaqueous, water suspendable or water-soluble) greatly influence the method and difficulties of removal. Developer residues can interfere with the functioning of the part if they involve a moving or wear surface. If not effectively removed, these materials can absorb and retain moisture, resulting in corrosion of the part.

When post-cleaning for method C, spray water or detergent solution on the part and wipe with a clean cloth. Check with a black light to ensure all chemicals are removed.

One point that is common to most developers is the increase in time that it stays on a part. The longer a developer remains on a part, the more difficult it is to remove. When post-cleaning for Method D, rinse the part in water to remove all excess chemicals.

222. Interpretation of indications

In modern machinery, failure of a single part may cause injury to personnel or could mean the failure of an important mission. Failure of just one component in a single engine aircraft can result in complete engine disintegration and an aircraft mishap. Whenever you inspect Air Force assets, you should only concern yourself with the condition of the part and the results of a defective part failure. Do not consider the cost of the rejected part or the resulting maintenance actions when you identify a cracked component. Cost, time, and labor are minor problems when everyone’s safety and your integrity are on the line.

Interpretation is the process of determining whether an indication is relevant, nonrelevant, or false. Evaluation involves assessing a relevant indication to determine the following:

- Its cause, type and reporting its category (relevant, nonrelevant, or false).
- The location.
- The approximate size.

Relevant indications

Relevant penetrant indications are actual discontinuities in a part. You must further classify these indications as detrimental or nondetrimental. Detrimental relevant indications are considered defects. Nondetrimetal relevant indications are classified as discontinuities affecting the appearance of the part, but not its serviceability.

Any defect you are capable of detecting visually is the most dangerous. Surface defects are more dangerous than subsurface defects. This is because, regardless of depth, surface defects create a more serious high stress condition and readily promote eventual failure. Wide, shallow defects rounded at the bottom, such as scratches and gouges, present less of a problem because they do not contribute greatly to part failure. Sharp, shallow defects, such as fatigue cracks, are the serious problem. When in service, they will grow into deep cracks and rapidly lead to a failure.

Nonrelevant indications

You need to be aware of the many conditions possibly leading to false indications on the parts you inspect. Although they can easily appear to be actual defects, these indications have no relationship to actual discontinuities affecting the serviceability of the part. A nonrelevant indication can result from an intentional change in part shape such as threads, or improper processing procedures. Nonrelevant indications are of concern because they may mask or cover a true discontinuity indication.

Lint or dirt in penetrant baths or on the part can be sources of false indications. Lint may attach itself to a surface roughness or to an edge on the part inspected.

Press fits or joints create another common nonrelevant indication. These occur where parts of an assembly are joined together. This construction related nonrelevant indication is normally easily recognizable.

Classification of indications

There are a number of ways of classifying discontinuities, such as appearance of the indication, its cause, material, and service conditions. The method of classification used depends upon the test method, the use of parts, and the original designer. We will discuss the following four typical types you will find in the field.

- Continuous linear indications.
- Intermittent linear indications.
- Round indications.
- Manufacturing discontinuities.

Continuous linear indications

Linear penetrant indications are caused by discontinuities such as cracks, seams, or laps. The width and brightness of the indication depend upon the volume of entrapped penetrant. The indication may be straight or may have some curvature, depending on how the discontinuity was formed. In addition, the edges may be jagged or smooth where the discontinuity meets the part surface. The surface appearance and a cross-section through a linear discontinuity with a large reservoir (fig. 4–8a) and a tight linear discontinuity (fig. 4–8b).

Intermittent linear indications

Intermittent linear indications are caused by the same discontinuities that form continuous linear indications; however, either a subsequent process or service use has partially sealed the surface edges. This occurs in forging laps or where the part had been subjected to a mechanical smearing action. A sub-surface discontinuity that intermittently breaks the surface for its entire length or a partially filled seam will also produce an intermittent linear indication (fig. 4–8c).

Round indications

Round indications have a length and width of approximately equal dimensions. Porosity or relatively small areas of unsoundness in metal components usually form rounded indications; however, the actual surface opening may be irregular in shape. Deep discontinuities, such as weld crater cracks, may appear rounded due to the large volume of entrapped penetrant. The appearance of large and small rounded indications (fig. 4–8d).

Manufacturing discontinuities

Many discontinuities result from manufacturing and repair processes. These will probably be detected each time the part is reinspected. The NDI inspector must be familiar with their appearance and cause in order to make valid interpretations of inspection results. Some of the common types of manufacturing discontinuities are described in lesson 205 of this volume.

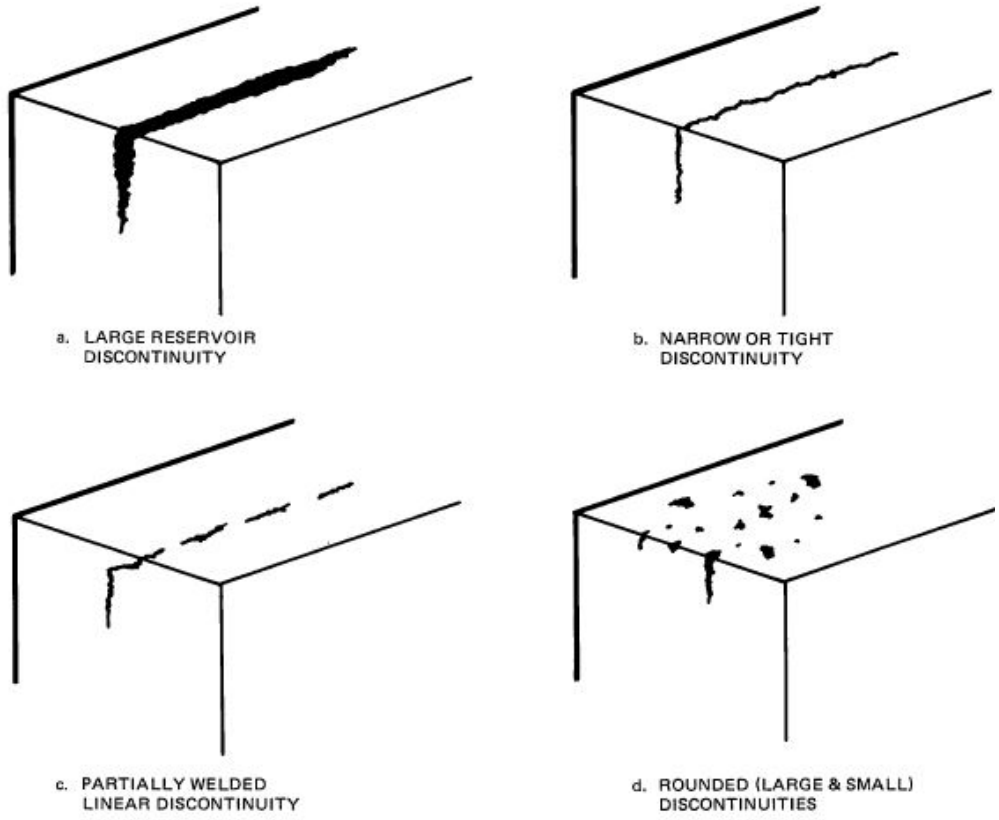

Figure 4–8: Typical penetrant indications.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

221. Penetrant processing sequence

1. How is penetrant applied when using method C?

2. List factors of penetrant application for method C penetrant inspection.

3. Why are method C solvents normally in aerosol cans?

4. What should you do during an initial wipe?

5. What should never be done to a cloth used to remove method C penetrant before inspecting?

6. What should you do in the developer process of method C prior to spraying?

7. How can parts be immersed with method D penetrant process?

8. How long is a part to remain in penetrant application, including the drain station?

9. How long is a part to be sprayed during pre-rinse?

10. What does the mechanical action of the pre-rinse water spray accomplish?

11. What are the agents referred to when remover attacks and removes just the surface of penetrant?

12. What is required during the remover immersion technique of the emulsifier or remover application in order to provide fresh remover to the surface?

13. During emulsifier or remover removal of method D penetrants, what is the distance a spray nozzle should be held from the surface of the part for best washing results?

14. During the developer application in which spraying, flowing or immersion is used, how long should the developer be allowed to drain prior to placing the part into the dryer?

15. What oven temperature is the recommended procedure for proper drying?

16. How long do you wait for your eyes to adjust to the darkened booth before inspecting parts?

17. What will occur if penetrant resides are not removed from discontinuities?

18. What can occur if the residue from the developer applied (dry-powder, nonaqueous, water suspendable or water-soluble) is not effectively removed?

222. Interpretation of indications

1. What two considerations should not affect your decision to call a part defective?

2. What is determined when evaluating a relevant indication?

3. What causes relevant penetrant indications on a part?

4. What type of indication will grow and lead to failure if not found?

5. Why are nonrelevant indications concerning?

6. List the four typical types of indications found in the field.

7. What type of discontinuity form from round indications?

4–4. Penetrant Inspection Process Control

Penetrant inspection is not a fail-safe process. While the presence of indications confirms the existence of discontinuities in the part, the absence of indications *does not guarantee* the absence of discontinuities. Flaws may be present, but not indicated for a number of reasons. The following are the two main reasons for discrepancies in inspection results:

- Substandard materials, either as received or through service degradation.
- Process deviations in equipment, procedures, or conditions.

For example, it is necessary to test the materials periodically and to inspect the equipment and process to be sure they are functioning correctly.

Consequently, this section will consider both the need for process controls, as well as performing those same controls. Your laboratory's schedule for completing process control checks are based on usage. By accomplishing the process control procedures outlined in this section, you can be certain you are providing the highest quality penetrant inspections available.

223. Need for process controls

The materials you use to perform penetrant inspections must be tested to ensure they meet minimum standards for detecting defects. Our materials are tested based on the following two categories: new materials and in-use materials.

New material testing

Although manufacturers go to great lengths to ensure their products are the best they can be, newly received penetrant materials must still be tested before use. It is possible to receive penetrant materials certified by the manufacture as acceptable, yet still fail to meet minimum Air Force standards.

Penetrant materials are subjected to extensive testing during their creation to assure their proper composition. However, materials not performing satisfactorily can still be received. In a number of instances, the discrepancies in performance have not been detected until a number of parts have been processed. Imagine how hard it will be to locate each part that was processed with defective penetrant. It could take days or weeks to locate parts and some may already be back on the aircraft. This is why it is important to test these new materials before use. Unsatisfactory materials can result from a number of causes, including the following:

- The penetrant supplier may inadvertently omit an ingredient or a process.
- An ingredient with similar characteristics may be substituted if the original material is unavailable.

The materials are stored in closed containers until they are used to minimize the possibility of material contamination or degradation.

In-use material testing

Most in-use materials are used in open tanks or open containers. When the immersion method is used, the surplus materials drain from the part back into the tank. When penetrants are applied by brushing, the brush is alternately stroking the part surface and being placed back into the tank. Both methods provide numerous opportunities for contamination and deterioration. Materials handled in this manner should be checked to be sure they are functioning properly.

Material degradation

Material contamination is a primary source of penetrant system performance degradation. There are different types of contaminating materials and their effect on performance. This is another reason why testing materials is important. Let’s look at how contamination may impact our inspection materials.

Material contamination

Some common contaminants that frequently contaminate our penetrant line are encountered in the following table.

Material Contaminates	
Contaminate	**Reason for Contamination**
Water	The most common type of contaminant. This can occur by careless or improper rinsing from other parts.
Organic materials	Paint, lubricants, oils, greases, and sealant are other sources of contamination. If not removed from parts during pre-cleaning, these materials can dissolve in the penetrant and react with or dilute it so it loses some or all of its ability to function.
Organic solvents	Degreaser fluid, cleaning solvent, gasoline, and antifreeze solution are common types of solvent contaminants. These materials dissolve in the penetrant and reduce its effectiveness in proportion to the amount present. A small change in performance is usually not noticeable (five percent or less of the total volume). The method of entry into penetrant is usually carry-over on the interior cavities of the part.
Dirt, soil, other insoluble solids	Soil/solid contamination can be carried into the penetrant, emulsifier, and developer tanks because of improper pre-cleaning and carry-over from other parts. Another common source of soil contamination occurs when the dwell stations are used to store parts. Most dwell stations have drain pans, which return back to the immersion tanks.

Material Contaminates	
Contaminate	**Reason for Contamination**
Acid and alkaline materials	Acid and alkaline contamination is extremely serious. They react with the penetrant to destroy fluorescence brightness even when present in small quantities. They are usually residues from etching, plating or the cleaning processes.
Penetrant	Penetrant is a normal contaminant of emulsifier in the post-emulsifiable process. It can be carried in on penetrant covered parts during the dwell step. As the penetrant builds up in volume, it will gradually slow the emulsifying action, and if the level becomes high enough, the process will stop.

Evaporation loss

Penetrant materials used in open tanks are continuously evaporating. The rate of evaporation is increased with warmer temperatures and large tank surface areas. Evaporation losses of penetrant result in an increase in viscosity, thus slowing down penetration and emulsification. Evaporation losses in developer solutions increase the concentration, which produces a heavier coating that may mask smaller indications.

Since evaporation losses take place gradually, performance change may become significant before you even notice it.

Heat degradation

Fluorescent penetrants are sensitive to elevated temperatures. Exposing penetrants to temperatures over 140 °F can reduce the fluorescence; and temperatures over 250 °F may even destroy it. High temperatures also speed evaporation of the components of penetrants, causing unwanted performance changes. High temperature exposure of penetrants can occur from the following:

- Immersion of heated or hot parts.
- Inspection of hot surfaces resulting from exposure to the sun, such as flight-line aircraft.
- Improper storage of penetrant materials (such as in direct sunlight) before being placed in use.
- Excessive exposure to heat in drying ovens.

Process degradation

Not only do materials degrade, but equipment and procedures can deteriorate as well. Black-light bulbs age and become dirty, reducing their output. Drying oven thermostats can be improperly set or may malfunction, resulting in excessive temperatures and causing incorrect critical procedures. Materials, equipment, and procedures should be checked periodically during their service life to ensure satisfactory process performance.

224. Performing penetrant process controls

Now that you have an understanding of what and why materials degrade, we must look at the different types of process controls needed to ensure an accurate inspection.

One of the factors influencing the degradation of a penetrant process (materials, equipment, and procedures) is the volume of parts processed. The opportunities for material contamination, drag-out, equipment malfunction, and procedure variations are directly proportional to the number of parts inspected. We will begin by looking at process control testing procedures and intervals.

NOTE: This section should not be used to perform process controls; TOs 33B–1–1, *Nondestructive Inspection Methods, Basic Theory,* and 33B–1–2, *Nondestructive Inspection General Procedures and Process Controls*, are the only sources for process controls.

Process control intervals

Equipment and process control intervals vary depending upon the specific item that is checked. Many items will degrade on a time rather than a use basis. Since there is no uniformity in workload between activities, a single calendar schedule cannot be established. The process and equipment shall be inspected at daily, weekly, monthly, bimonthly, quarterly, or semiannual intervals. The following table outlines a few of these intervals.

Penetrant Process Control Intervals	
Liquid Penetrant Testing	**Interval**
System performance test (cracked chrome panels)	Weekly
Water wash pressure and temperature test	Daily/prior to use
Black light intensity test	Daily/prior to use
Inspection booth cleanliness	Daily
Penetrant contamination of remover and developer	Daily/prior to use
Hydrophilic remover concentration test	Monthly
Hydrophilic remover performance test	Monthly
Developer concentration test	Monthly
Ambient white light test	60 days

System performance tests

Cracked-chrome panels evaluate the entire penetrant system (including remover and developer) discontinuity detection performance. They are typically used to provide a qualitative side-by-side comparison of penetrant performance. Their primary advantage is that small or gradual changes are readily noticed. Cracked-chrome panel indications will deteriorate with handling and repeated use. The panels are supplied in sets of two, with the supplier matching the panels as closely as possible.

System performance test (method C)

Solvent removable penetrant systems (spray cans) do not require a 7-day system performance test because the materials are not subject to reuse or contamination during use. However, system performance tests are performed on all solvent removable penetrant materials for the following conditions:

- On new material before placed into service.
- When solvent removable materials exceed the manufacturer’s recommended shelf life. Expired penetrant materials should be tested at least every 12 months.
- When stored in an environment that exceeds 120 °F.

This test is accomplished the same way as the method D test (in the following paragraphs), except you use chemical aerosol cans.

System performance test (method D)

This testing involves the inspection of a test panel containing known defects using samples of the penetrant, emulsifier or remover, and developer from the work tanks. The other half of the panel, or a similar panel, is processed with your reference material obtained when the materials were received. Resulting indications are compared and, if the results are the same, it is safe to assume the system is performing effectively.

Cracked chrome test panels are manufactured specifically to test penetrant inspection systems. These panels consist of a brass base material, a nickel plate subsurface layer, and a chrome surface layer (fig. 4–9).

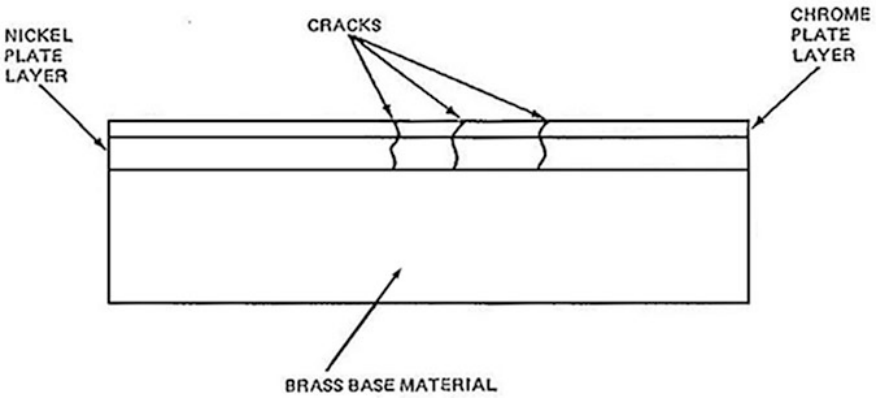

Figure 4–9. Cracked chrome test panel.

Refer to these steps in the following table when performing this test.

System Performance Test (Method D)	
Step	**Directions**
a	Wipe the cracked-chrome panels with a clean lint free cloth dampened with solvent. Allow to dry and examine under ultra violet light. **NOTE:** If residual penetrant is present, clean the panels.
b	Pour a small quantity of penetrant working bath and penetrant reference material into separate glass or metal container. **NOTE:** Do not apply reference material directly on the panel from its storage container.
c	Apply penetrant by brushing, swabbing, or flowing. Use the working materials on one panel and the reference materials on the other.
d	Allow penetrant to dwell for 5 minutes.
e	Perform a pre-rinse of 20-seconds or less.
f	Apply remover by immersing the panels in their correlating working bath and reference material. Removal time will be very short, between 10- to 20-seconds.
g	Perform a final rinse of 20-seconds or less.
h	Apply correlating working bath and reference developer by immersion, flowing, or spraying.
i	Place in clean drying oven.
j	Allow developer to dwell for 5-minutes.
k	Examine the panels side-by-side under a black light (see the following paragraphs).

Once the panels have processed through the entire penetrant line, examine them carefully. Any distinct differences you note between the in-use and reference panel indications are cause for additional testing to determine which material is not performing satisfactorily. Additional specific instructions for performing these tests are located in TO 33B–1–2.

Examination

When examining panels, first note the overall brightness and color of the indications. Second, examine each in detail by following individual indications across both panels. Look at the presence, absence, or diminishing crack indications on the working bath panel as compared to the reference sample panel and observe the difference in continuity, size and color. Any distinct difference should require additional testing to determine if the penetrant, remover, or the developer caused the difference in the indications.

Cleaning and handling test panels

All process control panels (cracked-chrome panels, Penetrant System Monitor (PSM) panels, grit-blast panels) should be cleaned after use (prior to use, if required) in accordance with the steps in the following table:

Cleaning Cracked Chrome Panels	
Step	**Directions**
a	Water spray panel to remove developer residue from the surface of panels. You may also use isopropyl alcohol to wash penetrant from tight defects.
b	Ultrasonically clean the panels in aqueous cleaner.
c	Rinse panel with clean water and then spray indications with solvent.
d	Ultrasonically clean again for 10-minutes.

When handling panels, follow these precautions:

1. *Do not* expose test panels to temperatures above 212 °F.
2. Use extreme care in handling and storing test panels. Do *not* drop, hit, or place undue stress on the panels or attempt to bend or straighten them.
3. Remove all residues from the panels following each use with solvent and confirm residue removal by checking the panels under a black light.
4. Minimize touching the chromed surfaces to avoid fingerprint contamination.
5. Use care during the penetrant removal step when processing the panels. The artificial cracks in the panels are not like typical parts, and it is very easy to remove all entrapped penetrant.
6. To avoid cross contamination, use separate brushes or swabs to apply the reference and in-use penetrant to system panels.

Penetrant process controls

Materials and process deficiencies are not always obvious. It is not easily determined if a penetrant has lost its ability to penetrate into a given flaw. Penetrant inspection, as well as all other nondestructive inspection processes, is not a perfect process. Flaws can or cannot be present for a number of reasons. The following are the two main reasons for discrepancies in inspection results:

1. Substandard inspection materials due to either receipt of bad material from the manufacturer or degradation in storage or service.
2. Process deviations in equipment, procedures, or operating conditions.

Surface wetting test

This test ensures the penetrant readily wets the surface and the penetrant film does not retract or form beads. The test is simple; first apply a small amount of penetrant to the clean, shiny surface of aluminum foil using a cotton swab. After 10 minutes, see whether the penetrant has pooled into beads or has retracted.

Rapid brightness test

This test method compares the in-use penetrant with the reference penetrant by comparing the brightness of two samples and an absorbent material.

- Place a drop of in-use penetrant on a paper towel.
- Place a second drop of reference standard penetrant near the in-use drop.
- When the two drops merge, examine them under a black light for differences in color and brightness.

Remover process controls

Penetrant is an unavoidable contaminant of remover. It is carried into the emulsifier on the surface of parts where it dissolves and is washed off during immersion and the drain process. Since emulsifier and penetrant are capable of being mixed in all concentrations, even small quantities of fluorescent dye will cause the emulsifier to fluoresce. It is also important to check the concentration. We will look at the following remover tests and how they are performed in the next few paragraphs and tables:

- Hydrophilic remover refractometer test.
- Hydrometer test.
- Quick test for penetrant contamination.
- Hydrophilic remover performance check.

Hydrophilic remover refractometer test

The refractometer test measures the refractive index using a scale, which ranges from 0 to 320, with water having a refractive index of 0. A refractometer is supplied in the penetrant process control kit and is the recommended method to use when determining initial water concentration in a new batch of remover. This is also an acceptable method for testing in-use hydrophilic remover concentration if penetrant contamination is not excessive. A hydrophilic remover performance check will usually indicate excessive penetrant contamination before the refractive index is affected by penetrant contamination. The following table provides the steps for accomplishing this test.

Hydrophilic Remover Refractometer Test	
Step	**Directions**
a	Dip the plastic rod supplied with the remover into the in-use hydrophilic remover.
b	Raise the cover plate on the refractometer and place two or three drops of the test solution on the prism face. Make sure the solution completely covers the prism face and then close the cover plate.
c	Hold the refractometer close to a bright light source so light enters and illuminates the prism. Look through the eyepiece of the refractometer and read the Brix value (refractive index units) where the bright and dark areas meet.
d	Record the refractive index units as indicated. Compare this value with the initial graph you created when mixing the bath. The working bath solution should be within 5-percent of the required concentration.
e	After reading and reviewing the results, make adjustments by either adding water or concentrate remover to bring the remover bath concentration to an acceptable level.
f	Clean the refractometer cover plate and prism face with a soft lint-free cloth when testing is complete.

Hydrometer test

The hydrometer test involves the use of a hydrometer to determine the concentration of a solution by specific gravity. The following table explains this process.

Hydrometer Test	
Step	**Directions**
a	Mix a reference sample of new hydrophilic remover as recommended by the manufacturer in a 500 ml graduated cylinder or similar container.
b	Using the hydrometer, check the concentration of the reference sample by noting its specific gravity and record this reading.
c	Place the hydrometer in the working bath; read and record the test results. Compare the results of the reference standard and the in-use remover. (**NOTE:** Adjust the in-use remover to achieve a concentration within 5-percent of the reference standard test results.)

Quick test for penetrant contamination

The quick test is simply just that. It is a fast and simple way to determine if penetrant is present in the remover in large quantities to become a possible contaminant. Perform this test by passing a black light over the surface of the remover in the tank and visually examine it for signs of green fluorescence. Remove penetrant by skimming or absorbing the penetrant with a paper towel.

Hydrophilic remover performance check

A performance check verifies the concentration or contamination of used immersion hydrophilic remover baths. Residual penetrant from parts disperse in the remover, can cause problems when performing a color comparison check and skew the refractive index when performing the refractometer test. Performance testing will usually indicate a problem with the remover bath well before a refractometer measurement will indicate a problem. The performance test involves processing two annealed type 301 or 302 stainless steel panels with different removal contact times and comparing the results using the procedure in the following table:

Hydrophilic Remover Performance Check	
Step	**Directions**
a	Immerse the panels in the working penetrant bath and allow it to drain for 10-minutes at proximately a 60° angle.
b	Process the first panel through a 10-second pre-rinse, 10-second drain, 20-second immersion in remover, 5-second drain, and 10-second rinse.
c	Process the second panel through the same cycle except double the immersion time to 40-seconds in the remover.
d	When the remover is fresh and uncontaminated, neither panel should exhibit any background fluorescence. As the penetrant level in the remover starts to build up, the short immersion time panel will begin to display some residual fluorescence while the longer immersion panel remains free of background.
e	Ultrasonically clean the test panels.

Developer process controls

There are a number of service factors affecting the performance of developers. The most significant of these are changes in the concentration and contamination. These tests are similar to some of the remover tests but differ in times and ranges. We will now look at the developer process controls.

Water-suspended and soluble developer concentration test

A specific gravity reading with a hydrometer is used to check the concentration of water-soluble developers just as it does for the remover. The supplier can provide an accurate conversion chart for its particular developer.

Reduced concentration results in thin coatings decrease the sensitivity of the system. Developer concentration may vary for a number of reasons, including the following:

- Evaporation - As water evaporates, the concentration levels increase, causing excessive coating thickness on the part.
- Drag-out - As parts are processed, developer adheres to the part surface. Unless concentrate is added, the developer loss adds up over time (referred to as drag-out).
- Inadequate agitation - Allows some of the developer particles to settle out, which also reduces concentration.
- Caking - It is also possible for the developer particles to cake on the bottom or in the corners of the tank, preventing them from being suspended.

The process for performing a concentration test is as follows:

Water-suspended and Soluble Developer Concentration Test	
Step	**Directions**
a	Place the hydrometer directly in the tank, ensuring it floats free, not touching the tank sides. Read the specific gravity from the scale on the hydrometer. It may be more convenient to take a sample from the tank using a graduated cylinder, which is deep enough to float the hydrometer.
b	Compare the reading from the hydrometer to the graph of specific gravity and make adjustments to the developer concentration as required. **NOTE:** The developer concentration shall be maintained within 5-percent of the required concentration.

Water-suspended or soluble developer penetrant contamination test

Penetrant can also contaminate water-suspended developer just as it does with remover. This test is similar to the remover contamination test; check for fluorescent penetrant dye contamination by visual examination of the bath surface while passing a black light over it. Uncontaminated developer appears dull white while fluorescent dye contamination will display as specks of yellow-green, floating on the top of the bath. Low-levels of contamination can be skimmed off the developer surface; however, baths that exhibit significant amounts of surface penetrant must be replaced.

Inspection booth checks

Inspection booth checks do not require documentation unless specifically stated in a technical order or other directives. The frequencies of the checks are at the supervisor's discretion unless otherwise directed.

- Verify the inspection booth is of adequate size for the parts to be inspected.
- Verify the booth is not used to store parts, consumables, or standards.
- The inspection booth should be cleaned frequently and background fluorescence from spilled penetrant kept to a minimum.

Black light intensity check

Black lights should be tested with an approved and calibrated UV-A digital radiometer. The intensity that you want to look for should be at least 1000 micro-watts per square centimeter ($\mu W/cm^2$) over a 3-inch diameter circle with a minimum distance of 15 inches from the filter lens.

Battery powered black lights require post inspection brightness checks both prior to powering off the lamp. In the event that the UV-A lamp is turned off, it will be turned on and allowed a minimum 5-minute warm-up prior to performing the post-inspection brightness check.

NOTE: UV-A lamps used solely in the penetrant rinse stations are not subject to process control intensity requirements.

Ambient white light check

The white light test must be performed to ensure the excessive white light is not present in either the inspection or inspection area. The test measures ambient white light from all sources including white light emitted from UV-A lamps and reflected white light from areas adjacent to the inspection booth.

The ambient test is performed in the inspection booth or inspection area with all UV-A lamps normally used in the booth turned on. This test is performed with an approved and calibrated photometer. The photometer sensor is placed in the area where parts are normally inspected. The ambient white light should not exceed 2-foot-candles.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

223. Need for process controls

1. Penetrant materials are grouped into what two categories?

2. What is the primary source of penetrant system degradation?

3. What is the most common type of contaminate of penetrant materials?

4. What is a normal contaminate of emulsifier?

5. How does evaporation impact liquid penetrant?

6. What are fluorescent penetrants sensitive to?

7. What three things should be periodically checked during their service life to ensure satisfactory process performance?

224. Performing penetrant process controls

1. How often is the system performance test completed?

2. What process control evaluates the entire penetrant system?

3. When should expired penetrant materials be tested with method C?

4. What material makes up the cracked chrome panel base?

5. How long do you allow penetrant to dwell when performing the method D system performance test?

6. What should you do if you notice differences in the cracked chrome test panels when doing your evaluation?

7. When examining test panels, what is the first thing you should notice?

8. How should you clean panels after spraying them with water?

9. What temperature levels should cracked chrome panels not be exposed to?

10. What test ensures that penetrant does not retract or form into beads?

11. What differences are examined with the rapid brightness test?

12. List the tests for the remover process controls.

13. What is the refractive scale index of water in the refractometer test?

14. When comparing the refractive index value with the initial value, the working bath solution should be within how much of the required concentration?

15. How should you clean the refractometer?

16. What test determines the concentration of a solution by specific gravity?

17. Which test is performed by passing a black light over the surface of the remover tank?

18. What does the hydrophilic remover performance check verify?

19. What does the performance check use when performing this test?

20. At what angle are panels set at while draining?

21. What are the most significant changes in developer process controls?

22. What is used to check the concentration of water-soluble concentration test?

23. What are the variations of developer concentration?

24. How often are inspection booth checks accomplished?

25. What is the minimum distance at which a black light intensity check should be tested?

Answers to Self-Test Questions

216

1. Surface tension, wetting, and capillary action.
2. Cohesion.
3. Adhesion.
4. When a liquid is in contact with a solid surface, the cohesive force competes with the adhesive force between the liquid molecules and the solid surface.
5. Capillary action.
6. Viscosity.
7. It decreases.
8. Weight of a substance to an equal volume of water.
9. 200 °F.
10. Heat fade.
11. Between 32 °F and 130 °F.
12. Toxicity, solvent ability, removability, water tolerance, brightness, and penetrant sensitivity.
13. Because toxicity measures adverse effects on humans resulting from contact with the material. Specifically, this applies to any abnormal effects ranging from nausea and dermatitis through dysfunction of major organs, such as the liver or kidneys.
14. To hold large quantities of dye in a solution over a wide range of temperatures.
15. Penetrant removal without additional processing.
16. By closing penetrant tanks.
17. It is the ability to produce indications from very small, tight cracks.

217

1. Type I, using fluorescent penetrant materials; and type II, which uses visible dye materials.
2. Type II, visible dye.
3. Post-emulsifiable hydrophilic penetrant.
4. Method A: water-washable.
5. Method C: solvent-removable.
6. The system concept.
7. A catch all term used to indicate how long a particular action is allowed to continue during penetrant inspection processing.
8. To allow the penetrant to seep into and fill any surface openings.
9. At least 30 minutes.
10. They range from 10-seconds to 5-minutes, with a typical dwell time of less than 1-minute.
11. To allow one-half of the penetrant dwell time.
12. Two hours.
13. When the part is completely free of moisture.

218

1. Methods C and D.
2. It can strip penetrant from defects or dilute it in a defect, which will in turn produce dim, fuzzy indications.
3. Water-soluble chemicals, and concentrated liquids.
4. A transparent pink solution.
5. As parts are processed, the amount of penetrant in the remover gradually increases. If the removal process is monitored, penetrant contamination will reach a point where a distinct performance change occurs.
6. From 5 to 6-percent.
7. Between 10 and 40 psi.

8. Between 50 °F to 100 °F.
9. An angle of 45 to 70 degrees.
10. As much as 600 times.
11. Dry powder, water-soluble, water suspended, and nonaqueous wet.
12. Water-soluble.

219

1. One or more cans of penetrant, remover, and developer; a black light; clean, lint-free rags and/or soft paper towels; cotton swabs; 10X magnifier; inspection mirror; flashlight; marking device cited in the equipment technical manual; and an approved carrying case.
2. A respirator.
3. Spray penetrant on cotton swabs or acid brushes while outside the area and use them to apply the penetrant to enclosed inspection areas.
4. Eye protection.
5. Place the materials off to the side in a shaded area.
6. Keep the kit clean and stocked with serviceable equipment and materials.

220

1. When high production, high level of sensitivity, or 100-percent inspection of a part is required.
2. Production requirements, size of inspection items, and inspection method used.
3. Type II.
4. Between 20 and 30 minutes.
5. High-pressure mercury vapor bulbs.
6. Up to 750 °F.

221

1. By spraying, brushing or swabbing.
2. Size, shape, and configuration of the part inspected; accessibility of the area; and availability of the inspection equipment.
3. Because of their high evaporation rate.
4. Wipe the surface with a clean, dry rag or paper towel to remove the major portion of surface penetrant.
5. It must not be saturated by either pouring, immersion or excessive spraying.
6. Agitate the developer spray container.
7. One at a time or, if small enough, can be batch processed by placing them in a basket or rack.
8. As determined by the recommended dwell time.
9. Thirty to 120 seconds.
10. It improves the efficiency of the process by reducing the amount of remover used, and cuts the remover contact time by about 50 percent.
11. Surfactants.
12. Agitation.
13. Twelve inches.
14. No more than 30 seconds.
15. Between 120 and 140 °F.
16. Five minutes.
17. They will dry, forming a varnish-like material in the flaw.
18. The material can absorb and retain moisture, resulting in corrosion of the part.

222

1. The cost of the rejected part or the resulting maintenance actions.
2. Its cause, type and reporting its category; the location; and the approximate size.

3. Actual discontinuities in the part.
4. Sharp, shallow defects, such as fatigue cracks.
5. Because they may mask or cover a true discontinuity indication.
6. Continuous linear indications, intermittent linear indications, round indications, and manufacturing discontinuities.
7. Porosity or relatively small areas of unsoundness in metal components.

223

1. New materials and in-use materials.
2. Material degradation.
3. Water.
4. Penetrant.
5. It results in an increase in viscosity, thus slowing down penetration and emulsification.
6. Elevated temperatures.
7. Materials, equipment, and procedures.

224

1. Weekly.
2. System performance test (cracked-chrome panels).
3. Every 12 months.
4. Brass base material.
5. Five minutes.
6. Perform additional testing to determine which material is not performing satisfactorily.
7. The overall brightness and color of the indications.
8. Ultrasonically in aqueous cleaner.
9. Temperatures above 212 °F.
10. Surface wetting test.
11. Color and brightness.
12. Hydrophilic remover refractometer test, hydrometer test, quick test for penetrant contamination, and the hydrophilic remover performance check.
13. Zero.
14. Five percent.
15. Use a soft lint-free cloth to clean the refractometer cover plate and prism face.
16. The hydrometer test.
17. Quick test for penetrant contamination.
18. The concentration or contamination of used immersion hydrophilic remover baths.
19. Two annealed type 301 or 302 stainless steel panels.
20. Sixty degrees.
21. Concentration and contamination.
22. A specific gravity reading with a hydrometer.
23. Evaporation, drag-out, inadequate agitation, and caking.
24. Checks are at the supervisor’s discretion unless otherwise directed.
25. Fifteen inches from the filter lens.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field Scoring Answer Sheet.

Do not return your answer sheet to AFCDA.

39. (216) What are desirable qualities within a penetrant?
    a. Low surface tension and a large contact angle.
    b. High surface tension and a large contact angle.
    c. Low surface tension and good wetting ability.
    d. High surface tension and good wetting ability.

40. (216) What generates forces to draw a penetrant into cracks?
    a. Viscosity.
    b. Wetting ability.
    c. Surface tension.
    d. Capillary action.

41. (216) What chemical property is required to dissolve and hold the dyes in a solution?
    a. Toxicity.
    b. Removability.
    c. Solvent ability.
    d. Water tolerance.

42. (216) What sensitivity level of penetrant is ultra-high?
    a. Level 3.
    b. Level 4.
    c. Level 5.
    d. Level 6.

43. (217) What is a Type I penetrant process?
    a. Dual mode materials.
    b. Visible dye materials.
    c. Fluorescent materials.
    d. Water-washable materials.

44. (217) What is a method C penetrant inspection?
    a. Lipophilic.
    b. Hydrophilic.
    c. Water-washable.
    d. Solvent removable.

45. (217) The system concept applies to what materials of a penetrant system?
    a. Penetrants, emulsifiers, and developers.
    b. Developers and emulsifiers.
    c. Penetrants and emulsifiers.
    d. Developers and penetrants.

46. (217) What is the *maximum* dwell time of an aqueous developer?
    a. 15 minutes.
    b. 30 minutes.
    c. 2 hours.
    d. 1 hour.

47. (218) In the hydrophilic process, what is the concentration range of hydrophilic remover in water?
    a. 5 to 35 percent.
    b. 5 to 45 percent.
    c. 10 to 35 percent.
    d. 10 to 45 percent.

48. (218) What type of developer consists of inert particles in water?
    a. Dry powder.
    b. Nonaqueous.
    c. Water-soluble.
    d. Water-suspended.

49. (219) What should you wear in case you mistakenly press the penetrant spray nozzle with the opening pointing back at you?
    a. Gloves.
    b. Dosimeter.
    c. Welder’s goggles.
    d. Chemical goggles.

50. (219) Aerosol cans can burst when heated to temperatures above
    a. 100 °F.
    b. 120 °F.
    c. 140 °F.
    d. 160 °F.

51. (220) The difference between the small, medium, and large fluorescent penetrant inspection units is the
    a. type of penetrant used.
    b. method of penetrant removal used.
    c. number of parts they can accommodate.
    d. size of the parts they can accommodate.

52. (220) What is the ideal output in nanometers (nm) of a black light bulb for penetrant inspections?
    a. 254 nm.
    b. 320 nm.
    c. 365 nm.
    d. 440 nm.

53. (221) What should you *never* do while utilizing the method C method?
    a. Use a black light to examine parts.
    b. Use water to remove excess penetrant.
    c. Dry wipe parts to ensure excess penetrant has been removed.
    d. Spray or pour solvent directly on a part surface before inspection.

54. (221) Nonaqueous solvent-based developers are always applied by
    a. spraying.
    b. brushing.
    c. swabbing.
    d. immersion.

55. (221) What is the concentration range of remover to water by volume?
    a. 1 to 5 percent.
    b. 1 to 3 percent.
    c. .01 to .05 percent.
    d. .01 to .03 percent.

56. (222) Which of the following is considered a defect?
    a. A detrimental relevant indication.
    b. A nondetrimental relevant indication.
    c. A detrimental nonrelevant indication.
    d. A nondetrimental nonrelevant indication.

57. (222) What indications are caused by discontinuities such as cracks, seams, or laps?
    a. Round indications.
    b. Continuous linear indications.
    c. Intermittent linear indications.
    d. Manufacturing discontinuities.

58. (223) Which of these contaminates are *not* frequent contaminates of penetrant line materials?
    a. Alkaline materials.
    b. Organic solvents.
    c. Developer.
    d. Water.

59. (223) Since fluorescent penetrants are sensitive to elevated temperatures, fluorescence may be destroyed by being exposed to temperatures above
    a. 120 °F.
    b. 140 °F.
    c. 200 °F.
    d. 250 °F.

60. (224) What is the interval for performing a system performance test*?*
    a. Daily.
    b. Weekly.
    c. Monthly.
    d. Biweekly.

61. (224) Method C system performance tests are completed when penetrant materials are stored in an environment that exceeds
    a. 100 °F.
    b. 120 °F.
    c. 150 °F.
    d. 200 °F.

62. (224) When cleaning test panels for the second time while using the system performance test, or method D, how long do you let them sit in an ultrasonic cleaner?
    a. 20 minutes.
    b. 15 minutes.
    c. 10 minutes.
    d. 5 minutes.

63. (224) What type of contamination does a hydrophilic remover performance test for?
    a. Developer.
    b. Penetrant.
    c. Water.
    d. Dirt.

64. (224) What is used for testing the performance of hydrophilic remover?
    a. Black light.
    b. Refractometer.
    c. Cracked chrome panels.
    d. Type 301 or 302 stainless steel panels.

65. (224) As parts are processed, developer adheres to the part surface; unless concentrate is added, the developer loss adds up. What is the term for this loss over time?
    a. Caking.
    b. Drag-out.
    c. Evaporation.
    d. Inadequate agitation.

66. (224) The desired intensity in micro-watts per square centimeter ($\mu W/cm^2$) of a black light check should be at least
    a. 1200 $\mu W/cm^2$.
    b. 1000 $\mu W/cm^2$.
    c. 750 $\mu W/cm^2$.
    d. 600 $\mu W/cm^2$.

Please read the unit menu for unit 5 and continue ➔

Unit 5. Magnetic Particle Inspection Method

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IN THE EARLY STAGES of the development of the magnetic particle inspection process, it was predicted that this method would never get beyond the research stage. There was serious doubt about it ever being in production lines to inspect thousands of parts per hour. Nevertheless, it has become one of NDI's most used methods. Not only is it used in overhaul shops where service defects are sought, but it is also used in the manufacturing industry to locate processing and inherent defects.

The information presented in this unit will enable you to inspect parts with a high degree of accuracy in a minimum amount of time. We will begin with a discussion on the principles of magnetism and then build on methods and techniques used in magnetic particle inspection. This will include looking further into the theory and properties of magnetic fields, as well as a discussion in magnetic particle equipment classifications based on stationary and portable inspections. In addition, we will discuss how to select and apply the right materials and equipment for inspections. Further, we will consider the process controls used to verify the performance of equipment and materials, to include evaluating the inspection processes themselves in order to ensure they are working property to detect the deficiencies.

5–1. Principles of Magnetism

When ferrous materials, such as iron, are placed in a strong magnetic field or have electric current flow through them, they will become "magnetized." The degree of magnetization affects the strength of the magnetizing field. When a surface or near-surface discontinuity interrupts the magnetic field in a magnetized part, some of the field is forced into the air above the discontinuity resulting in a leakage field. The size and strength of the leakage field depends on the size and proximity of the discontinuity to the magnetic field.

This is the basic principle of magnetism; in this section, we will look further into the theory, properties, and magnetic fields to give you a better understanding of how it works. Our intent is not to cover every theory of magnetism or expect you to understand all principles involved. Our focus is to provide information on basic magnetism in order to perform your NDI tasks requiring magnetic inspections.

225. Theory behind basic magnetism

By this point in your life, you should be familiar with the unseen force of electricity. As you will recall from previous study, a magnetic field exists where electricity is flowing. You need to understand the relationship between the flow of electricity and the resulting magnetic field so that you are able to correctly set up and apply magnetic particle inspection techniques. As a result, this unit will provide a discussion of the characteristics of a magnetic field; electricity and magnetism; as well as well as the properties of the hysteresis curve with reference to a magnetic field, magnetic flux, and components impacted.

Magnetic field characteristics

In the past, electricity was believed to flow through a wire, just as water flows through a pipe. According to this viewpoint, a pressure is required to push the electricity through the wire; the term “electrical pressure” described this characteristic.

Electromotive force

The term electrical pressure represents the same concept described by electromotive force, which is defined as the “force that causes electrons to move through a conductor.” The unit of measure for electromotive force is the *volt* and is measured between two points in a circuit. If you say “a battery contains a full charge,” what you really mean is the battery contains a potential force or source of energy held in readiness to do work when a suitable circuit is connected.

Electric current

An electric current flows when electrons move along a conductor. This current is a direct result of an electromotive force and continues to flow as long as it exists between the ends of the conductor. Electron flow through a conductor starts from the negative terminal to the positive terminal of the source. These terminals maintain negative and positive charges due to the action within the source of the electromotive force.

Current is the rate at which electrons pass a given point in a conductor. The unit of measure of current is the *ampere* (amps). To measure current, you place a meter in the circuit so that current flowing in the circuit must also flow through the meter.

Electricity and magnetism

Electric currents create or induce magnetic fields into parts made of ferromagnetic materials. Magnetic lines of force are then aligned at right angles (90°) to the direction of electric current flow. It is possible to control the direction of the magnetic field by controlling the direction of the magnetizing current. This makes it possible to induce magnetic lines of force so they intercept defects at right angles.

Magnetic permeability

Magnetic permeability is the ease with which a ferromagnetic part is magnetized. It is equal to the ratio of the flux density produced to the magnetizing force inducing the magnetic field. It changes in value with variations in the strength of the magnetizing force. A metal that is easy to magnetize, such as soft iron or low carbon steel, has a high permeability or is highly permeable.

Retentivity

The property of a metal that remains magnetized after the magnetizing force is removed is called retentivity. A metal, such as hard steel, has a high percentage of carbon and can retain a strong magnetic field after removing magnetic current. Hard steel has high retentivity, or is highly retentive.

Hysteresis curve

Ferromagnetic metals are attracted very strongly by a magnetic field and depend on this force exhibited in a hysteresis curve. They are the only materials capable of inspecting when using magnetic particle inspection (MPI).

Let's start with looking at a hysteresis curve (fig. 5–1) and the basic terms used, since you will need to know how a magnetic field works before understanding your inspection.

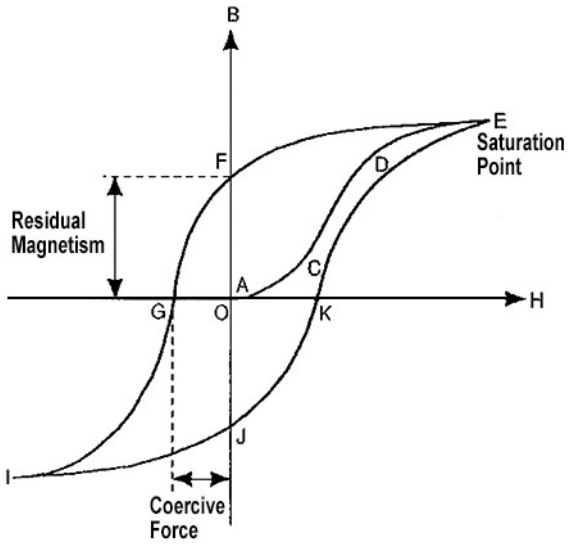


Figure 5–1. Hysteresis curve.

Understanding the Hysteresis Curve		
Point on the Hysteresis Loop	**Term**	**Represents**
A	Magnetic field	A magnetic field describes the volume surrounding either a magnetized part or a current carrying conductor where a magnetic force is exerted. The magnetic field within an unmagnetized piece of steel is zero. As the magnetizing force (H) increases from zero, the flux density (B) within the part will also increase from zero. The curve from points (A/E) illustrates this behavior.
B	Flux density	Flux density is shown by the strength of a magnetic field expressed in flux lines (Maxwells) per unit cross-sectional area (B) entering a magnetic pole. The unit of measure is *gauss*; one gauss is equal to one Maxwell per square centimeter. The total flux *does not* give a true picture of the concentration of these lines. Flux density is the number of lines per square centimeter in a plane perpendicular to the direction of the magnetic field.
E	Saturation point	When flux density increases up to a point and then tends to level off, it is called *magnetic saturation* or *saturation point* (E). This is the level of magnetism in a ferromagnetic material where the magnetic permeability is equal to one. The increasing magnetizing force (H) results in no greater increase in a magnetic field than would occur in a vacuum or air.
F	Residual magnetism	When the magnetizing force reduces to zero, the flux density does not return to zero. Instead, the flux density returns to a value shown at point (F). *Residual magnetism* is the magnetic field that remains in the part when the external magnetizing force is reduced to zero.

Understanding the Hysteresis Curve		
Point on the Hysteresis Loop	**Term**	**Represents**
G	Coercive force	*Coercive force* is the negative or reverse applied magnetizing force necessary to reduce the residual magnetizing force to zero in a ferromagnetic material after magnetic saturation. As the magnetizing force (H) increases from zero in the opposite direction, the flux density will decrease to zero, and then start to increase to point (I).The line (O/G) represent the magnitude and direction of this force.
H	Magnetizing force	Magnetizing force represents the strength (H) required to reduce the flux density (B) to zero in a saturated ferromagnetic material. It is defined as the magnetizing field applied to a ferromagnetic material to induce magnetization. It is the total force tending to set up a magnetic flux in a magnetic circuit and the unit of measure is the “Oersted.”
I	Magnetizing current	A further increase in the magnetizing force (H) to point (I) results in saturation of the material in a direction opposite to that represented by point (E). Reduction of the magnetizing force to zero will reduce the flux density to the value represented by point (J).
J	Reduced magnetism	Reduced magnetizing force in the original direction will change the flux density as shown in portion (J/K) of the hysteresis curve. Increasing the magnetizing force sufficiently will return the material to saturation as illustrated at point (E).

226. Magnetic properties of material

For centuries, people have experimented with substances exhibiting magnetism. The ancient Greeks discovered that certain stones, found in the city of Magnesia in Asia Minor, attracted bits of iron. They called these stones magnetite. The Orientals discovered that when a piece of magnetite was suspended and rotating freely in a horizontal plane, it would turn so that one particular end always pointed North. The Europeans later learned of this discovery and used it to develop the first magnetic compass as a navigation aid that helped lead the Europeans to new lands. Because of this, magnetite came to be known as leading stones, or lodestones.

The simplest way to learn about magnetism is to start with some basic understandings of magnets.

Magnets

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

Figure 5–2. Horseshoe magnet.

Horseshoe magnet

A familiar type of magnet is the horseshoe magnet (fig. 5–2). This is a permanent magnet and possesses residual magnetism. It will attract iron filings to its ends where a leakage field occurs. These ends are commonly called “North” and “South” poles, indicated by N and S on the diagram. A *leakage field* is the magnetic field outside of a part resulting from the presence of a discontinuity, or a change in the part’s cross-section.

Continuous *magnetic flux lines*, or *lines of force* in leakage fields, flow from North to South. In an ideal horseshoe magnet, the flux lines leave only at the poles and are capable of attracting magnetic materials at these poles. This action provides an example of a longitudinal magnetic field. In a real

horseshoe magnet, very small discontinuities disperse throughout creating small, weak, localized leakage fields over the surface of the magnet.

If the shape of an ideal horseshoe magnet is changed, the ends will still attract iron filings. However, if the ends of the magnet are fused or welded into a continuous ring as shown (fig. 5–3), the magnet will no longer attract or hold exterior magnetic materials. This is because the North and South poles no longer exist; thus, a leakage field does not exist. The magnetic field will remain as shown by the arrows, but no iron filings are attracted.

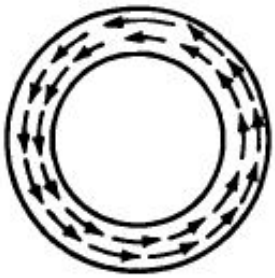


Figure 5–3. Horseshoe magnet fused into a ring.

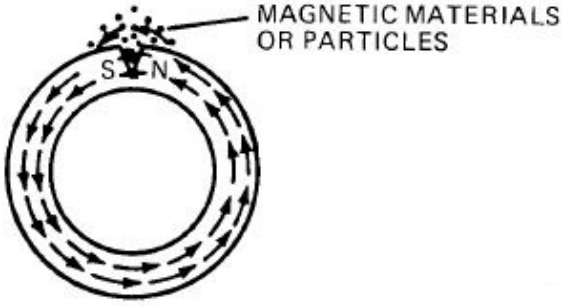


Figure 5–4. Crack in fused horseshoe magnet.

A transverse crack in the fused magnet or circularly magnetized part (fig. 5–4) will create a leakage field with North and South poles on either side of the crack. Some of the magnetic flux will exit the metal and form a leakage field. This leakage field forms an indication in the metal part, and attracts ferrous particles. This is the principle which describes where magnetic particle indications form.

Bar magnet

If a horseshoe magnet is straightened, a bar magnet is created (fig. 5–5). The bar magnet has poles at both ends, and the magnetic lines of force flow through the length returning around the outside. Magnetic particles are attracted *only* to the poles and has a longitudinal field.

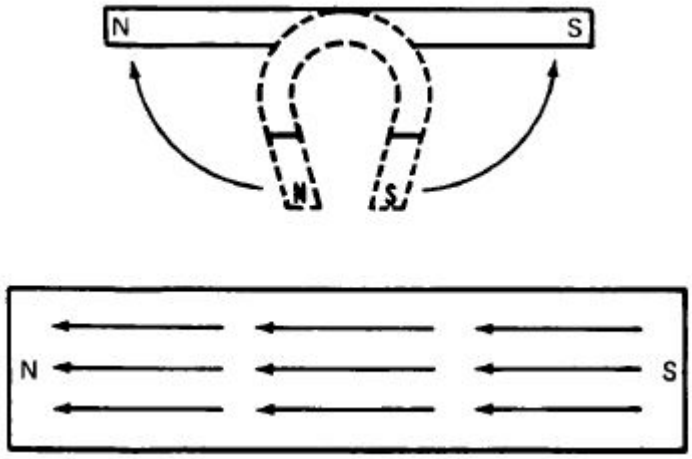


Figure 5–5. Bar magnet.

A discontinuity in the bar magnet that crosses the magnetic flux lines will create North and South poles on either side of the discontinuity. The resulting leakage field will attract magnetic particles just like a horseshoe magnet. In a similar manner, a crack will create magnetic poles as indicated in figure 5–6. These poles will also produce a leakage field that can attract magnetic particles. The strength of the leakage field is based on the number of flux lines present in the depth of the crack, and the width of the air gap at the surface. The strength of this leakage field determines the number of magnetic

particles gathered to form indications. Clear indications are seen at strong leakage fields, while weak indications are formed at weak leakage fields.

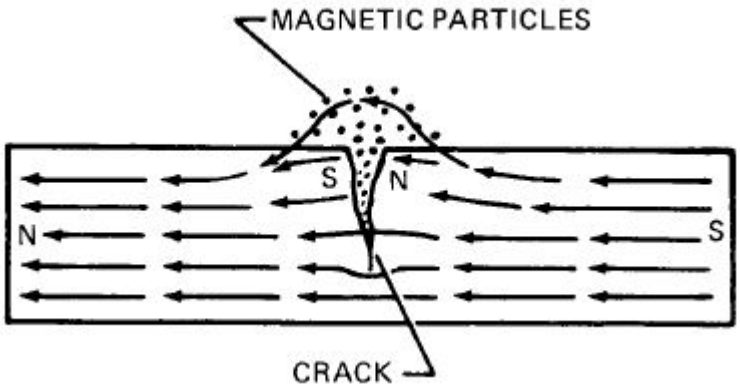


Figure 5–6. Crack in a bar magnet.

Effects of flux direction

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

Magnetic attraction

Magnetic attraction can be explained by using the concept of flux lines or lines of force. When a piece of soft iron is placed in a magnetic field, it will develop magnetic poles. These poles will be attracted to the poles of the magnetic object that created the initial field. As it approaches closer to the source of the original field, more flux lines will flow through the piece of iron, thus creating stronger magnetic poles and further increasing the attraction. This concentrates the lines of flux into the easily traversed high permeability (iron path) rather than the alternative low permeability (air paths). This is magnetic attraction and is the reason magnetic particles concentrate at leakage fields. This is demonstrated in a magnetograph within figure 5–7.

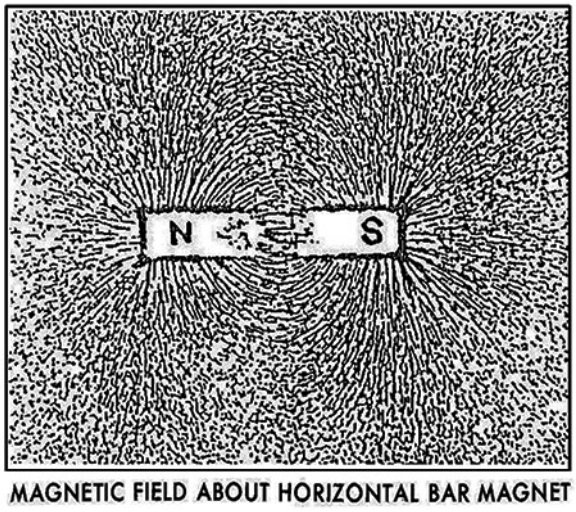


Figure 5–7. Magnetograph of a bar magnet.

Field intensity

You can tell from the pattern made by iron fillings and the position a compass needle assumes when it moves in a magnetic field. The following two characteristics of a magnetic field make up its intensity.

1. The *direction* of a magnetic field is the direction of the force it exerts on a North pole placed within the field.
2. The *strength* of a magnetic field, or field intensity, at any point in the field, is the force it exerts on a unit North pole placed there.

Polarity

North and South poles in magnets establish the basic laws of attraction and repulsion in magnetism. Like poles repel, as illustrated in figure 5–8; alternatively, unlike poles attract, as illustrated in figure 5–9.

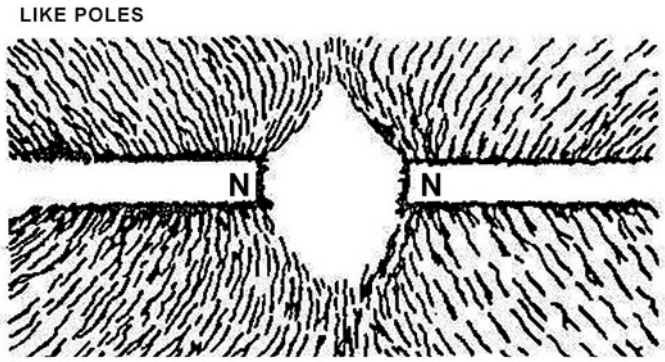


Figure 5–8. Magnetograph of like poles adjacent to each other.

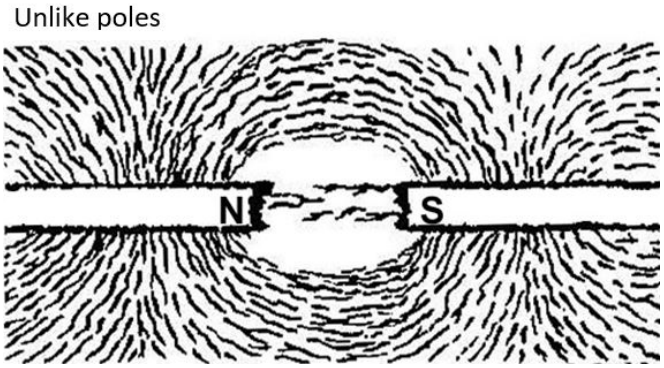


Figure 5–9. Magnetograph of unlike poles adjacent to each other.

Magnetic domain

When you take two identical bars of steel and make one of them into a permanent magnet, you cannot determine any differences between them without specialized tests. There is no physical difference in size, weight, or shape of the bars. However, it now possesses certain properties that it did not have before.

One of the accepted theories of magnetism, describing ferrous materials, is called the *domain theory*. In this theory, domains are classified as groups of magnetically coupled atoms within a ferromagnetic material (fig. 5–10). These groups of atoms form singular microscopic magnetic domains, each having some degree of flux density greater than zero. Although the atoms within a domain align magnetically, the domains themselves may not be aligned. Within completely demagnetized ferromagnetic material, these domains are randomly oriented, resulting in an overall flux density of

zero (fig. 5–11A). When magnetically saturated, all of the individual domains within the material become oriented with the magnetizing force (fig. 5–11C). When the magnetizing force is removed from a ferromagnetic material, or if an insufficient magnetizing force was applied, most domains will remain aligned while a few become randomly oriented (fig. 5–11B). The percentage of domains remaining aligned determines the amount of retained magnetism in the material. You can say that a material with all domains aligned is completely magnetized and a material with all domains randomly oriented in completely demagnetized.

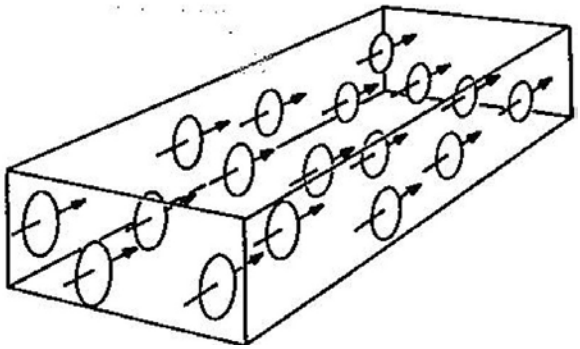


Figure 5–10. A magnetic domain.

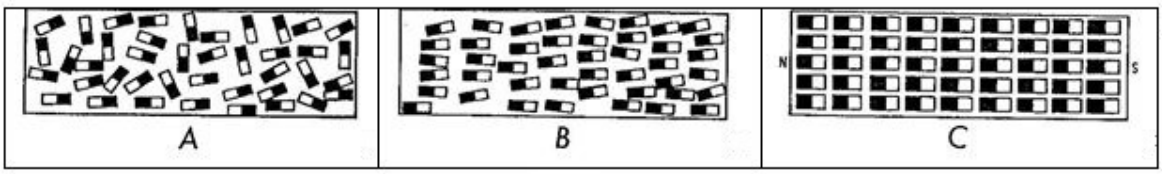


Figure 5–11. Arrangement of domains in a magnetic material.

Residual magnetism

Residual magnetism is what a material retains after the magnetizing force is removed. A residual magnetic field (perpendicular to a previously established residual field) is produced only by application of a magnetic field (in the perpendicular direction) strong enough to rotate the domain 90-degrees. When the preferred orientation of the domains are rotated, the previous residual field no longer exists. For this reason, longitudinal magnetization, strong enough to produce indications of discontinuities in a part that previously had a residual circular magnetic field, reduces the circular residual field to zero. If the magnetizing force is not of sufficient strength to establish the longitudinal field, the strength should be increased.

The following rules are generally applied to residual magnetism:

- The amount of magnetism retained in carbon steel increases with carbon content and hardness. The maximum retention appears to reach about 0.95 percent carbon in fully hardened materials.
- The amount of residual magnetism retained by heat-treated alloy steels is greater than in soft alloy steels.

The amount of residual magnetism retained depends on the size and shape of a part. Size and shape become factors when poles are developed, as in a bar magnet, and are close enough to exert what is known as a demagnetizing effect. The amount of magnetism retained by these types of parts will always be less than the maximum flux density. In general, long slender specimens retain more magnetism than do short specimens with a large cross section when the basic magnetic characteristics of both are approximately equal.

Demagnetization

Any ferromagnetic material subjected to magnetic particle inspection requires demagnetization. When performing magnetic particle inspection of aircraft parts, it is essential to demagnetize them. The inspector should understand the reasons for this step, as well as the problems involved and the available means for solving them. We will learn more about this process later in this unit.

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

One of the simpler methods subjects a part to a continually reversing magnetizing force. At the same time, the force gradually decreases in strength. As the decreasing magnetizing force is applied, first in one and then the opposite direction, the magnetization of the part is decreased. By placing a part within this field and slowly removing it from the field, you can constantly reverse the magnetic field in the part, while steadily decreasing it to zero. Figure 5–12 shows a hysteresis loop of the demagnetization process.

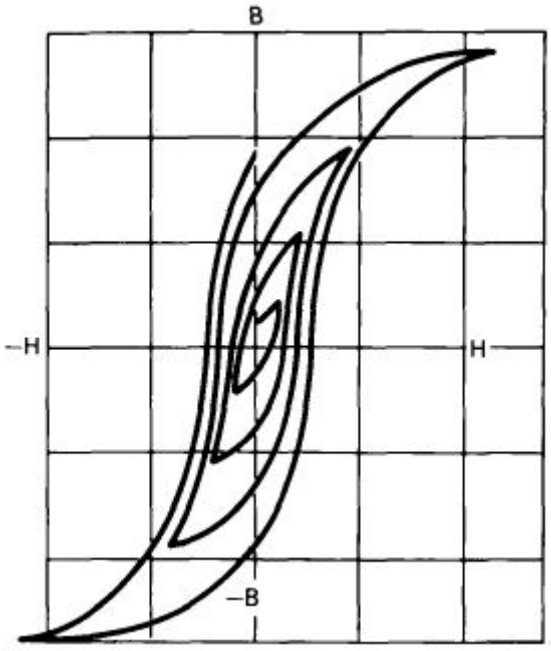


Figure 5–12. Hysteresis loop showing demagnetization.

227. Current and magnetic fields

While there are many different methods of magnetizing metal, some of them are not practical for our use. For example, you can actually partially magnetize steel bars by hammering them on one end. Placing a part parallel to the Earth's magnetic field in a North-South direction has a tendency to induce a limited amount of magnetism in a part. Neither of these methods can ever produce sufficient magnetization for NDI. Although not practical for inspections, knowing how parts can be magnetized is useful. Manufacturers of demagnetizing equipment often suggest that you install the equipment so the parts are oriented in an east-west direction. This enables the Earth's own magnetic field to assist demagnetization.

You will use electric current to magnetize parts for magnetic particle inspection. Either direct current (DC) or alternating current (AC) can be used. Each type has benefits for different applications. Part of your responsibility when establishing an inspection technique, is deciding which type of current will result in the most reliable inspection.

Magnetic fields

The proper orientation of the magnetic field in a part, in relation to the direction of the defect, is a more important factor than the strength of the magnetizing current. For greatest sensitivity, the magnetic lines of force should be close to right angles.

The two basic magnetic fields you will induce into a part include circular magnetism and longitudinal magnetism.These magnetic fields can be created in a part by several different methods. Special techniques of inducing magnetic fields and specific applications of these fields are discussed under each method.

Right-hand rule

Use the “right-hand-rule” when attempting to better understand or even to remember field direction and current flow. The easiest way to demonstrate this rule is to grasp a straight bar in your right hand so your right thumb points in the direction that electrons flow from negative to positive. Notice the direction your fingers curl around the bar while doing this. The direction your fingers point indicate the direction of the magnetic field in the straight bar, as illustrated in figure 5–13.

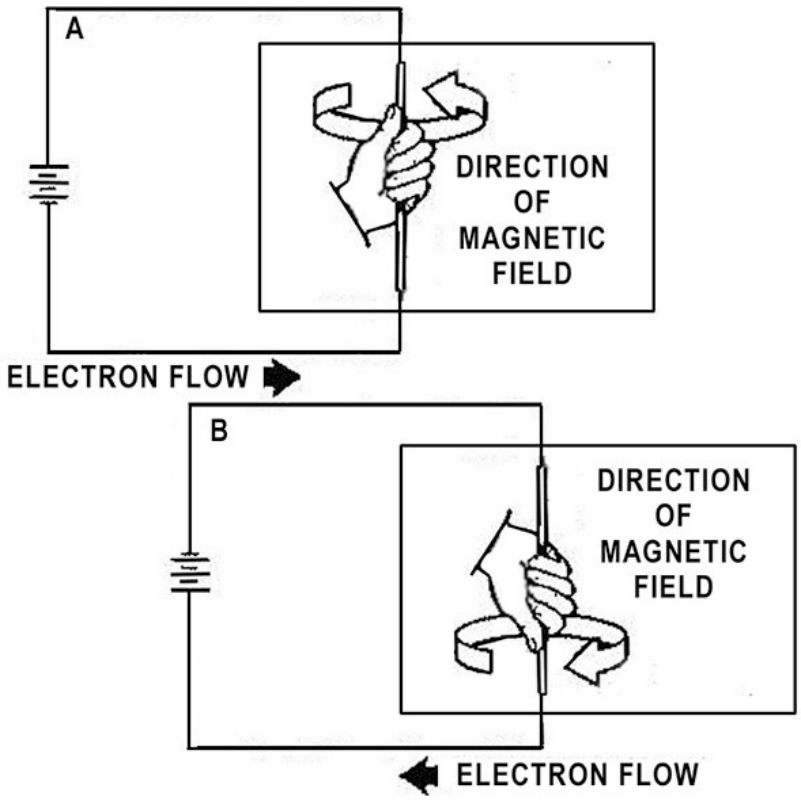


Figure 5–13. Right-hand rule.

If several loops or turns of wire are wound to form a coil, the lines of force will produce a magnetic field similar to the magnetic field of a bar magnet (fig. 5– 14). It makes a North pole at one end of the coil and a South pole at the other end. The magnetic field within the coil and at the poles are stronger than the field produced by a single, or even a few wires. Practically all lines of force, previously around individual wires, now encircle the entire coil. While current is flowing, the coil has the properties of a permanent magnet. If the current in the coil is reversed, the polarity of the coil is also reversed.

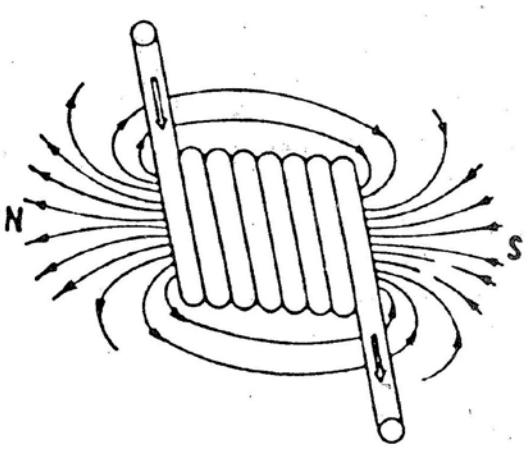


Figure 5–14. Magnetic field around a coil.

Circular field magnetization

Circular field magnetization is used for the detection of radial discontinuities around edges of holes or openings in parts. It is also used for the detection of longitudinal discontinuities, which lie in the same direction as the current flow. This circular field is generated either in a solid or hollow part which may require the use of a central bar conductor (CBC). A circular magnetic field always surrounds a current carrying conductor, such as a wire or a bar (fig. 5–15).

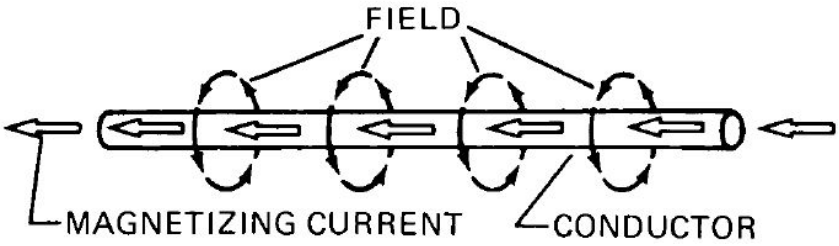


Figure 5–15. Magnetic field surrounding an electrical conductor.

Field orientation and magnitude are based on the direction and amount of current flow. A circular magnetic field is generated in a part whenever an electric current is passed through it or through a CBC. In the case of a cylinder part, a circular field traveling around the inside of the part will be entirely contained within the part and no magnetic poles are produced. Magnetic poles will only be produced under the following circumstances:

- The part is not a cylinder.
- The part is irregularly shaped.
- The path of the current flow is not located on the part's geometric axis.

When using a conventional stationary unit, you clamp the part between contact plates of the head and tailstock. By passing the electric current through the part, you induce circular magnetization.

NOTE: Bad contact between the part and the contact plates when using circular magnetism may cause an electrical arc and may burn the ends of the part.

Using circular magnetization in a part

One method of creating or inducing a circular field within a part with stationary equipment is to clamp the part between two contact plates and pass current through the part as previously stated and

shown in figure 5–16. If a longitudinally aligned crack or discontinuity exists within the part, a leakage field will be established at the site of each crack or discontinuity.

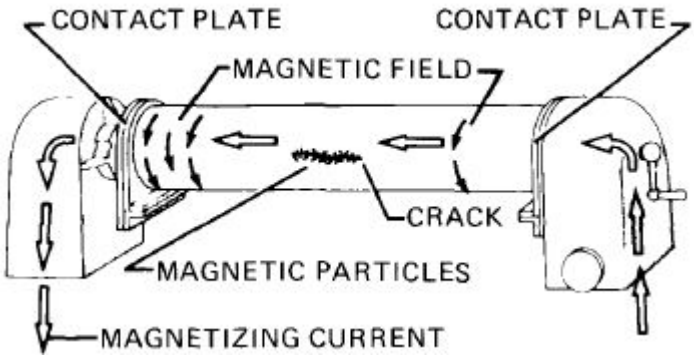


Figure 5–16. Creating a circular magnetic field in a part.

Circular magnetization exists because the lines of force represented by the orientation of magnetic flux within the part are circular in form. Therefore, there are *no poles* in a part circularly magnetized. The magnetic field is contained completely within the part and cannot be detected, except with complex instruments, unless there is a break near the surface forming a leakage field. This leakage then draws particles and forms an indication, as shown in figure 5–17.

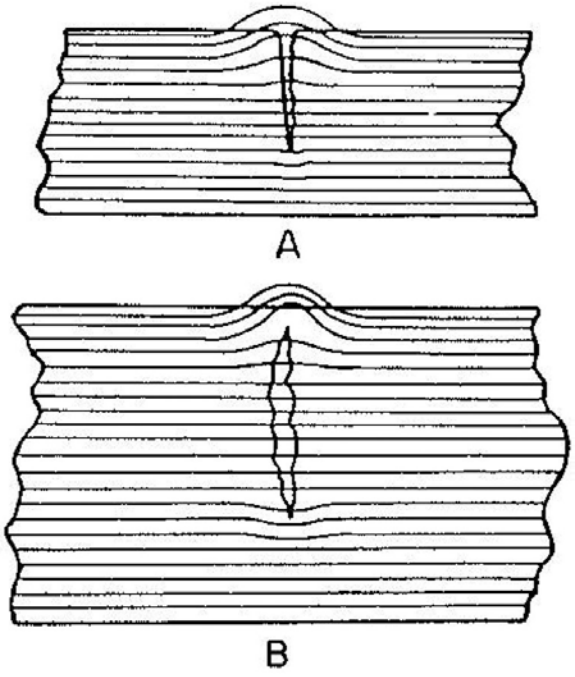


Figure 5–17. Leakage fields of a crack.

Using central conductor bar

CBCs are any conductive material, such as a copper bar or cable, placed in the center of a part under inspection. This technique produces circular magnetization by passing electric current through a conductor that has been placed in an opening, frequently in the center of a part, as shown in figure 5–18. A magnetizing field exists outside a central conductor carrying current, so the walls surrounding a central conductor become magnetized. Since the circular field produced around a central conductor is

at a right angles to the axis of the conductor, the central conductor technique is very useful for the detection of discontinuities that lie in a direction generally parallel with the conductor.

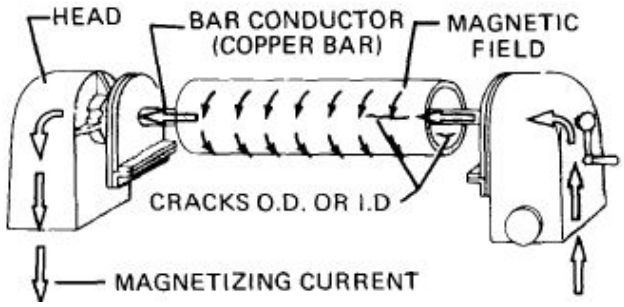


Figure 5–18. Creating a circular magnetic field with a central conductor.

When inspecting hollow parts, it is often important to inspect both the inside and outside surfaces. When such parts are circularly magnetized, the magnetic field on the inside surface is smaller and opposite than what is produced on the outside surface. When current is passed directly through ring-shaped parts, a satisfactory magnetic field is seldom formed on the inside surface of the part. Whenever a part is hollow, or has holes through which a CBC can pass, use this method to induce a circular magnetic field, as shown in figure 5–19.

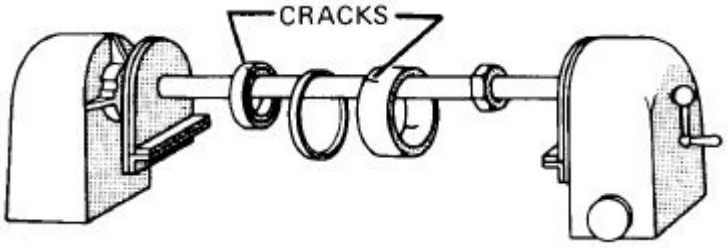


Figure 5–19. Creating a circular magnetic field in ring like parts.

When you inspect a large-diameter ring-shaped part, rest the part on the CBC and magnetize it. The magnetic field concentrates around the area where the part makes contact with the conductor. After inspecting the area, turn the part and repeat the same procedure. When using circular magnetism, the rings outside diameter determine the number of times the part must be turned and shot.

Longitudinal magnetization

If a part is placed inside a coil (fig. 5–20), the magnetic lines of force created by the coil are aligned along the longitudinal axis of the coil. Parts placed in a coil are commonly called a *coil shot*. If the part is ferromagnetic, the high permeability concentrates the lines of flux within the part and induces a strong longitudinal magnetic field. A longitudinal field in a part forms North and South poles within the part.

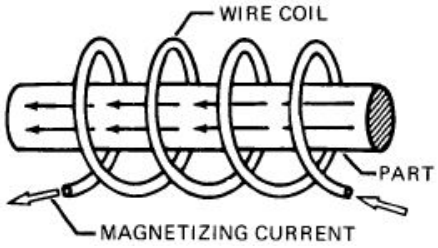


Figure 5–20. Longitudinal magnetic field in a part placed in a coil.

When a transverse discontinuity exists in a part, as in figure 5–21, a magnetic leakage field is formed at the crack location. This attracts magnetic particles, forming an indication of the discontinuity.

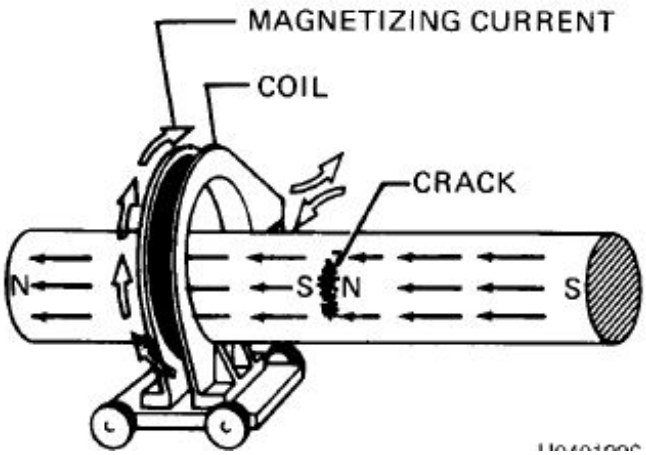


Figure 5–21. Longitudinal field with a crack indication.

A longitudinal magnetic field can also be induced in a part by using a *yoke*. A yoke is a C-shaped piece of magnetic material with a coil that carries the magnetizing current. When ends of the yoke are placed on a part and the coil is energized, the part completes the loop and a longitudinal field is set up between the ends (fig. 5–22). Most portable equipment you will see uses this method of induced longitudinal magnetization.

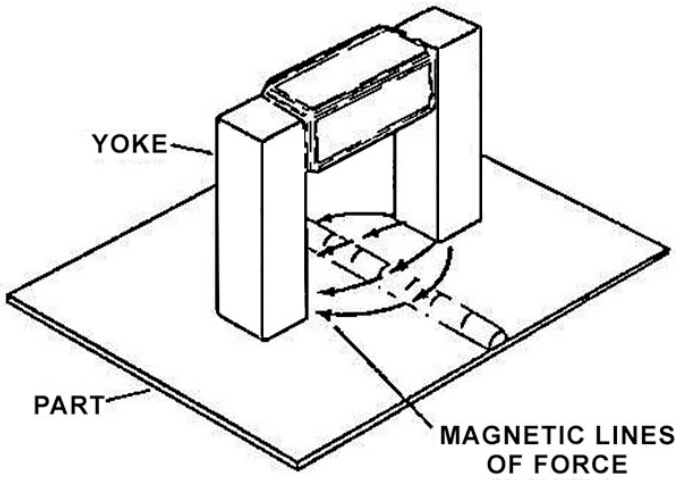


Figure 5–22. Magnetic field created by a yoke.

Currents used to generate magnetic fields

The two types of current used in MPI include DC and AC. Only one type of current is best suited for each type of inspection. AC is preferred for the detection of surface discontinuities. DC, full-wave direct current (FWDC), or half-wave direct current (HWDC) can be used for both surface and subsurface discontinuities. The following table describes different types of AC and DC currents more in depth. Keep in mind as you read the table that the description discusses how AC is recitified in order to obtain DC in the left column.

Type of DC	Description
Pure	Pure DC Is obtained only from storage batteries. It is unlikely that you will encounter battery-powered magnetic particle inspection equipment. The heavy weight of batteries required to produce sufficient magnetic fields makes their use impractical.
Half-wave	Half-wave is obtained by rectifying AC. A rectifier is an electrical device that permits current to flow through it in one direction only. When placed in an electrical circuit and is connected to an AC source, current flows in only one direction through the circuit. If no other alterations are made in the circuit, output is half-wave DC. Half-wave DC is widely used for inspecting welds, castings, and other parts having defects under the surface, particularly when using dry particle application techniques.
Full-wave	Full-wave is also a form of rectified AC. The difference between full-wave and half-wave is that four rectifiers are connected in the circuit, resulting in a doubling of the DC current flow peaks amperages over the same period of time.
Three-phase full-wave	Nearly all of the stationary inspection units you will use have either 220 or 440 volt, three-phase AC power. This power comes to your inspection unit on three separate wires and is much more reliable than a single-phase system. When three-phase AC passes through a full-wave rectifier, it produces three peak DC amperages in the same amount of time as one peak in full-wave systems. Additionally, pulses never drop much below the maximum before the next wave of electricity pushes the amperage back up to the peak. Three-phase, full-wave DC is about as close as you can get to pure DC, but at a much reduced cost.

Notice that the current selector on your stationary, mobile, or portable equipment indicates DC, but does not specify the type of DC supplied. Any one of the three is normally satisfactory whenever the use of DC power is indicated. However, you must refer to the TO for your specific equipment.

Alternating current

AC in magnetic particle inspection is effective only for the detection of surface discontinuities. This is because AC magnetic fields have very shallow penetration, making them impractical for detecting subsurface discontinuities. These types of discontinuities comprise the majority of service-induced defects. Fatigue, overload, and stress corrosion cracks are examples of cracks usually open to the surface.

AC advantages include the rapid reversal of the magnetic fields while current is applied. With dry powder applications, this causes the particles to “dance” on the part surface and helps them to move to any leakage fields. The effect is less pronounced in wet techniques. Another advantage of AC is the peak amperages obtained. To get equivalent magnetizing effects from straight DC, more power and heavier equipment are required. Therefore, AC equipment is usually lower in cost, lighter, and better adapted for portable applications.

The alternating currents used in magnetic particle inspection have low excitation voltages. Current values from stationary equipment range from about 100 to 10,000 amps, depending upon the test part and the magnetization technique.

Direct current

Magnetic fields produced by direct current penetrate deeper into a part than fields produced by alternating current, making the detection of subsurface discontinuities possible. However, direct current is also suitable for finding both surface and subsurface defects and is generally used during wet particle techniques.

For longitudinal magnetization, DC magnetizes the entire part’s cross-section more or less uniformly. For direct contact (circular) magnetization, a straight-line gradient of field strength (from a maximum at the surface to zero at the center) is experienced.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

225. Theory behind basic magnetism

1. What is a force that causes electrons to move through a conductor called?

2. What is the unit of measure for electric current?

3. How are magnetic lines of force aligned?

4. What is magnetic permeability?

5. What type of material is highly retentive?

6. What is a magnetic field current value within an unmagnetized piece of steel?

7. What measurement is one gauss equal to?

8. What do you call the number of lines magnetic force per square centimeter in a plane *perpendicular* to the direction of the magnetic field?

9. What is a coercive force?

10. What is the unit of measure for magnetizing force?

226. Magnetic properties of material

1. What do you call the magnetic field outside of a part resulting from the presence of a discontinuity, or a change in the part's cross-section?

2. What are continuous lines of force in leakage fields called?

3. What are leakage fields created by?

4. What does the strength of a leakage field depend on?

5. What develops when a piece of soft iron is placed in a magnetic field?

6. What two characteristics of a magnetic field make up its intensity?

7. What magnetic theory postulates that groups of atoms in ferromagnetic material are magnetically aligned?

8. When the previous field no longer exists because domains have rotated 90 degrees, what has a part established?

9. What does the amount of residual magnetism retained depend on?

10. What three factors does the demagnetizing technique depend upon?

227. Current and magnetic fields

1. What two basic magnetic fields are induced into parts?

2. What can be used to better understand current flow?

3. What is circular magnetism used for?

4. What always surrounds a current carrying conductor, such as a wire or a bar?

5. What can happen if there is bad contact between a part and the contact plates when using circular magnetism?

6. Which type of magnetism does not produce poles?

7. Where are discontinuities located when using a central conductor?

8. How are hollow parts inspected?

9. How many times are hollow parts turned and shot when using circular magnetism?

10. How are magnetic lines of force aligned when created by a coil?

11. Besides a coil, how else can longitudinal magnetic fields be induced?

12. What are the two types of current used in MPI?

13. Which type of current is used for surface discontinuities?

14. What type of current is obtained from storage batteries?

15. What type of current is about as close as you can get to pure DC but at a much reduced cost?

16. What type of defects are usually open to the surface?

17. What are the current values with AC stationary equipment?

18. What type of current finds both surface and subsurface defects?

5–2. Magnetic Particle Equipment and Hazards

Magnetic particle equipment classifications are based on stationary and portable inspections. Equipment discussed in this section is representative of the various types across the Air Force but may not be identical to the equipment that you will use. Not only will we address the type of equipment, but also the maintenance and hazards associated with the equipment that you may use.

Before operating any equipment, check the current TO for the specific type or model you are to use and follow the directions. Finally, we will discuss the methods for selecting and applying magnetic particles.

228. Types of magnetic particle equipment

In the first portion of this lesson, we provide you with an overview of the different types of equipment you will encounter in your work area. In the second half of this lesson, we outline the operation and maintenance of the different types of magnetic particle equipment discussed in the first half of the lesson. So let’s begin with the discussion of the types of equipment to lay the foundation.

Equipment types

A variety of stationary, bench-type MPI units are available, with many characteristics that fit different testing requirements. Smaller size units are for small parts and are easily transported and handled by hand. Larger units are for heavy parts such as long engine crankshafts, where handling must be by crane. These units are made to deliver AC or DC with various types of current control.

All magnetic inspection equipment falls into one of the following three categories:

1. Stationary.
2. Mobile.
3. Portable.

Stationary equipment

A typical stationary horizontal wet magnetic particle inspection unit has two contact heads (headstock and tailstock). These are used for either direct contact or central conductor, circular magnetization using a copper rod between the heads. Many of the units contain a coil used for longitudinal magnetization. The coil and one contact head are movable on rails while the other contact head is fixed. The unit has a self-contained power supply with all the necessary electrical controls.

Magnetizing currents are usually three-phase full-wave DC or AC, depending upon usage requirements. The units come in several different sizes to accommodate different length parts and various output currents. A full-length tank with pump, agitation and circulation system for wet inspection is located beneath the head and coil mounting rails. A hand hose with nozzle is provided for applying the bath.

Figure 5–23 shows the location of controls and other features of a typical stationary magnetic particle unit. The numbers in parenthesis in the following table correspond to the bold numbers on figure 5–23. For purposes of our discussion, we will assume that the size and design of the part to requires both circular and longitudinal magnetization.

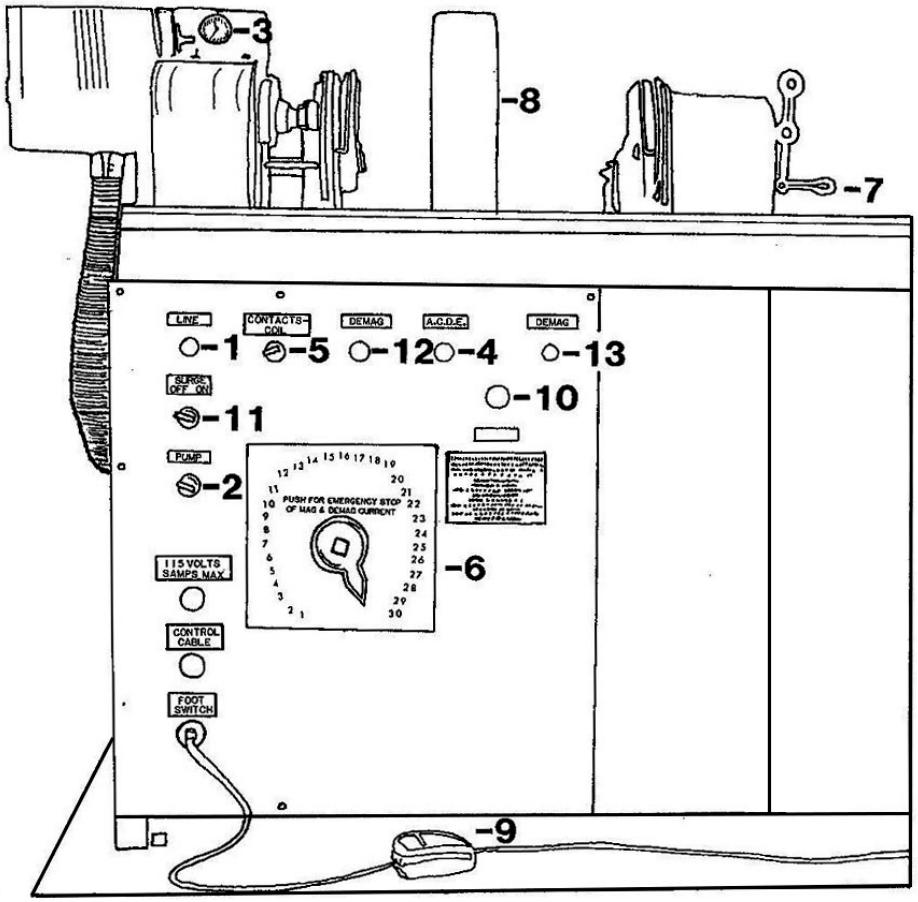


Figure 5–23. Typical stationary magnetic particle unit.

Method	Instructions
Circular magnetization	Energize the equipment using the fuse or breaker box, normally mounted on the wall, and note that the red LINE pilot light (1) will light up when in use. Turn the PUMP switch (2) on and allow the pump to circulate the bath for 30 minutes and check the bath concentration. After bath concentration has been verified as being “within limits,” proceed as follows: 1. Check air pressure at regulator (3) and adjust to 40 psi if required. 2. Use the AC/DC selector (4) to select magnetizing current. 3. Set the contacts-coil switch (5) to CONTACTS position. 4. Use the current control tap switch (6) to select the amount of magnetizing current required for the part you are inspecting by rotating the switch to the proper setting. Proper switch settings are determined by experience and testing. 5. Check air pressure at regulator (3) and adjust to 40 psi if required. 6. Use the AC/DC selector (4) to select magnetizing current. 7. Set the contacts-coil switch (5) to CONTACTS position. 8. Use the current control tap switch (6) to select the amount of magnetizing current required for the part you are inspecting by rotating the switch to the proper setting. Proper switch settings are determined by experience and testing.

Method	Instructions
Circular magnetization (continued)	9. Use the tailstock adjustment handle (7) to move the tailstock along the rails to a position where shelves on the tailstock and headstock can support the part. Place the part in position and lock the tailstock in place. 10. Move the coil (8) along the rails until its base is against either the headstock or tailstock where it will not interfere with the application of magnetic particles. 11. Fully depress and release the foot switch (9) to clamp the part in place. Remember that air pressure moves the headstock, locking the part in place. Use caution and make sure that your hands or fingers are not in the way. 12. Some equipment has a surge feature that will produce a momentary extra high surge of current through the test part (or coil). If required, you may employ the surge feature by placing the surge switch (11) to the ON position. If this position is not needed, place the switch to the OFF position. 13. For residual techniques, depress the magnetizing button (10) and then, using the hand hose, apply magnetic particle bath over the part. For continuous methods, apply the bath and energize the unit at the same time. During the magnetization shot, the current may read on the ammeter (not shown). 14. Depress and release the foot switch to release the part and examine it for indications.
Longitudinal magnetization	After the part has been examined for indications with circular magnetization, longitudinally magnetize and inspect as follows: 1. Set the contacts-coil switch to the COIL position. 2. Reset the current control switch to give proper magnetization in the coil. 3. Properly place the part in the coil. 4. Use residual or continuous methods to apply the bath and energize the part. 5. Examine the part for indications. If the part is longer than the field for your coil, it must be magnetized and inspected in sections no longer than the effective field.
Demagnetizing	If no indications are observed in either inspection, the part may be demagnetized, cleaned, and returned to service. Demagnetization is accomplished by using the following step-down process: 1. The contacts-coil switch should still be in the COIL position from the longitudinal magnetization. If it is not, place the switch in the COIL position. 2. Place the part in the coil and set the current switch slightly above the power used to magnetize the part. 3. Press and hold the DEMAG switch (12) until the demagnetization operation starts. The DEMAG light (13) should glow green. When the cycle is complete, the light will go out to indicate that the part has been demagnetized.
Circular step-down	Circular step-down demagnetization is similar in principle to the method just described, except as follows: 1. Clamp the part between the headstock and tailstock. 2. Place the contacts-coil switch in the CONTACTS position. 3. Press the DEMAG switch. Unless there is a good reason for using this particular demagnetizing method, the longitudinal step-down method or an AC solenoid should be used. Circular step-down tends to heat small parts and may burn large ones at the points of contact because of the high current required. Remember, there is no way to check the effectiveness of the demagnetization when it is done with a circular field.

Mobile equipment

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

Both half-wave DC and AC outputs are included in most mobile units to increase their versatility. Half-wave DC is useful for detecting subsurface discontinuities when the wet method is used with mobile equipment. This equipment is not often used in the Air Force.

Portable equipment

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

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

Portable power pack

Portable power packs are high amp output devices. Examples of this equipment are the Magnaflux P–1500 or DA–1500, which are capable of putting out 1500-amps AC or HWDC fields. These power packs weigh in at 93-pounds and have a duty cycle of two-minutes on and two-minutes off. Field selection is determined by using the appropriate field cable connector. Current output is indefinitely variable from zero to maximum by use of the current control located on the front panel meter. The actual current output is determined by cable size and length.

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

Probes and yokes

Probes and yokes (e.g., Magnaflux DA–200) are versatile, lightweight hand-held devices used for inspection of small parts and localized inspections of large parts. These are easy to use and often provide adequate magnetic particle inspections. They are essentially U-shaped laminated cores of soft iron with a coil wound around the base of the U. Yokes or probes are limited to the detection of surface and near surface discontinuities *only*. They should not be used for deep-seated, subsurface discontinuities due to the limited penetration of the induced magnetic field. Because of their size, they cannot be used with a 100-percent duty cycle. Rather, they are limited essentially to spot-checking and occasional sample testing rather than continuous production testing.

Under optimum operating conditions, the fixed leg yoke has a limited inspection area governed by the distance between and immediately surrounding the legs. The moveable leg yoke can inspect either a

larger area (legs apart) or detect finer discontinuities by concentrating the magnetic field in a smaller area (legs closer together). No electrical current passes through the part.

They also have a duty cycle that will be defined in the operating instructions for the specific yoke. As an example, for the DA–200, duty cycle is two minutes on and two minutes off.

Operating Portable Equipment

The DA–200 contour probe (fig. 5–24) has only three controls. The toggle switch (1) on the back of the unit is used to select AC or pulsed-DC magnetizing current. When the test switch (2) on top of the unit is pressed, it applies the magnetic field. The rheostat on the front of the unit (3) is used to select the DC field strength.

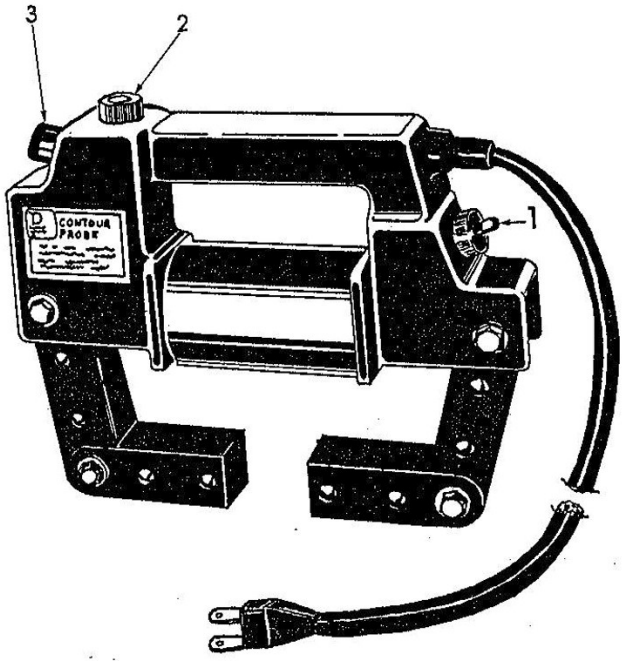


Figure 5–24. DA–200 contour probe.

Operation	Operating Instructions
Inspection	To inspect parts, accomplish the following: 1. Select either AC or DC, depending on the type of defect you expect. 2. Place the pole pieces on the part, with the suspected defects at right angles to a line drawn from one pole piece to the other. 3. Push the test switch and apply the particles. 4. Inspect the part. 5. Turn the probe 90° and repeat the procedure. Release the test switch immediately after application of the particles for continuous methods. *Do not* exceed the duty cycle of the unit. The probe should be operated with a pole piece spacing of five to six inches. However, they may be extended to a maximum of 16 inches, or reduced to their minimum spacing to create a high-density field over a small area.

Operating Portable Equipment	
Demagnetization	You can easily demagnetize small parts that have been residually magnetized by either the AC or the DC method. 1. Place the selector switch in the AC position. 2. Press the test switch to turn on the probe. 3. Pass small parts between the pole pieces and withdraw them to a distance of two feet before releasing the test switch. On larger parts, perform the following: 1. Place the probe in the same position used for magnetizing the part. 2. Turn on the test switch. 3. Lift the probe to a distance of two feet before turning the probe off.

Contact prods and clamps

When non-aircraft parts are too large to fit into a stationary unit, or if only mobile or portable equipment is available, then the part, or areas of the part, can be magnetized using cables and two hand-held prods. The current passes between the two contact prods and creates a circular field.

NOTE: Contact prods are not used on aerospace components or parts.

Contact clamps (fig. 5–25) can be used with cables instead of contact prods, particularly when the parts are relatively small in diameter. They produce circular magnetism by positioning the clamps so it directs the current through the inspection area. Make sure the circular field created is perpendicular to the direction you think cracks may be developing.

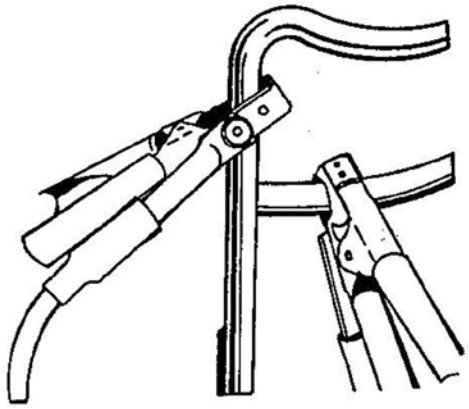


Figure 5–25. Clamps used for circular magnetization.

Field strength measurement devices

Magnetic particle equipment is not just the units that generate magnetic fields, but also devices used for measuring them. The following list provides equipment used for testing/measuring field strength.

- Field indicator.
- Compass indicator.
- Gauss meter/Tesla meter.
- Quantitative Quality Indicator (QQI).

Field indicator

The field indicator is a pocket instrument used to determine the intensity of leakage fields. When measuring the strength of leakage fields, the indicator senses only the field at some distance from the

part. This distance is from the center of the sensing element to the bottom of the indicator when placed on the part's surface. The flux density of the field will be greater than indicated by the field indicator. Figure 5–26 shows a typical field indicator.

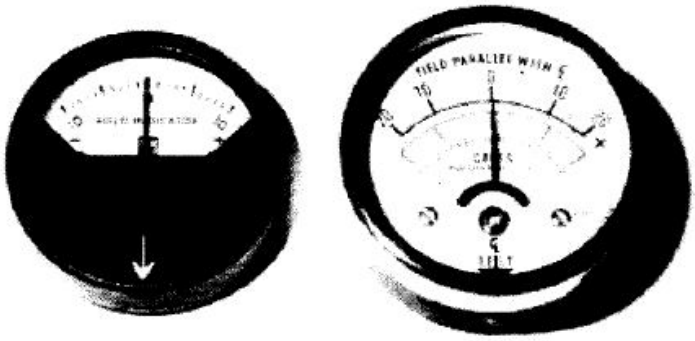


Figure 5–26. Field indicator.

Compass indicator

A compass is sometimes used for indicating the presence of external leakage fields. A compass can be placed upon a nonmagnetic surface and a magnetized part (aligned due east and west) moved slowly toward the east or west side of the compass case. The presence of an external leakage field from the part can cause the compass needle to deviate from its normal North-South alignment. However, demagnetized parts will cause the needle to deviate from its normal position if the compass case is not approached from an easterly or westerly direction.

The theory of operation is very similar to the field indicator since the compass needle is a permanent bar magnet.

Gauss meter

The gauss meter or Tesla meter has interchangeable probes to permit measurement of the magnetic field either parallel or perpendicular to the axis of the probe. Place the probe in the hole or on the surface to a magnetic field (fig. 5–27).

Figure 5–27. Gauss meters.

Quantitative quality indicator

The QQI is a small, thin, metal shim, made of low carbon steel that contains artificial defects for establishing or verifying techniques. Examples of QQIs are illustrated in figure 5–28. By using an etching process that produces very narrow flaws with tightly controlled depths, artificial defects are formed. The thickness of the shim is either 0.002 or 0.004-inch.

The basic QQI shim satisfies most needs because its circular and crossed-bar flaw configuration is suitable for longitudinal and circular fields. The circular flaw is especially useful in balancing multi-directional fields. The miniature shim is designed for small areas on a test part. The QQI, with three

concentric circular flaws with different depths, may be used for more quantitative assessment of a magnetic field and may be useful in covering a curved area of a part, such as a radius.

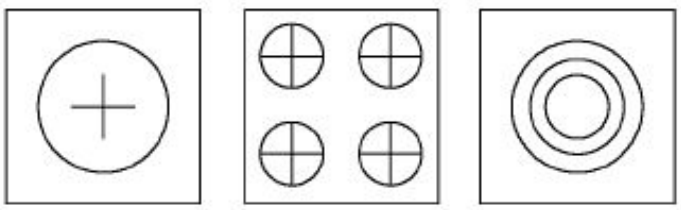


Figure 5–28. Quantitative quality indicator.

229. Magnetic particle equipment maintenance and hazards

When using equipment, it is important to understand different maintenance practices which, if not followed, could lead to hazards within your work area. In this lesson, we will look at both the maintenance required, and precautions which need to be exercised when performing magnetic particle inspection. This includes exposure to oils and electrical current. Please refer to your laboratory supervisor or provisions outlined in Air Force Instruction (AFI) 91–203, *Air Force Consolidated Occupational Safety Instruction*, for lab safety.

Magnetic particle equipment maintenance

Magnetic particle inspection can be a reliable method of inspection only when the equipment you use is properly serviced and maintained. No matter how highly skilled an inspector you may be, the results you obtain from magnetic particle inspection are directly related to the condition of the materials and equipment you use. Maintenance and servicing of magnetic particle units should be accomplished in accordance with the TO for the particular type and model you are using.

Stationary

Maintenance and servicing of a typical stationary inspection unit is discussed in the following table:

Inspection	Instructions
Daily	1. Clean the sump screen and check the bath strength, as we discuss later. 2. Do not allow clutter, such as rags or parts, to accumulate on or around the machine during operation. 3. It is a good idea to wipe down the headstock, tailstock, coil rails, and grill assembly after use or at the end of each day. Accumulations of residue on these parts will eventually lead to nonrelevant indications in the form of fluorescent smudges.
Weekly	1. Remove accumulated moisture from the air filter. 2. Check the oil level in the air cylinder lubricator bowl. If it is below the recommended level, shut off the air supply. After the pressure has dropped to zero, add the required amount of oil.
Monthly	Monthly, or when the bath is changed, clean the hand hose, nozzles, grills, and inspection area with an approved solvent.
Semiannually	Check rectifier plates for accumulations of deposits. If the deposits are excessive, remove the rectifiers and clean them with a mild soap solution and soft brush. **NOTE:** *Do not* use solvents, because they may attack the insulating varnish. Be careful not to scratch the rectifier plates.

Portable equipment

General cleaning techniques suitable for portable electronic equipment will suffice. *Do not* attempt internal repairs on the DA–200. If the seal is broken, it will void the factory warranty. Periodic cleaning is accomplished as required. Do not allow particles to accumulate at the front of the handle and top joint. To improve the flexibility of the pole pieces, apply a few drops of silicone lubricant at each joint. *Do not use oil!*

Magnetic particle safety practices

Safety standards regulate practices used in the NDI laboratory and on the flightline. These standards give specific information for each NDI inspection method and provide general safety information. NDI equipment used in hazardous areas must meet hazardous requirements (e.g., use explosion-proof equipment in an explosive environment). In addition, follow these general safety practices:

- Ensure equipment has a working three-wire, grounded power cord or is a double-insulated design.
- Ensure the continuity of the equipment ground circuit is checked every 90 days and record the results on the equipment inspection record.
- In hazardous locations, use explosion-proof locking fixtures to hold the extension cord to the power cord of equipment.
- Use only one length of extension cord per piece or unit of equipment.
- *Do not* use two-wire extension cords or adapters with three-wire, grounded equipment.
- *Do not* allow the power connections between cords to contact wet surfaces.

Before you use UV-A equipment inside hangers, coordinate such action with the base fire department because ultraviolet sources could activate automatic fire suppression systems and cause damage. You must be careful when using line-powered ultraviolet lights because the operating temperature of the bulbs exceed 750 °F, and you must keep them away from flammable materials and explosive vapors.

Safety standards are provided in the following table for NDI laboratories.

Safety Requirements for NDI labs	
Name	**Precaution**
Floor matting	Use rubber insulating floor matting in front of magnetic particle units. This matting should be rated for the voltage of the equipment being utilized, and it should be replaced when it is worn to one-half. Use only one continuous length of matting and ensure it continues beyond the ends of the equipment for at least 24-inches. If facility construction or safety walkways prevent extension beyond equipment; local safety office may approve deviation in accordance with AFI 91–203 or other service directive.
Wet suspension	Wet magnetic particle materials are normally nontoxic, but continuous exposure to oils used in the wet bath method may cause dermatitis or cracking of the skin. Protective gloves should be worn during this process. If a magnetic particle suspension oil, with a flash point of less than a 200 °F is maintained in a Type II stationary magnetic particle unit, the following minimum safety requirements apply: • Provide an adequate exhaust ventilation system as determined by the local base bioenvironmental engineer. • Maintain a maximum of less than 25 gallons of liquid suspension in the tank. • Cover the liquid suspension by a screened drain board. • Provide a portable fire extinguisher, sufficient in size and/or volume to suppress any fire, which could occur from the magnetic particle suspension oil.

Arcing	Arcing may be caused by poor contact between the headstocks of the stationary magnetic particle unit. This arcing or excessive magnetizing current may injure the eyes. Arcing may also ignite combustible magnetic particle baths (e.g., oil). Ensure good electrical contact between the heads and the inspected part to prevent this. The headstocks should be wetted with the magnetic particle bath prior to energizing to reduce the possibility of arcing. Even the smallest of arc burns can seriously damage a part if it occurs in a highly stressed location.
Headstocks	Many units can be hand cranked to hold the part in place between the headstocks, and then air-controlled pressure is applied with a foot pedal to ensure a solid fit between the stocks. In order to avoid injuring the inspector's hands, extreme care shall be maintained when placing articles between the headstocks of a magnetizing unit.
Black lights	Prolonged direct exposure of hands to the filtered UV-A lamp beam may be harmful. Suitable gloves should be worn during inspections when exposing hands to the main beam for extended periods. • Black lights should not be operated when flammable vapors are present. • Exercise care when using hot black lights so as not to burn hands, arms, face, or other exposed body areas. • When practical, provide brackets or hangers in the area of black light use to permanently mount black lights at the wash station and within the inspection booth. • Replace cracked, chipped, or broken filters before using the light. Injury to eyes and skin will occur if the light from the mercury vapor bulbs is not filtered. UV-A filtering safety glasses, goggles, or face shields will be worn. • Black lights should not be operated when flammable vapors are present.
Aerosol cans	Aerosol cans are a convenient method of packaging a wide variety of materials. Their wide use, both in industry and the home, has led to complacency and mishandling. The containers are gas pressure vessels which, when heated to temperatures above 120 °F, increases the gas pressure resulting in possibly bursting the container. Any combustible material, regardless of flash point, can ignite with explosive force when finely divided and dispersed in air. These aerosol cans containing magnetic particle materials should be stored in a cool dry area, protected from direct sunlight.

NOTE: Magnetic inspection prods are prohibited on aircraft parts and in any hazardous area.

230. Selecting and applying magnetic particles

The magnetic particles you use for inspections are commercial products consisting of iron oxide or minute iron particles. Selection is based on proper size and shape, having good magnetic permeability, and ideal retentivity.

For this lesson, we will focus our attention on the florescent wet method since this is the approved method for Air Force.

Magnetic particles

Both wet and dry are the two types of particles used in magnetic particle inspections. They may be applied to the part being inspected as a suspension in a liquid or as a dry powder.

Wet particles

Wet particles consist of magnetic particles suspended in a liquid. They are applied by either dipping the part in a solution or by using a hose to deliver the solution to the part. The liquid transporting the magnetic particles is called a *vehicle*.

Vehicles

The most commonly used vehicle for a magnetic particle bath is refined, odorless oil or a petroleum distillate. It has a low viscosity, low sulfur content, and a high flash point.

Water can also be used as a vehicle in magnetic particle inspection; you will often see it used in the civilian world because it is cheaper than oil or a petroleum distillate. However, in order to be used for aerospace applications, water vehicles require that many supplements including wetting agents, dispersing agents, rust inhibitors, and antifoam agents be added. This makes it a complex formulation and increases the cost. The downside is that if a water-based vehicle is not used often, the water will evaporate and it is likely to start rusting. For these reasons, *using water as a vehicle for the magnetic particle bath is not recommended for normal operating conditions.*

Fluorescent wet particles

The fluorescent wet method has been used in increasing numbers of inspection applications for many years because of the ease of seeing the faintest indication. These particles are designed for use only in a liquid suspension. They cannot be seen under normal lighting conditions.

These particles are specially treated with a dye that will glow with a highly visible yellow-green color when exposed to a near ultraviolet or black light. Indications produced are easily seen and the fluorescent particles give much stronger indications of small discontinuities than do visible particles.

Dry particles

The dry powder method is primarily used for inspecting welds and castings where the detection of defects lying wholly below the surface is considered important. The dry method particles are provided in powder form in red, black, yellow, and gray colors. Like wet visible particles, the key factors in selecting powder is the one that gives the best contrast and visibility on parts.

NOTE: Dry particles are typically *not* used in the Air Force.

Application methods

Wet or dry particles are applied by using two methods, continuous or residual. These are explained in detail in the following table.

Method	Description
Continuous method	In this method, applying the particles to a part is conducted simultaneously with the magnetizing operation. When using the *wet continuous method* with conventional magnetic particle inspection equipment, the normally recommended procedure is as follows: 1. Flow the bath through the nozzle until the bath has an even mixture. 2. Apply the particles to the entire surface of the part. 3. Apply the magnetic field at least twice in rapid succession. 4. Divert or turn off the particle flow just before the final application of current. **NOTE:** On larger parts where the entire area of interest cannot be flooded at once, additional applications of current are applied as the suspension hose is moved away from each area of application. By following these steps, the magnetic field is induced into the part while the particles are the thickest. This ensures a greater number of particles in the area of a discontinuity, increasing the magnitude of indications. Because of the strong field produced, this method is especially useful in locating subsurface defects and has a greater sensitivity than residual method.

Method	Description
Residual method	In the residual method, the bath or particles are applied to the part *after* the magnetizing current has been turned off. In this method, the remaining residual magnetism attracts the particles to the discontinuity to produce an indication. For this method, follow these steps: 1. Pass the current through the part or coil to magnetize it. 2. Turn off the current. 3. Apply the particles (either wet or dry) to the part. The residual method is only effective on parts having good retentivity. Steel parts having a high carbon content respond favorably to this method because of their high retentivity. The residual method is very efficient for processing large numbers of small parts when they have sufficient retentivity to produce good conditions.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

228. Types of magnetic particle equipment

1. List the three types of magnetic particle inspection equipment.

2. How long do you allow a pump to circulate the bath after you turn on the pump switch?

3. What is the next step after placing a part in a coil during longitudinal magnetization?

4. Why should the circular “step-down” not typically used when demagnetizing parts?

5. What type of equipment has wheels that are mounted on?

6. What is the difference between portable equipment and stationary/mobile equipment?

7. What is the duty cycle of a portable power pack?

8. What portable equipment devices are easily used and often provide adequate magnetic particle inspections?

9. What should probes and yokes not be used for?

10. When using a DA–200, what is the next step after selecting your current?

11. When demagnetizing with portable equipment, what is the last step performed on larger parts?

12. What four different equipment are used to test for field strength?

13. What is a gauss or Tesla meter?

14. What material is a QQI made out of?

229. Magnetic particle equipment maintenance and hazards

1. How often is the sump screen cleaned on a typical stationary inspection unit?

2. How often is the oil level in the air cylinder lubricator bowl checked?

3. How do you improve the flexibility of pole pieces of portable equipment?

4. How often is the continuity of the equipment ground circuit checked?

5. What should you do before using UV-A equipment inside hangers?

6. How long should rubber matting extend beyond the ends of your equipment?

7. What is the maximum requirement of a liquid suspension that should be in your tank?

8. What should be worn when working with a UV-A lamp?

9. How should aerosol cans containing magnetic particle materials be stored?

230. Selecting and applying magnetic particles

1. What is the selection of magnetic particles based on?

2. What are the two types of particles used in MPI?

3. Describe the most commonly used vehicle used in magnetic particle bath.

4. What is not recommended for normal operating conditions as a vehicle for the magnetic particle bath?

5. What type of particles cannot be seen under normal lighting conditions?

6. What is primarily used for inspecting welds and castings?

7. What application method is conducted simultaneously with the magnetizing operation?

8. What application method is only effective on parts with good retentivity?

5–3. Magnetic Particle Inspection Process

Many factors affect the reliability of a magnetic particle inspection. These include such things as the type of particles used, type and level of magnetizing current, and magnetic field used. Information in this section will help you to select and correctly apply the right materials and equipment for achieving the best possible inspection.

231. Inspection preparation

Before performing an inspection, just like in penetrant application, you must first prepare your part. If your part is not correctly disassembled, cleaned, and prepared, it could hinder your inspection by hiding actual defects. In this lesson, you will learn the correct way to prepare your part for MPI.

Part disassembly

Disassembly eases accessibility to most if not all surfaces, thus permitting a more thorough inspection. If the critical area of an assembly is completely accessible for inspection without any

disassembly, and if the inspection part can be removed, then it is acceptable to inspect those areas or parts in place without disassembly.

Example: Steel propeller blades may be inspected in the blade area while they are in place on the aircraft; however, to inspect the shank area, which is concealed by the hub, it is necessary to disassemble.

Check all technical data to ensure actual defect location; this will aid in locating potentially missed inspection areas. Some parts require entire areas to be inspected and require disassembly.

Pre-cleaning

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

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

Preparation of part

The removal of surface oil and grease is very important when preparing a part prior to wet fluorescent magnetic particle inspection. Oil or grease can harm aqueous inspection baths in several ways. Either their presence on the test surface can prevent the bath from wetting or covering the entire surface or it can cause the bath to peel off the surface, stripping any indications. Most petroleum distillates, lubricating oils, and grease fluoresce, making your inspection difficult if not cleaned properly.

Oil bath will dissolve oil or grease from parts, but this builds up the viscosity of the bath and shortens its useful life. Nonferromagnetic coatings, both nonmetallic (e.g. paint) and metallic (e.g. chrome), if over 0.003-inch thick, may have to be stripped.

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

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

Determining technique

The choice of technique for a particular magnetic particle inspection depends upon the following items:

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

232. Current values and surface conditions

In this lesson, we cover the following three areas vitally important to your inspection techniques: current values, surface conditions affecting indications, and recording particle indications.

Each of these areas affects the quality of results you get from a particular inspection technique.

Current values

To produce the best indication from a discontinuity, you must have a magnetic field of the correct intensity. The intensity of the magnetic field is determined by the amount of current you use. The

minimum amount of current necessary to produce a readable indication at a discontinuity in a part is called the *threshold value* of current for the part.

The desirable strength of a magnetic field falls between the threshold value and a point where the field starts to produce nonrelevant indications. All parts should be magnetized to fall within this area for reliable inspection. This desirable area is obtained by application of the correct amount of current.

The field strength needs to be high enough to reveal all significant discontinuities, but not so strong that it masks small discontinuities. Using too strong a magnetic field may not only mask relevant defects, but will also produce strong leakage fields at projections, offsets, corners, and angles in the part tested. This could produce excessive particle accumulations so large that they require special cleaning operations after demagnetization.

NOTE: Parts magnetized for inspection, which fall *below* the threshold value, can be magnetized again to produce a stronger magnetic field. Parts magnetized *above* the correct current values must be demagnetized before the correct current value can be obtained.

Current amperage for direct contact

A problem arises when deciding what current to use for a given part, particularly when the part has a complicated shape. A “rule-of-thumb” suggests currents from 300 to 800 amperes per inch (A/in) of the part diameter, when the part is reasonably uniform and cylindrical in shape, may be used. Except for some special alloys, the use of current values in the upper half of this range will result in excessively high field strength, thus impeding the detection of discontinuities.

Generally, the diameter of the part should be taken as the largest distance between any two points on the outside circumference of the part. However, as a starting point, the lower limit of the “rule-of-thumb” should be used as the initial magnetization current level. From this point, either use a gauss meter or shim indicators to find the correct current level.

Current amperage for central conductor

Induction current requirements using a central conductor will depend upon the part’s size and the diameter of the opening through which the conductor is located. In the case of a centrally-located conductor, suggested currents from a “rule of thumb” may range from 100 A/in of the hole diameter, to as much as 1000 A/in of the hole diameter, depending upon part material and the nature of the suspected discontinuities. Keep in mind the magnetizing field strength around a central conductor decreases with distance away from the conductor. The strongest flux field is present at the inner surface of the hole through which the central conductor passes.

Current values of longitudinal magnetization

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

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

The smaller the L/D ratio, for any given coil and current amperage, the lower will be the magnetic flux density in the part, and the weaker will be the leakage fields over discontinuities. In other words, the smaller the L/D ratio, the greater the coil current amperage must be to produce the same flux density or field strength in the part.

Coil amperages become impracticably large for L/D ratios of two or less. If L/D is less than two, pole piece may be placed on one or both ends to effectively increase the L/D to two or greater. Long parts, with L/D ratios greater than 15, should receive multiple inspections along the length of a part. The most effective magnetic field in a part extends about six to nine inches on each side of a coil.

It is critical to determine the relationship between the *cross-sectional area* of the part and the cross-sectional area of the coil. This relationship will determine whether the part can be inspected within a coil of a given diameter by laying the part in the bottom or next to the side of the coil wall, or by centering the part in the coil, and which formula will be used for estimating the amperage required.

If the cross-sectional area of the part is *less than* one-tenth the cross-sectional area of the coil, it can be magnetized on the coil bottom. If the cross-sectional area of the part is *greater* than one-tenth the cross-sectional area of the coil, it must be centered.

When the part is centered in the coil, a formula called *high fill factor* should be used for estimating the required amperage (see TO 33B–1–1).

EXAMPLE: You have equipment with a 12-inch coil. The cross-sectional area is then 113 square inches. One-tenth of 113 is 11.3. Therefore, any part with a cross-sectional area equal to or less than 11.3 square inches can be magnetized in the bottom of the coil. Anything greater must be centered.

This is shown in the following table. The cross-sectional area for the part and coil are determined as shown in the following equation:

$$A = \Pi r^2.$$

Where: A = cross-sectional Area.
r = radius (1/2 of the diameter).
π = 3.1416 (Pi).

The diameter of the part should be taken as the largest distance between any two points on the outside circumference of the part.

Current Values for a Longitudinal Magnetizing Current	
Parts Lying in Bottom of Coil	For parts having a cross-sectional area less than one-tenth the coil, use the following formula: $I = \frac{KD}{NL}.$ Where: I = Current through the coil (amps). K = 45,000 (a constant, *ampere-turns*). L = Length of the part (inches). D = Diameter of the part (inches). N = Number of turns in coil.
Parts Centered in Coil	For parts with a cross-sectional area greater than one-tenth and less than one-half the cross-sectional area of the coil, determining the current when the part is centered in the coil uses the following formula: $I = \frac{KR}{N(6(L/D)-5}.$ Where: I = Current through the coil (amps). K = 43,000 (a constant, *ampere-turns*). R = Radius of the coil (inches). N = Number of coil turns. L = Length of the part (inches). D = Diameter of the part (inches).
NOTE: See 33B–1–1 chapter 3 for formulas for hollow parts.	

Current values of portable equipment

With portable equipment, wrapping a cable around the part usually creates the longitudinal field. When a coil is used, the effective field it creates is determined by the product of the number of amps and the number of turns in the coil. For example, a current of 1,000 amps through a four-turn coil creates a magnetizing force of 4,000 ampere-turns (1,000 amps multiplied by four turns). Theoretically, the more turns of cable or in a coil, the stronger the field. Actually, there is a limit to how many turns will increase the flux density. Between three and five turns is generally the best number.

233. Inspection process

In this lesson, we discuss the general procedures for step-by-step inspections using circular and longitudinal magnetism with stationary and portable inspection methods. These procedures are general setup and inspection requirements for magnetic particle and should not be used as actual inspection guidance. Please refer to TO 33B–1–2 for inspection criteria.

General procedures

After a part has been properly cleaned, determine the correct current value for circular magnetization. When a part has variable diameters, you should apply magnetizing current and inspect the smallest diameter first.

NOTE: If the largest diameter is shot first, the small diameter will be over-magnetized and cause masking of the possible defects.

The type of current for magnetizing depends upon the nature of the parts to be inspected and the type of defects that are to be located. In most cases, any type of current may be used for inspection; however, certain applications may specify AC or DC.

Magnetic particles may be applied by either the continuous method or the residual method, depending upon the material’s retentivity. After you apply the particles, inspect the part for longitudinal discontinuities. If no defects are found, the part is then longitudinally magnetized and inspected for transverse discontinuities. If current values are equal to, or higher than, the current values of the circular inspection, the part does not need to be demagnetized before a longitudinal field is induced. When the current of the circular magnetization is greater than the current you will use for longitudinal magnetization, you must demagnetize the part before applying the longitudinal magnetization.

NOTE: When you use both circular and longitudinal fields during an inspection, always use longitudinal last.

It is extremely hard to detect a circular field contained in a part, but easy to detect a longitudinal field with a field indicator. If you use longitudinal magnetism last, you will be able to determine when you have successfully demagnetized the part. If no defect is found, demagnetize the part, clean off the inspection residue, and return to service. Procedures for demagnetizing will be explained later.

Circular magnetization technique

This technique produces circular magnetization by passing electric current through the part itself as previously discussed. Direct contact is applied to parts by placing them directly between the headstock and tailstock. The following table explains this process.

Using Direct Contact Technique	
Step	**Description**
a	For parts with more than one current level required for circular magnetization, amps shall be applied lowest to highest.
b	Place a CBC between the headstock and tailstock. Lock down the tailstock.

Using Direct Contact Technique	
Step	**Description**
c	Pour or spray the bath vehicle where the bar and contact pads meet.
d	Fully depress the foot switch to clamp the CBC firmly in place.
e	Select the type of current, AC or DC. Some units will have an Energize Master switch that needs to be pulled out to the ON position.
f	Set the amperage to the approximate setting required for the test part.
g	Initiate the contact shot. Note the amps indicated on the ammeter. Adjust the amp control to achieve the required output.
h	Initiate the contact shot again and verify the amps indicated on the ammeter meets the setting requirements.
i	Fully depress the foot switch to release the CBC, and remove.
j	Place the part between the stocks. Adjust the tailstocks to accommodate the test part and lock it down.
k	Pour or spray the bath vehicle where the part and contact pads meet.
l	Fully depress the foot switch to clamp the part firmly in place.
m	Check the equipment setting to ensure correct configuration.
n	Circularly magnetize the part using the wet continuous method.
o	Inspect and evaluate indications under a black light.

Circular magnetism induced with a central bar

An induced circular magnetic field is an excellent procedure to inspect the inside diameter of ring-shaped or cylindrical test parts. The effective field strength decreases the further it extends from the CBC. If the inside and outside surfaces of the test part must be inspected, a central bar with DC current will provide the most effective inspection. A central bar with AC shall be used when *only* the inside surface requires inspection.

To perform this technique, use the preceding step-by-step process (contact technique), and replace step j with the following:

> *Step j:* place the CBC through the part and insert the CBC into the stocks. Adjust the tailstocks to accommodate the test part and CBC and lock down.

Longitudinal magnetization technique

Longitudinal magnetization should be performed after circular magnetization, unless otherwise specified in a part specific procedure. The following table shows a step-by-step process of this technique.

Using Longitudinal Magnetization Technique	
Step	**Description**
a	For parts with more than one current level required, amps shall be applied lowest to highest.
b	Unlock and roll back the tailstock. Lock the tailstock down when it has cleared the area needed to perform the inspection.
c	Unlock and position the coil so that the inspector has easy access to both sides of the coil and has room to position the test part as required. Lock down the coil.
d	Set the appropriate type of current (AC/DC). Some units will have an energize master switch that needs to be pulled out to the ON position.

Using Longitudinal Magnetization Technique	
Step	**Description**
e	Adjust the magnetic inspection unit to the required amperage. This adjustment is made with the coil empty. Energize the unit to ensure the correct amperage setting.
f	Place the part on the bottom or center of the coil, based off the cross-sectional area.
g	Parts shall be magnetized and inspected in length increments equivalent to the diameter of the coil, not to exceed 18-inches. A 3-inch overlap in coverage is required.
h	Use ferromagnetic steel pole pieces or additional parts placed at the ends of the part if necessary to establish a part length to diameter ratio of at least 2.
i	Process the part using the wet continuous method.
j	Inspect and evaluate indications under a black light.
k	If necessary, rotate the part and repeat the process to examine areas around the circumference of the part more effectively.

Recording magnetic particle indications

The inclusion of some visible record of the indication on a record or report makes your inspection much more complete. Visual records of indications may consist of a sketch of the part showing the location and extent of the indication. Other types of visual records may consist of photographing the indication, preserving the actual indication on the part, or transferring the indication to a page in a record or report. These last three methods are discussed in the following paragraphs.

Photographing

When photographing indications, show enough to make it possible to recognize both the part and the position of the indication. Taking photographs of fluorescent indications calls for use of special photographic techniques (fig. 5–29).

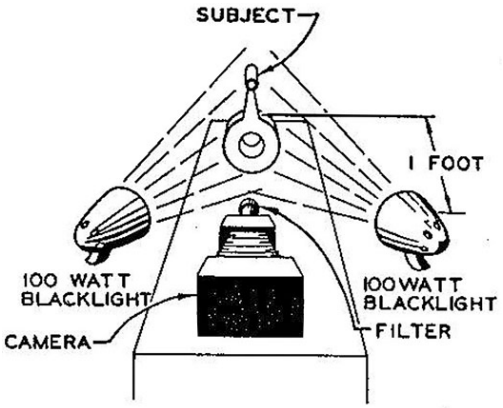


Figure 5–29. Setup for photographing a fluorescent indication.

Set up fluorescent photography in a darkened room, as shown in figure 5–29. A light-colored, nonfluorescent background is often desirable because it allows the outline of the part to show against it in silhouette. A number 2E filter over the lens of the camera is essential to filter out the black light and to allow the emitted light from the indication to pass through and produce a more natural photo. See TO 33B–1–1 for more detailed information on photographing fluorescent indications.

Preserving on the part

If the part itself can be retained for a record, the indication should be preserved on the part so it can be handled and examined without smudging or smearing the indication.

One method of fixing the indication on the part is by using clear lacquer. Before using this method, however, you must make certain that the part is completely dry. If the wet method produced the indication, allow the oil vehicle to evaporate. Heating the part can accelerate normal evaporation. It is usually desirable to thin out the clear lacquer by adding lacquer thinner. Then spray or flow-on the lacquer, since brushing would smear the indication.

Transferring with transparent tape

When using this method, you lift the particles forming the indication from the part with transparent pressure-sensitive tape and then place the tape on stiff white paper. The procedure for taking tape transfers is simple, and can be accomplished quickly and accurately with little practice. When tape transfer of an indication is taken, it is customary to sketch the part and locate the position of the preserved indication on the sketch. This method is most effective with visible particles.

Tape transfer can be taken of fluorescent particle indications, but there are some disadvantages to using the process. Such preserved indications must usually be viewed under black light to properly interpret them, since the number of particles in the suspension is much less than when using visible particles. Some transparent tape will fluoresce under black light and may mask the fluorescence of the indications.

234. Interpreting indications

After an indication is produced on a part, it is necessary to interpret it. Interpretation is the determination of what caused an indication to show. Knowledge of metal processing is often invaluable in identifying the cause of an indication.

The correct evaluation of discontinuities is extremely important and is sometimes difficult to make from only observing the indications. The principal distinguishing features of indications are the shape, buildup, width, and sharpness of the outline. In general, these characteristics are more valuable in helping you distinguish between the types of discontinuities than they are in helping you determine their severity. However, you should always include careful observation of the magnetic particle pattern in a complete evaluation of the significance of an indicated discontinuity.

Discontinuity groups

By this point in your studies, you should know the difference between a discontinuity and a defect. As a brief review, notice the following:

- *Discontinuity* is an interruption in the normal physical structure or configuration of a part.
- *Defect* is a discontinuity that interferes with the usefulness of a part.

Discontinuities in magnetic particle inspections fall into two groups—surface and subsurface, described in the following table.

Type	Description
Surface	By far the most important discontinuities you will encounter are those found on the surface. They are caused by the most dangerous defects. Indications caused by discontinuities at the surface of a part have particles usually held tightly to the surface by a relatively strong magnetic leakage field. In surface cracks, the line of particles is sharp and well defined with a noticeable buildup. This buildup consists of a slight mound or pile of particles and, on deep surface cracks, is sometimes high enough above the surface of the part to cast a shadow. If such an indication is wiped off, the discontinuity can usually be seen.
Subsurface	Indications caused by discontinuities below the surface are broad, fuzzy-looking accumulations of particles rather than sharp well-defined ones.

The difference in appearance of the indications for surface and subsurface discontinuities in a weld is shown in figure 5–30. Notice the sharpness and definition of the line of magnetic particles in figure 5–30, view A. The pattern in figure 5–30, view B, is much broader and is typical of indications formed over subsurface discontinuities. Leakage fields set up by subsurface discontinuities grow weaker as the depth of the discontinuity below the surface increases. In other words, this type of defect is held less tightly to the surface by a weaker leakage field.

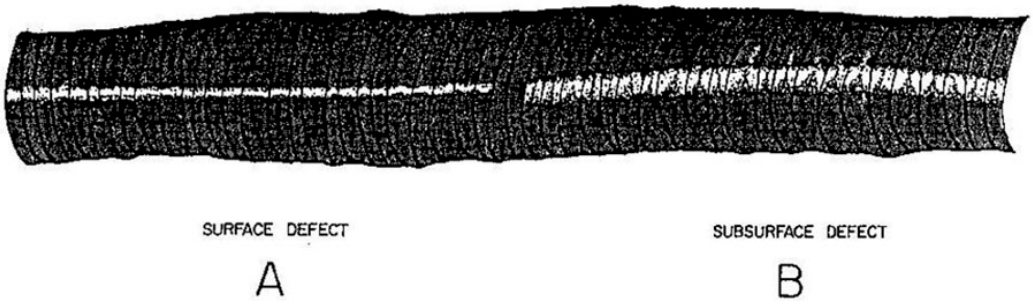


Figure 5–30. Surface and subsurface indications in a weld.

Relevant indications

Particle accumulation has well defined edges and a noticeable ‘‘buildup’’ of particles. Discontinuities are best detected when they are perpendicular to the magnetic field. Discontinuities at an angle of 15° to the flux show only faint indications. However, they are likely to exist at any angle to the major axis of the part. To obtain the most favorable direction of flux for any possible direction of discontinuity, you develop flux in directions both parallel and perpendicular to the major axis of the part. This is why we use two separate magnetizing and inspection operations.

Figure 5–31 shows you how a defect orientation affects the indications produced by circular fields while figure 5–32 shows you orientation affects in a longitudinal field.

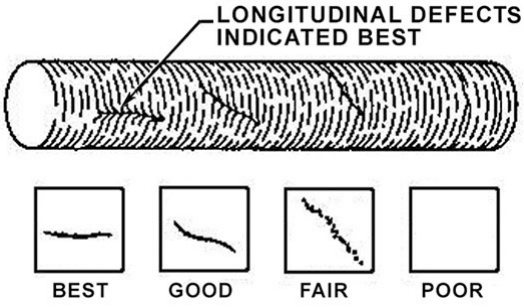


Figure 5–31. Cracks oriented at different angles in a circular magnetic field.

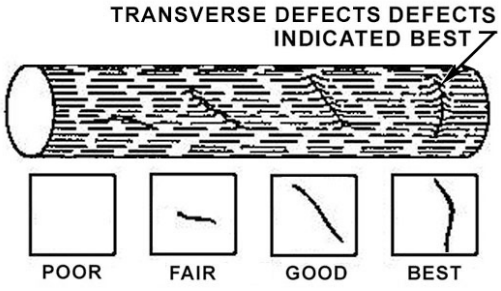


Figure 5–32. Cracks oriented at different angles in a longitudinal magnetic field.

When you magnetize a part for inspection, defects show up best when their longest dimension is in the same direction as the magnetizing current-flow.

Service cracks

The objective of magnetic particle testing is to locate and eliminate discontinuities that happened during fabrication and put parts back into service free of defects. However, even when this is accomplished, failures in service still occur as a result of cracking caused by service conditions. The following are the three service cracks: fatigue cracks, stress-corrosion cracks, and overstressing.

The following table describes each type of service crack.

Types of Service Cracks	
Type	**Description**
Fatigue cracks	Fatigue stress will eventually cause cracks, and finally fracture. Fatigue cracks are shown in figure 5–33.  **Figure 5–33. Indication of a typical fatigue crack.**
Stress-corrosion cracks	Parts under either residual or applied tensile stress and exposed to a corrosive environment may develop stress-corrosion cracking. The primary role of corrosion in this cracking mode is to produce hydrogen. The hydrogen migrates to the tip of a stress-corrosion crack where its presence increases the stresses at the tip, thus driving the crack even deeper. When corrosion is added to a fatigue-producing service condition, it is called *corrosion fatigue*.
Overstressing	Parts stressed beyond the level for which they were designed can crack or break. Such overstressing may occur as the result of an accident, or a part may become overloaded due to some unusual or emergency condition not anticipated by the designer, or a part may be loaded beyond its strength because of the failure of some related member of the structure. After complete failure has occurred, magnetic particle testing obviously has no application with regard to the fractured part. However, other parts of the assembly, which may appear undamaged, could have been overstressed during the accident.

Nonrelevant indications

It is possible to magnetize parts of certain shapes in such a way that magnetic leakage fields are created even though there are no discontinuities in the metal at that point. Such indications are sometimes called *false indications*. They should be called “nonrelevant indications” since they are actually caused by distortion of the magnetic field. They are true indications, but since there is no interruption of the material, they do not affect the usefulness of the part. It is important for the inspector to know how and why these nonrelevant indications are formed and where they can occur. The following are the six classes of nonrelevant indications:

1. Magnetic writing.
2. Longitudinal magnetization.
3. Cold working.
4. Hard or soft spots.
5. High temperature exposure.
6. Abrupt changes.

It may first appear to the inspector that some types of nonrelevant indications discussed and illustrated in the preceding material would be difficult to recognize and interpret. For example, the nonrelevant indications may look like indications of subsurface discontinuities. There are several characteristics of nonrelevant indications. On all similar parts, given the same magnetizing technique, the indications will occur in the same location and will have identical patterns. This condition is not usually encountered when dealing with real subsurface defects.

- The indications are usually uniform in direction and size.
- The indications are usually ‘fuzzy’ rather than sharp and well defined.
- Nonrelevant indications can always be related to some feature of construction or cross section, which accounts for the leakage field creating the indication.

Magnetic writing

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

Longitudinal magnetization

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

Cold working

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

Hard or soft spots

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

High temperature exposure

Heat-treating a part consists of heating it to a high temperature and then cooling it under controlled conditions. The cooling may be relatively rapid or it may decrease the hardness or the grain size of the metal by varying the temperature and the rate of cooling. On a cold chisel, the point is hardened to cut better and to hold an edge. The head of the chisel, which is the end struck by the hammer, is kept softer than the cutting edge so it won't shatter and break. The edge of the hardened zone frequently creates a leakage field when the chisel is inspected with magnetic particle inspection.

Abrupt changes of section

Where there are abrupt changes in section (e.g., thickness of a magnetized part), the magnetic field may be said to expand from the smaller section to the larger. Frequently, this creates local poles due to magnetic field leakage or distortion. If a part, as shown in figure 5–34, is magnetized in a coil, poles are setup at each end and some leakage occurs at A and B. In addition, the change of section at C is quite abrupt and there may be a leakage across this corner as shown. These leakage fields will attract magnetic particles, thereby creating an indication. The indications formed at A and B are usually very easily interpreted; consequently, an indication at C may be more difficult to recognize as being nonrelevant. If the indication is continuous around the shaft, it should be suspected as being caused by the shape of the part rather than by a discontinuity. The nonrelevant indication at C will usually be "fuzzy" like a subsurface defect. If there is a crack or discontinuity in that area, it will usually produce a sharper indication and it probably will not run completely around the part.

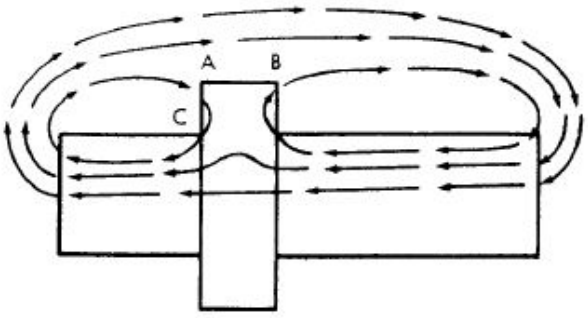


Figure 5–34. Pole changes by abrupt changes of a part.

235. Demagnetizing parts and post-cleaning

Remember our demagnetizing theory in the beginning of the unit. Figure 5–35 shows a comparison of the decreasing, reversing magnetizing force and the resulting hysteresis loop. Notice that the loop is not closed and it traces the same general pattern, while continually decreasing in size.

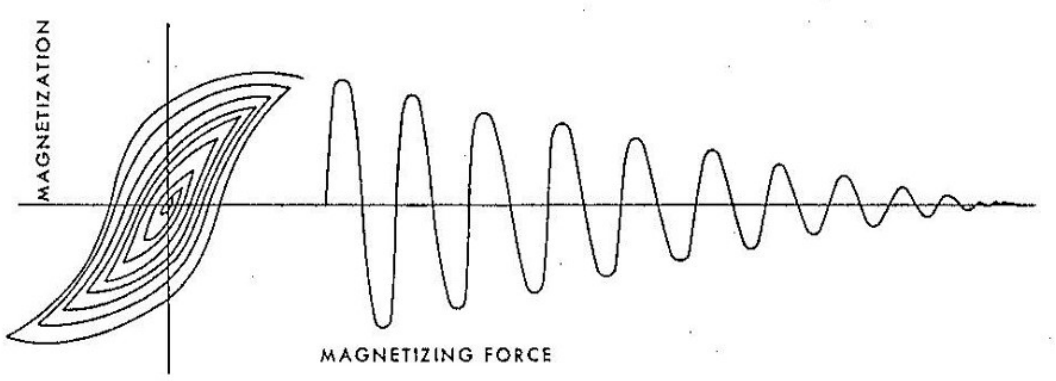


Figure 5–35. Hysteresis loops produced during demagnetization.

The need for demagnetizing parts

When performing magnetic particle inspections on aircraft parts, it is essential to demagnetize them. We do this to prevent attracting filings, grindings, chips, or other abrasive materials to the part. Such accumulations may cause scratching of bearings or wear in other parts. Parts are also demagnetized to prevent excessive magnetic flux from affecting the aircraft instrumentation.

Alternating and direct currents are used in demagnetizing aircraft parts after magnetic particle inspection. Although direct current can be used for demagnetization, alternating current demagnetization has been found to be more convenient. Since alternating current does not penetrate very deeply below the surface of magnetic materials, some parts may be difficult to demagnetize completely using alternating current.

Direct current can be used to demagnetize if there is provision for current decay or reduction and a means for reversing the direction of the current. Demagnetization accomplished in this manner with direct current is the most complete and effective.

Direct contact demagnetization

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

To demagnetize a part by direct contact, clamp the part between the contact heads. Demagnetizing currents should start from the same or slightly higher amps than were used for magnetizing. If longitudinal demagnetization is desired, the coil is then placed in position with the part still clamped in the heads.

NOTE: Care should be taken not to demagnetize very small parts between the heads because the high initial current can overheat the parts.

AC demagnetization with stationary equipment

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

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

Step-down feature is completed in about 30-seconds, one-second per step. The one-second at each step allows time for the field in the part to reach a steady state, at which time induced currents become zero. The step-down feature permits the demagnetization of parts without removal from the magnetizing equipment. This procedure is more effective on long, circularly magnetized parts than the separate coil method.

Using the stationary equipment, demagnetize the test part using AC as follows:

AC Demagnetization	
Step	**Description**
a	Select AC, Coil, and Demag (demagnetizing) operation on the unit's selector switches.
b	Turn the current control clockwise to 3/4 of scale or 10% greater than the magnetizing current used on the test part.
c	Initiate shot. During the AC Demag cycle, the current is ramped down to zero in approximately five to 10 seconds.
d	Measure the field at the ends of the test part. Residual field should be two (2) increments or less on field indicators or three (3) gauss or less using a gauss meter.

DC demagnetization with stationary equipment

Demagnetizing by the direct current reversing step-down feature is essentially identical in principle to the AC method, but is more effective on parts with heavy cross sections. Modern stationary DC magnetizing equipment usually incorporates this capability. This method of demagnetizing is especially effective in removing circular fields when the current is passed through the part, and it works well with a central conductor.

Demagnetize the test part using DC as follows:

DC Demagnetization	
Step	**Description**
a	Select DC, Coil, and Demag operation on the unit's selector switches.
b	Turn the current control clockwise to 3/4 of scale or 10% greater than the magnetizing current used on the test part.
c	Initiate shot. Output current will pulse at reversing polarities and decay to zero during its 25 to 30 second cycle.
d	Using a field indicator measure the ends of the test part. Residual field should be two (2) increments or less on field indicators or three (3) gauss or less using a gauss meter.

Demagnetization coil procedure

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

To use a demagnetizing coil, such as illustrated in figure 5–36, the part is placed in the coil and the current turned on. While the current remains on, the part should be slowly withdrawn from the yoke a distance of four to five feet before the current is shut off. The axis of the part should be parallel to the axis of the yoke for regularly shaped parts. On complex parts, more complete demagnetization is sometimes possible if the part is rotated and turned end for end. For best results, the diameter of the demagnetizer yoke should be just large enough to accommodate the part. However, for practical purposes, one or two yoke sizes will satisfactorily serve an inspection facility. To demagnetize small parts in a large coil, place the parts close to the inside wall or corner of the yoke since the demagnetizing forces are strongest in that area.

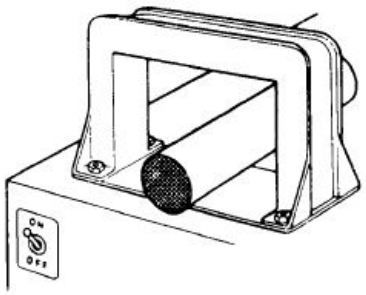


Figure 5–36. Part in demagnetizing coil.

Demagnetize the test part using a demagnetization coil as follows:

Demagnetization Coil	
Step	**Description**
a	Slowly pass the part through the coil when turned ON.
b	Measure the field at the ends of the test part. Residual field shall be two (2) increments or less on field indicators or three (3) gauss or less using a hall-effect gauss meter.
c	Repeat or reorient the part as needed until demagnetization requirements are met.

Demagnetizing with portable equipment

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

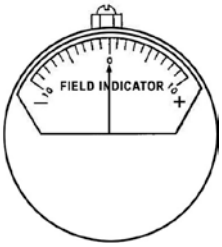
When the probe incorporates a DC magnetization capability, it can be used for DC demagnetization as well.

Demagnetize using portable yokes as follows:

Demagnetization Coil	
Step	**Description**
a	Set current to AC/DC.
b	Open the legs of the yoke so the test part can pass through it.
c	Hold the test part one foot from the yoke.
d	Slowly pass the part through the yoke legs and three to five feet beyond while the yoke is energized.
e	Turn the test part 90° and repeat the procedure.
f	If the test part is too large to handle in this way, follow the same basic procedures moving and rotating the yoke instead of the test part.
g	Measure the field at the ends of the test part. Residual field should be two (2) increments or less on field indicators or three (3) gauss or less using a gauss meter.

Measuring demagnetization

Various detecting devices easily determine the presence of a longitudinal field. However, a circular magnetic field is nearly impossible to detect, except with extremely complex and expensive instruments. This is why you have been instructed to apply circular magnetization to a part first and longitudinal last. In this way, you can effectively detect the removal of the magnetic field during demagnetization. In the following table, the methods of detecting a magnetic field do not show an exact measurement of field strength, but they do show relative values and are effective.

Method	Instructions
Field indicator	The magnetic field indicator (fig. 5–37) will display a leakage field from a part. When placed in a magnetic field, the field indicator shows the strength of the field passing through the sensitive element of the indicator. It gives an indication of the magnetizing force of the leakage field rather than the flux density. Use the field indicator for measuring the magnetizing force of a field in a part.  **Figure 5–37. Field indicator.**
(continued)	Do not store field indicators in areas where a rapid change in magnetic fields could damage the needle (e.g., on top of stationary head or tailstocks). Never store field indicators within the influence of any magnetizing or demagnetizing fields.
Compass	Place a compass on a nonmagnetic surface and move a magnetized part, aligned east-west, toward the east or west side of the compass. If a compass needle does not deviate from its normal North-South orientation, the part is satisfactorily demagnetized.
Other methods	Other methods of testing for demagnetization include using a piece of steel wire and testing whether it is attracted to the part. You can also hang a small steel paper clip on a string and test whether the paper clip is attracted to the part.

Post-cleaning

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

After the demagnetization operation has been accomplished, dip the test part in a clean vehicle that does not contain magnetic particles. Check the test part under a black light for fluorescence. Wipe down the test part with a clean cloth or paper towel dampened with an approved solvent.

After portable inspections, wipe the test part down with a clean dry cloth or paper towel. Perform a final wipe down with a clean cloth or paper towel dampened with an approved solvent. Check the test part under black light for excessive fluorescence. Inventory all equipment, as well as both expendable and consumable items used during the inspection procedure. Perform a final walk around of the inspection site.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

231. Inspection preparation

1. What eases accessibility to most surfaces, thus permitting a more thorough inspection?

2. Why should parts require pre-cleaning?

3. Why is it important to prepare a part prior to wet fluorescent particle inspection?

4. What happens when moisture settles on a test part?

5. What does the choice for determining your technique depend on?

232. Current values and surface conditions

1. What is determined by the amount of current used to magnetize a part?

2. What is the minimum current necessary to produce a readable indication called?

3. What must you do with parts magnetized above the threshold value?

4. What is a good rule of thumb for current amperage for direct current?

5. Discontinuities detected by the longitudinal method lie generally in what direction?

6. How far does the effective magnetic field extend on each side of the coil?

7. Where is a part magnetized in a coil if the parts cross-sectional area is less than one-tenth?

8. For parts with a cross-sectional area greater than one-tenth and less than one-half the cross-sectional area of the coil, what is the formula used to determine the current when the part is centered in the coil?

9. What is the limit of cable turns that will increase the flux density with portable equipment?

233. Inspection process

1. What happens to the smallest diameter of a part when the largest diameter is shot first?

2. What won't you have to do to a part if current values are equal to or higher than the values of circular inspection?

3. What is the next step after completely saturating the area of contact pads and CBC bar?

4. What is an excellent procedure for inspecting inside diameter of ring-shaped or cylinder test parts?

5. How many inches should parts not exceed during longitudinal magnetism when inspecting with a coil?

6. What type of filter is placed over the lens of a camera for filtering out a black light and allowing emitted light from an indication when photographing your inspection?

7. When recording your inspection, what technique lifts particles from an indication and placed on stiff white paper?

234. Interpreting indications

1. What are the principal distinguishing features of indications?

2. What are the most important discontinuities encountered by magnetic particle inspection?

3. How should the line of particles look with surface cracks?

4. How should the line of particles look with subsurface cracks?

5. What happens to leakage fields as subsurface discontinuities depth below the surface increases?

6. What angle to the flux do discontinuities show only faint indications?

7. List the three types of service cracks.

8. What is caused by distortions of the magnetic field and are sometimes called false indications?

9. What is magnetic writing?

10. What is cold working?

11. What is the area of a part called when it has a different degree of hardness than the rest of the part?

235. Demagnetizing parts and post-cleaning

1. What is it essential to do on aircraft parts when performing magnetic particle inspections?

2. Why may some parts be difficult to demagnetize using AC?

3. Which type of demagnetization is usually less time consuming?

4. Why should you take care not to demagnetize very small parts between the heads?

5. How long does it take for the step-down feature to be completed?

6. Current is ramped down to zero in how many seconds during the AC demagnetizing cycle?

7. What is DC demagnetizing with stationary equipment effective in removing?

8. When demagnetizing with DC stationary equipment, what position should you turn the current control, and what percentage of the magnetizing current should be used?

9. How far do you withdraw a part from a coil before current is shut off?

10. Within how many increments on field indicators should residual fields be measured?

11. How far do you withdraw a part from a portable yoke when demagnetizing before current is shut off?

12. What type of magnetic field is nearly impossible to detect, except with complex and expensive instruments?

13. Where should you *not* store field indicators?

14. How should you treat a part after it has been demagnetized in the post-cleaning step?

5–4. Magnetic Particle Process Control

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

236. Quality and process control

Any discussion of standards or equipment control ultimately comes back to the individual. As an inspector, you are only as good as your training, your mental attitude, and the equipment you are using. You have been given the tools necessary to perform adequate inspections through courses, on-the-job training, and a collection of technical data. Now you must ensure that the equipment and materials you are using are functioning properly and safely. In this way, you can maintain the integrity of your techniques.

Within this lesson, we will examine the processes involved in ensuring the quality of the inspection as well as the equipment. In addition, we will look at each individual inspection in order to assist you in understanding how each is accomplished, as well as why each is necessary.

Causes of system degradation

Some inspection processes use the magnetic particle materials only once. In these processes, spraying or dusting is usually the means used to apply the materials. The materials are stored in closed containers until they are used. These processes minimize the possibility of material contamination or degradation during use.

Materials in open tanks where excess materials drain from parts go back into the tank. This provides numerous opportunities for contamination, deterioration, and changes in concentration.

Contamination

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

Contamination of Magnetic Particle	
Type	**Description**
Water	Water is a common contaminant in petroleum-based baths. It may occur due to condensation, leaks, dripping overhead pipes, or moisture carryover on parts.
Organic substances	Organics such as paint, lubricants, oils, greases, and sealants are other sources of contamination. These materials are usually introduced into the magnetic particle bath on the parts being inspected; they can either react with or dilute a bath so it loses its ability to function. Organic solvents such as degreaser fluid, cleaning solvent, gasoline, and antifreeze solution, are also potential contaminants. These materials can mix with the inspection bath, or float on top of it, reducing the bath's effectiveness.
Dirt	Dirt, soil, and other insoluble solids can be carried into the magnetic particle bath as a result of inadequate pre-cleaning.
Acidic and alkaline solutions	Acidic and alkaline solutions can be residues of previous plating, paint stripping, and cleaning processes; these solutions can contaminate the magnetic particle baths.

Evaporation losses

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

Drag-out

Particle concentration is reduced when they adhere to parts being inspected and are not returned to the suspension.Like evaporation, the resulting change occurs slowly and can go unnoticed until significant performance loss is experienced, resulting in the term "drag-out."

Heat degradation

Fluorescent dyes are sensitive to elevated temperatures; for example, temperatures of over 140 °F may reduce the fluorescence, and temperatures over 250 °F may destroy it completely. High temperatures in magnetic particle inspection materials usually occur when materials are improperly stored. For instances, a dark colored container stored in direct sunlight can reach temperatures above 140 °F.

Equipment and process degradation

Similar to materials degradation, the performance of the equipment can also decline due to frequent use. The magnetizing equipment can lose power, while black light bulbs age and become dirty.

Equipment tests

Intervals for process control checks are established in TO 33B–1–2, Work Package (WP) 103 00. Various equipment tests are designed to ensure processes meet acceptable operating standards. The minimum equipment tests we will cover are as follows:

- System effectiveness check.
- Settling check, to include the concentration check, background fluorescence check, and contamination check.
- Amperage indicator check.
- Quick break test.
- Dead weight test.
- Field indicator check.
- Inspection area cleanliness.

Equipment interval checks are provided in the following table:

Magnetic Particle Process Control Intervals	
Test	**Interval**
System Effectiveness Check	Daily or prior to use
Settling Check	Prior to use and after 8-hours of continuous use
Fluorescent Background Check	Daily or prior to use
Inspection Booth Cleanliness	Daily
Field Indicator Check.	Weekly
Amperage Indicator Check	60 days
Quick Break Test	90 days

NOTE: Aerosol products (spray cans) require a system effectiveness check prior to initial use. Aerosols that are older than two years from the manufactured date, or are undated, also require a systems effectiveness check before daily use.

System effectiveness check

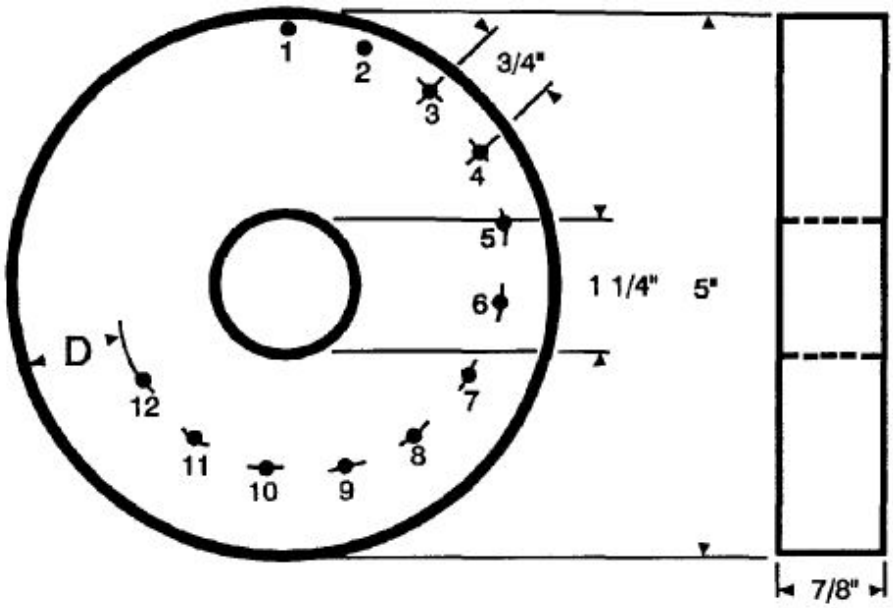
This test is unique, as it is capable of providing a relatively quick evaluation of both the equipment and the materials. The intent is to use a test specimen or set of specimens to assure the system is capable of producing an adequate magnetic particle inspection.

There is no Department of Defense standard specimen for this requirement; however, listed are a few ways to fulfill this requirement:

- Ketos or AS5282 ring (standard tool used by the Air Force to evaluate system effectiveness of magnetic inspection processes).
- QQI.
- Cracked parts.

Figure 5–38 is a specific standard called a Ketos ring and is used to check the system effectiveness of AC and DC magnetic particle inspections. Evaluate the system by using the wet continuous method with circular magnetization applied through a 1-inch diameter central conductor.

Since each check method has strengths and limitations, it is often advisable to use two or more methods to validate effectiveness. If a failure is indicated during the system effectiveness check, the amperage indicator and particle concentration tests should be accomplished to identify the problem.



HOLE	1	2	3	4	5	6	7	8	9	10	11	12
DIAMETER	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07
" D "	.07	.14	.21	.28	.35	.42	.49	.56	.63	.70	.77	.84

Figure 5–38. Specification of Ketos ring.

Conduct the system effectiveness check as follows (check the latest updates outlined in TO 33B–1–2):

System Effectiveness Check	
Step	**Description**
a	Check for residual magnetism by applying the magnetic particle bath, then wait 60 seconds for any indications to form. If any indications are present on the outer edge, the Ketos/AS5282 ring should be demagnetized and the check repeated until no indications are formed.
b	Place a one-inch CBC between the stocks and initiate the air cylinder to clamp the CBC into place. Set unit for AC operation in the CONTACT mode. Adjust the current control until 1000 amps is displayed on the readout.
c	Remove the CBC from the stocks and slide the Ketos/AS5282 ring onto the bar. Clamp the CBC into the stocks. Perform the wet continuous method of particle application at 1000 amps. Wait 60-seconds for any indications to form on the outer edge of the Ketos/AS5282 ring. An indication should form above the first hole.
d	Remove the CBC from the stocks and slide the Ketos/AS5282 ring off the bar. Place the CBC back into the stocks and initiate the air cylinder to clamp it down.
e	Set the magnetic particle unit to DC operation in the CONTACT mode. Adjust the current control until 1400 amps for the Ketos ring and 500 for the AS5282 ring.
f	Remove the CBC from the stocks and slide the Ketos/AS5282 ring onto the bar. Clamp the CBC into the stocks. Perform the wet continuous method of particle application to the next amperage described in the 33B–1–2. Wait 60 seconds for any indications to form on the outer edge of the Ketos/AS5282 ring. An indication should form above the third hole.

NOTE: Repeat the preceding steps until all indications are detected.

Settling check

Three sources of deterioration occur in a bath of fluorescent particles, including magnetic particle concentration, separation of the fluorescent pigment from the magnetic particles, and contamination (made up of the accumulation of nonfluorescent magnetic dust or dirt in the bath). When the condition becomes excessive, it will be required to dispose of the bath. The three procedures outlined under the settling check include the particle concentration test, fluorescent background check and contamination check.They are described in the next few paragraphs.

Particle concentration test

The following procedure is used to determine the concentration of magnetic particles and to check for the accumulation of dirt or other contaminants in a suspension. The equipment required is a 100-cubic centimeters (cc) or 100-milliliters (ml) pear-shaped, graduated centrifuge tube and nonferrous stand (fig. 5–39).

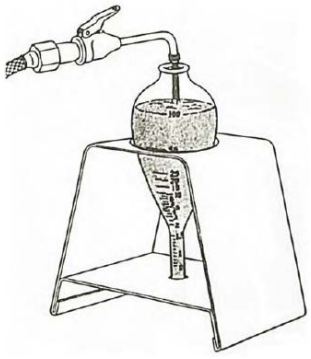


Figure 5–39. Centrifuge tube.

Thoroughly agitate the suspension and let it run through the hose for at least one minute. This is to ensure the suspension in the hose is fresh and agitated. Fill the centrifuge tube with the suspension and demagnetize; this helps to reduce clumping. Place the centrifuge tube in a nonferromagnetic stand and allow settling on a vibration free surface as follows:

- One hour for oil baths.
- Thirty minutes for water baths.

Observe the total level of particle concentration.

Besides the magnetic particles, dirt in the bath will also settle out and will usually appear as a separate layer on top of the particles. The layer of dirt and lint is usually easily distinguishable, since it is of a different color and texture from the particles. Also easily distinguishable are iron peening shot and blasting grit; both will settle faster and lie beneath the magnetic particles.

If the concentration of magnetic particles is above or below the range required, correct by adding vehicle or magnetic particle powder.

Visible magnetic particle bath concentrations should be as follows:

- From 1.2 to 2.4 ml of particles per 100 ml of vehicle.
- The optimum range is 1.5 to 2.0 ml/100 ml.

Fluorescent magnetic particle bath concentrations should be as follows:

- From 0.1 to 0.4 ml of particles per 100 ml of vehicle.
- The optimum range is 0.15 to 0.20 ml/100 ml.

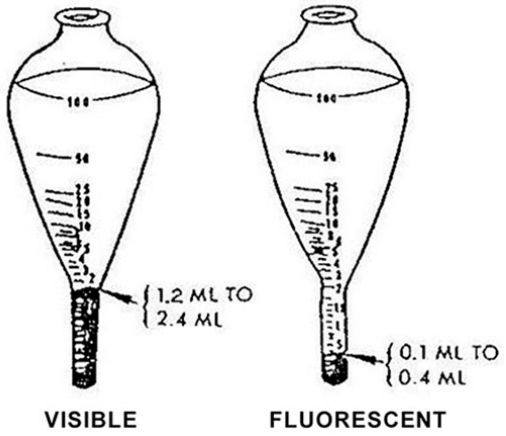


Figure 5–40. Optimum ranges for visible and fluorescent bath.

NOTE: Prior to adding magnetic particles to the vehicle, the particles should be demagnetized to eliminate any clumping that may have developed during storage due to magnetization.

Fluorescent background check

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

A fluorescent background check should be accomplished on vehicle materials used in the fluorescent particle inspection method if in question. One procedure for checking the background is as follows:

Fluorescent Background Check	
Step	**Description**
a	Obtain a clean glass tube of sufficient length to reach from the middle of the bulk vehicle container to at least six inches above the container opening when it is in the vertical position.
b	Insert the tube slowly into the bulk vehicle.
c	Place thumb over protruding end of the glass tube and remove the tube from the container.
d	Illuminate vehicle in the glass tube with a UV-A lamp in a darkened area.
e	If vehicle does not fluoresce, proceed with its use. If the vehicle fluoresces, determine the fluorescence in accordance with the appropriate section and dispose of vehicle not conforming to standard.

Contamination check

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

Adding new materials

Magnetic particle materials are thoroughly tested during manufacture. However, unsatisfactory materials still can be received and you should test newly received materials before you use them in your inspection system. The following table shows steps on preparing new bath for your unit.

Adding New Materials	
Check	**Description/Instructions**
Prepared bath	Before mixing a new bath, drain the inspection unit and clean it thoroughly. Follow these steps to complete this procedure: 1. Remove and clean the agitator pipe. Pick or brush all residues from the holes along its length. 2. Remove and clean the strainer screen. 3. Clean accumulations of dirt and particles from the tank. 4. Flush all parts with solvent. 5. Replace the strainer screen and agitator pipe, making certain to position the agitator pipe with openings down. After the unit has been thoroughly cleaned, close the drain cock and fill the tank with the amount of oil specified by the TO or recommended by the equipment manufacturer. The concentration check is then performed.

Amperage indicator check

The amperage indicator check should be performed using a calibrated ammeter/shunt. Operate the ammeter/shunt in accordance with the commercial manufacturer's operating instruction. DC amperage variations exceeding ±10% of read-out value or ±60 amps, whichever is greater, requires

troubleshooting and maintenance action. AC amperage variations exceeding ±10% requires troubleshooting and maintenance action. Perform the amperage indicator check on the range expected to be used.

Quick break test

The quick break test is accomplished to ensure an accurate decay rate, which is sufficient for quick break magnetization. A quick break tester is authorized in AS–455. Operate the quick break tester in accordance with the commercial manufacturer's operating instructions. Failure of the quick break test requires troubleshooting and maintenance action.

Dead weight check

The dead weight check is conducted on portable electromagnetic yokes (e.g., Parker Probes). Repair or replace equipment that fails the dead weight check. (**NOTE:** A 10-pound weight is required for AC operation, while either a 30- or 50-pound weight is required for DC operation.) Perform the process control check as follows:

Dead Weight Check	
Step	**Description**
a	Place the 10-pound weight on the floor. Set the portable magnetic particle Yoke to AC operation. Extend the legs straight out and space the legs from two to six inches. Place the leg ends on the test weight and energize the unit. Lift the test weight off the ground. A portable magnetic particle unit must be able to hold the suspended ten-pound test weight.
b	Place the 30-pound weight on the floor. Set the portable magnetic particle Yoke to DC operation. Extend the legs straight out and space the legs from two to four inches. Place the leg ends on the test weight and energize the unit. Lift the test weight off the ground. A portable magnetic particle yoke must be able to hold the suspended 30-pound test weight. A 50-pound test weight and a four to six inch leg spread may also be used.

Field indicator check

Performance of the field indicator check requires a bar magnet or magnet with a North and South Pole. Hold the in-use field indicator next to one end of the magnet; a full-scale deflection in one direction should be observed. Move the indicator away from the magnet and note the return to zero or centerline. Hold the indicator next to the opposite end of the bar magnet, note a full-scale deflection in the opposite end of the scale. Move the indicator away from the magnet and note the return to zero. If proper deflections are observed, then field indicator is serviceable.

Inspection area cleanliness

The inspection area, as well as the hands and clothing of the inspector, should be clean and free of extraneous fluorescent materials. Nonrelevant indications may be formed when parts contact extraneous fluorescent materials. In addition, the fluorescence from this material will raise the ambient light level, thus increasing the amount of black light necessary to produce a visible indication of a small defect.

Make sure you incorporate black light and white light checks as outlined in the penetrant process control section and in TO 33B–1–2.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

236. Quality and process control

1. What is a primary source of magnetic particle bath degradation?

2. What can be carried into the magnetic particle bath as a result of inadequate pre-cleaning?

3. Why does the rate of evaporation increase in a large tank?

4. What is drag-out?

5. At what temperature is magnetic particle fluorescents reduced?

6. How often is the system effectiveness check performed?

7. How often is the amperage indicator check performed?

8. How often are aerosol cans required to have a system effectiveness check performed?

9. Which two tests must be accomplished to identify the problem when your system effectiveness check fails?

10. When performing a system effectiveness check, how long do you wait for indications to form when applying the magnetic particle bath with the Ketos/AS58282 ring?

11. What three sources of deterioration occur in a bath of fluorescent particles?

12. How long do you allow the centrifuge tube to sit before checking bath particle concentration?

13. What is the optimum concentration range of fluorescent particles in a bath?

14. What check is completed when fluorescent pigments separate from magnetic particles?

15. What is the first step when changing out new bath after draining and cleaning the unit?

16. What are the DC value amperage variations of the amperage indicator check when trouble shooting is needed?

17. What type of weight is used for AC operation when performing the dead weight check?

18. What is required when performing the field indicator check?

19. What may form when parts contact extraneous fluorescent materials?

Answers to Self-Test Questions

225

1. Electromotive force.
2. Ampere.
3. At right angles (90°) to the direction of electric current flow.
4. The ease with which a ferromagnetic part is magnetized.
5. Hard steel.
6. Zero.
7. One Maxwell per square centimeter.
8. Flux density.
9. The negative or reverse applied magnetizing force necessary to reduce the residual magnetizing force to zero in a ferromagnetic material.
10. Oersted.

226

1. A leakage field.
2. Magnetic flux lines.
3. A transverse crack in the fused magnet or circularly magnetized part will create a leakage field with North and South poles on either side of the crack. Some of the magnetic flux will exit the metal and form a leakage field.
4. The number of flux lines the depth of the crack and the width of the air gap at the surface have.
5. Magnetic poles.
6. Direction and strength.
7. Domain theory.

8. Residual magnetism field.
9. The size and shape of a part.
10. Electrical power and equipment available, the degree of demagnetization required, and the skill of the inspector.

227

1. Circular magnetism and longitudinal magnetism.
2. Right hand rule.
3. The detection of radial discontinuities around edges of holes or openings in parts.
4. Circular magnetic field.
5. It may cause an electrical arc and may burn the ends of the part.
6. Circular magnetization.
7. In a direction generally parallel with the conductor.
8. Inspect both the inside and outside surfaces.
9. It is determined by the rings outside diameter.
10. Along the longitudinal axis of the coil.
11. By a yoke.
12. DC and AC.
13. AC.
14. Pure.
15. Three-phase, full-wave DC.
16. Service induced defects such as fatigue, overload and stress corrosion cracks.
17. One hundred to 10,000 amps, depending upon the test part and the magnetization technique.
18. DC.

228

1. Stationary, mobile, and portable.
2. Thirty minutes.
3. Use residual or continuous methods to apply the bath and energize the part.
4. Circular step-down tends to heat small parts and may burn large ones at the points of contact because of the high current required. Also, there is no way to check the effectiveness of the demagnetization.
5. Mobile equipment.
6. The compactness allows areas to be inspected where larger equipment may prohibit access.
7. Two-minutes on and two-minutes off.
8. Probes and yokes.
9. Deep-seated, subsurface discontinuities due to the limited penetration of the induced magnetic field.
10. Place the pole pieces on the part, with the suspected defects at right angles to a line drawn from one pole piece to the other.
11. Lift the probe to a distance of two feet before turning the probe off.
12. Field indicator, compass indicator, Gauss meter/Tesla Meter, and QQQI.
13. It has interchangeable probes to permit measurement of the magnetic field either parallel or perpendicular to the axis of the probe.
14. Low carbon steel.

229

1. Daily.
2. Weekly.
3. Apply a few drops of silicone lubricant at each joint.
4. Every 90 days.

5. Coordinate such action with the base fire department because ultraviolet sources could activate automatic fire suppression systems and cause damage.
6. Twenty four inches.
7. Less than 25 gallons.
8. UV-A filtering safety glasses, goggles, or face shields.
9. In a cool dry area, protected from direct sunlight.

230

1. Proper size and shape, having good magnetic permeability, and ideal retentivity.
2. Wet and dry.
3. It is refined, odorless oil or a petroleum distillate, having a low viscosity, low sulfur content, and a high flash point.
4. Water.
5. Fluorescent wet particles.
6. Dry powder.
7. Continuous method.
8. Residual method.

231

1. Disassembly.
2. To remove all contaminants, foreign matter, and debris that might interfere with the application of current or the movement of the magnetic particles on the test surface.
3. Oil or grease can harm aqueous inspection baths in several ways. Either their presence on the test surface can prevent the bath from wetting or covering the entire surface or it can cause the bath to peel off the surface, stripping any indications.
4. It can be emulsified into an oil bath, causing the magnetic particles to thicken and settle out of the bath where they are no longer available to form indications.
5. The type of discontinuity or defect; the part's material, shape, and size; and the magnetic particle inspection equipment available.

232

1. The intensity of the magnetic field.
2. Threshold value.
3. They must be demagnetized before the correct current value can be obtained.
4. Use currents from 300 to 800 A/in of the part diameter, when the part is reasonably uniform and cylindrical in shape.
5. Transverse or crosswise to the direction of the applied field.
6. Six to nine inches.
7. On the coil bottom.
8. $I = \dfrac{KR}{N(6(L/D)-5}$.
9. Between three and five turns.

233

1. It will be over-magnetized and cause masking of the possible defects.
2. Demagnetizing the part before a longitudinal field is induced.
3. Fully depress the foot switch to clamp the CBC firmly in place.
4. Circular magnetic field induction.
5. Eighteen inches.
6. A number 2E filter.

7. Transferring with transparent tape.

234

1. Shape, buildup, width, and sharpness of the outline.
2. Those found on the surface.
3. Sharp and well defined with a noticeable buildup.
4. Broad, fuzzy-looking accumulations of particles rather than sharp well-defined ones.
5. They grow weaker.
6. Fifteen degrees.
7. Fatigue cracks, stress-corrosion cracks, and overstressing cracks.
8. Nonrelevant indications.
9. A condition caused by a piece of steel rubbing against another piece of steel that has been magnetized.
10. Changing the size or shape of a metal part without raising its temperature before working.
11. Hard or soft spots.

235

1. Demagnetize them.
2. Because alternating current does not penetrate very deeply below the surface of magnetic materials.
3. AC demagnetization.
4. Because the high initial current can overheat the parts.
5. In about 30-seconds, one-second per step.
6. Five to 10 seconds.
7. Circular fields, when the current is passed through the part.
8. Clockwise to ¾ of scale, or 10% greater than the magnetizing current.
9. Four to 5-feet.
10. Two increments or less.
11. Three to five feet.
12. Circular magnetic field.
13. In areas where a rapid change in magnetic fields could damage the needle; this includes areas within the influence of any magnetizing or demagnetizing fields.
14. Dip the test part in a clean vehicle that does not contain magnetic particles.

236

1. Contamination.
2. Dirt, soil and other insoluble solids.
3. Warmer temperatures and larger tank surfaces.
4. It is the result of reduced particle concentration occurring when they adhere to parts being inspected and are not returned to the suspension. This change occurs slowly and can go unnoticed until significant performance loss is experience.
5. Over 140° F.
6. Daily or prior to use.
7. Every 60 days.
8. Prior to initial use.
9. Amperage indicator and particle concentration tests.
10. Sixty seconds.
11. Magnetic particle concentration, separation of the fluorescent pigment from the magnetic particles, and contamination (made up of the accumulation of nonfluorescent magnetic dust or dirt in the bath).
12. One hour for oil baths, and 30 minutes for water baths.
13. From 0.15 to 0.20 ml/100 ml.

14. Fluorescent background check. Pick or brush all residues from the holes along its length.
15. Remove and clean the agitator pipe.
16. They exceed ±10% of read-out value or ±60 amps.
17. Ten pounds.
18. A bar magnet or magnet with a North and South pole.
19. Nonrelevant indications.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field Scoring Answer Sheet.

Do not return your answer sheet to AFCDA.

67. (225) What is the unit of measure for electromotive force?
    a. Volt.
    b. Watt.
    c. Ohm.
    d. Ampere.

68. (225) What is the term for the rate at which electrons pass a given point in a conductor?
    a. Current.
    b. Ampere.
    c. Electromotive force.
    d. Magnetic permeability.

69. (225) A metal that is easily magnetized has
    a. low retentivity.
    b. high retentivity.
    c. low permeability.
    d. high permeability.

70. (226) What are lines of force in a leakage field called?
    a. Flux density lines.
    b. Leakage field lines.
    c. Magnetic flux lines.
    d. Magnetic field lines.

71. (226) The best results obtained from flux lines are located in which direction to discontinuities?
    a. Any angle.
    b. Perpendicular.
    c. Forty five degree angles.
    d. Parallel to linear discontinuities.

72. (226) With an increase of magnetic flux lines flowing through a piece of iron, magnetic particles concentrate at
    a. North poles.
    b. leakage fields.
    c. discontinuities.
    d. demagnetized poles.

73. (226) When domains that are randomly oriented result in an overall flux density of zero, a part
    a. is magnetized.
    b. has residual magnetism.
    c. is insufficiently magnetized.
    d. has been completely demagnetized.

74. (227) Which type of magnetization detects longitudinal discontinuities?
    a. Circular field.
    b. Direct current.
    c. Longitudinal field.
    d. Alternating current.

75. (227) What is a conductive material that is placed in the center of a part under inspection called?
    a. Cable bar.
    b. Central conductor bar.
    c. Circular conductor bar.
    d. Longitudinal conductor bar.

76. (227) What is the recommended current value in amperes (amps) on a stationary equipment when inducing AC current?
    a. 100 to 800 amps.
    b. 300 to 1,000 amps.
    c. 100 to 10,000 amps.
    d. 600 to 16,000 amps.

77. (228) Which magnetic particle equipment requires the operator to depress a foot switch?
    a. MA–2.
    b. Mobile.
    c. Portable.
    d. Stationary.

78. (228) What portable equipment devices are limited to the detection of surface and near surface discontinuities only?
    a. Probes and yokes.
    b. Mobile equipment.
    c. Portable power packs.
    d. Contact prods and clamps.

79. (228) When demagnetizing, how far do you lift a model type DA–200 away from a large part *before* turning the probe off?
    a. 6 inches.
    b. 1 foot.
    c. 2 feet.
    d. 4 feet.

80. (228) What type of measuring device is a quantitative assessment of a magnetic field and may be useful in covering a curved area of a part, such as a radius?
    a. Quantitative Quality Indicator (QQI).
    b. Compass indicator.
    c. Field indicator.
    d. Gauss meter.

81. (229) How often should accumulated moisture from a stationary inspection unit’s air filter be removed?
    a. Daily.
    b. Weekly.
    c. Monthly.
    d. Semiannually.

82. (229) To improve flexibility of pole pieces on portable equipment, what should you NOT use?
    a. Oil.
    b. Solvent.
    c. Vehicle.
    d. Silicone lubricant.

83. (230) What is the liquid transporting magnetic particles called?
    a. Oil.
    b. Bath.
    c. Vehicle.
    d. Wet particles.

84. (230) What is primarily used for inspecting welds and castings where defects are found below the surface?
    a. Dry particles.
    b. Wet particles.
    c. Residual method.
    d. Continuous method.

85. (230) When applying particles, which method do you turn off the particle flow just before the final application of current?
    a. Dry residual.
    b. Wet continuous.
    c. Wet or dry visible.
    d. Wet or dry continuous.

86. (231) When inspecting with magnetic particle, parts may need to be stripped if the thickness *exceeds*
    a. 0.3 inch.
    b. 0.03 inch.
    c. 0.003 inch.
    d. 0.0003 inch.

87. (231) All of these determine the choice of technique for a particular magnetic particle inspection *except* the
    a. type of defect.
    b. shape of the part.
    c. equipment available.
    d. part’s surface condition.

88. (232) The depth at which a discontinuity can be longitudinally detected depends upon the size and shape of the discontinuity relative to all of these *except* for the
    a. surface conditions affecting indications.
    b. length to diameter ratio (L/D) of the part.
    c. strength of the applied magnetizing field.
    d. size of the cross section in which it is located.

89. (232) In order to produce the same flux density in a part, the
    a. smaller the diameter ratio (L/D) ratio, the greater the coil current amperage must be.
    b. smaller the L/D ratio, the smaller the coil current amperage must be.
    c. larger the L/D ratio, the smaller the coil current amperage must be.
    d. larger the L/D ratio, the greater the coil current amperage must be.

90. (233) Which type of magnetic field is easily detected with a *field indicator*?
    a. Circular field.
    b. Direct current.
    c. Longitudinal field.
    d. Alternating current.

91. (233) When using longitudinal magnetization technique, use additional parts if necessary in order to establish a part length of a ratio diameter of at least
    a. ½.
    b. 1.
    c. 2.
    d. 3.

92. (234) Discontinuities are *best detected* when they are
    a. parallel to the magnetic field.
    b. perpendicular to the magnetic field.
    c. parallel to the longitudinal axis of the part.
    d. perpendicular to the longitudinal axis of the part.

93. (234) What may occur as the result of an accident or a part becoming overload?
    a. Overstressing.
    b. Fatigue cracks.
    c. Cold working cracks.
    d. Stress-corrosion cracks.

94. (234) What is it called when two parts touch creating magnetic poles at the points of contact?
    a. Hard spot.
    b. Cold working.
    c. Abrupt change.
    d. Magnetic writing.

95. (235) What is the term to describe demagnetizing of a part using stationary equipment, with the motor used to drive the demagnetization switch contactor going from maximum to minimum current positions?
    a. Step-down procedure.
    b. Motorized demagnetization.
    c. Direct current (DC) demagnetization.
    d. Alternating current (AC) demagnetization.

96. (235) When demagnetizing using a portable yoke, what is the next step after passing the part through the yoke legs while energized?
    a. Set the current to direct current (DC) and repeat the process.
    b. Turn the test part 90° and repeat the procedure.
    c. Measure the field at the ends of the test part.
    d. Hold the test part one foot from the yoke.

97. (236) What is a common contaminant of petroleum-based baths?
    a. Dirt.
    b. Water.
    c. Organic substances.
    d. Acidic and alkaline solutions.

98. (236) When do aerosol cans need the system effectiveness check completed?
    a. Monthly.
    b. Weekly.
    c. Daily or before use.
    d. Prior to initial use, and before daily use if they are older than two years from manufacture.

99. (236) How long do you agitate the suspension for before performing the particle concentration test?
    a. 30 minutes.
    b. 5 minutes.
    c. 1 minute.
    d. 1 hour.

100. (236) Which process control is performed on portable electromagnetic yoke equipment?
    a. Settling check.
    b. Quick break test.
    c. Dead weight check.
    d. Amperage indicator check.

Student Notes

Glossary of Abbreviations and Acronyms

°F	degrees Fahrenheit
π	Pi
µW/cm²	micro-watts per square centimeter
A	area (cross-sectional)
AA	Aluminum Association
AC	alternating current
AFI	Air Force instruction
AFTO	Air Force technical order
A/in	amperes per inch
AISI	American Iron and Steel Institute
ALC	Air Logistics Center
amp	ampere
AMS	aerospace materials specification
AS	allowance standard
BE	Bioenvironmental Engineering
CBC	central bar conductor
cc	cubic centimeters
CDC	career development course
CRT	cathode ray tube
CTK	composite tool kit
DC	direct current
FS	fuselage station
FWDC	full-wave direct current
H_20	water
HWDC	half-wave direct current
IACS	International Annealed Copper Standard
kV	kilovoltage
L/D	length to diameter ratio

mA	milliamperage
ml	milliliters
MPI	magnetic particle inspection
NDI	nondestructive inspection
nm	nanometers
POD	probability of detection
psi	pounds per square inch
PSM	penetrant system monitor
QPL	qualified products list
QQI	quantitative quality indicator
r	radius
SAE	Society of Automotive Engineers
SPO	system program office
TM	technical manual
TO	technical order
UV	ultraviolet
UV-A	ultraviolet black light
VAC	volts alternating current
WP	work package

Student Notes

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