CHAPTER 5. NONDESTRUCTIVE INSPECTION (NDI)

SECTION 1. GENERAL

5-1. GENERAL. The field of NDI is too varied to be covered in detail in this Advisory Circular (AC). This chapter provides a brief description of the various Nondestructive Testing (NDT) used for inspection of aircraft, powerplant, and components in aircraft inspection. The effectiveness of any particular method of NDI depends upon the skill, experience, and training of the person(s) performing the inspection process. Each process is limited in its usefulness by its adaptability to the particular component to be inspected. Consult the aircraft or product manufacturer's manuals for specific instructions regarding NDI of their products. (Reference AC 43-3, Nondestructive Testing in Aircraft, for additional information on NDI.

The product manufacturer or the Federal Aviation Administration (FAA) generally specifies the particular NDI method and procedure to be used in inspection. These NDI requirements will be specified in the manufacturer's inspection, maintenance, or overhaul manual; FAA Airworthiness Directives (AD); Supplemental Structural Inspection Documents (SSID); or manufacturer's service bulletins (SB). However, in some conditions an alternate NDI method and procedure can be used. This includes procedures and data developed by FAA certificated repair stations under Title 14 of the Code of Federal Regulations, (14 CFR), part 145.

5-2. APPROVED PROCEDURES. Title 14 CFR, part 43 requires that all maintenance be performed using methods, techniques, and practices prescribed in the current manufacturer's maintenance manual or instructions for continued airworthiness prepared by its manufacturer, or other methods, techniques, and practices acceptable to the administrator. If the maintenance instructions include materials, parts, tools, equipment, or test apparatus necessary to comply with industry practices then those items are required to be available and used as per part 43.

5-3. NDT LEVELS. Reference Air Transport Association (ATA) Specification 105-Guidelines For Training and Qualifying Personnel In Nondestructive Testing Methods.

a. Level I Special.

Initial classroom hours and on-the-job training shall be sufficient to qualify an individual for certification for a specific task. The individual must be able to pass a vision and color perception examination, a general exam dealing with standards and NDT procedures, and a practical exam conducted by a qualified Level II or Level III certificated person.

b. Level I/Level II.

The individual shall have an FAA Airframe and Powerplant Mechanic Certificate, complete the required number of formal classroom hours, and complete an examination.

c. Level III.

(1) The individual must have graduated from a 4 year college or university with a degree in engineering or science, plus 1 year of minimum experience in NDT in an assignment comparable to that of a Level II in the applicable NDT methods: or

(2) The individual must have 2 years of engineering or science study at a university, college, or technical school, plus 2 years of experience as a Level II in the applicable NDT methods: or

(3) The individual must have 4 years of experience working as a Level II in the applicable NDT methods and complete an examination.

5-4. TRAINING, QUALIFICATION, AND CERTIFICATION. The success of any NDI method and procedure depends upon the knowledge, skill, and experience of the NDI personnel involved. The person(s) responsible for detecting and interpreting indications, such as eddy current, X-ray, or ultrasonic NDI, must be qualified and certified to specific FAA, or other acceptable government or industry standards, such as MIL-STD-410, Nondestructive Testing Personnel Qualification and Certification, or Air Transport Association (ATA) Specification 105-Guidelines for Training and Qualifying Personnel in Nondestructive Testing Methods. The person should be familiar with the test method, know the potential types of discontinuities peculiar to the material, and be familiar with their effect on the structural integrity of the part.

5-5. FLAWS. Although a specific discussion of flaws and processes will not be given in this AC, the importance of this area should not be minimized. Inspection personnel should know where flaws occur or can be expected to exist and what effect they can have in each of the NDI test methods. Misinterpretation and/or improper evaluation of flaws or improper performance of NDI can result in serviceable parts being rejected and defective parts being accepted.

All NDI personnel should be familiar with the detection of flaws such as: corrosion, inherent flaws, primary processing flaws, secondary processing or finishing flaws, and in-service flaws. The following paragraphs classify and discuss the types of flaws or anomalies that may be detected by NDI.

a. Corrosion. This is the electrochemical deterioration of a metal resulting from chemical reaction with the surrounding environment. Corrosion is very common and can be an extremely critical defect. Therefore, NDI personnel may devote a significant amount of their inspection time to corrosion detection.

b. Inherent Flaws. This group of flaws is present in metal as the result of its initial solidification from the molten state, before any of the operations to forge or roll it into useful sizes and shapes have begun. The following are brief descriptions of some inherent flaws.

(1) Primary pipe is a shrinkage cavity that forms at the top of an ingot during metal solidification, which can extend deep into the ingot. Failure to cut away all of the ingot shrinkage cavity can result in unsound metal, called pipe, that shows up as irregular voids in finished products.

(2) Blowholes are secondary pipe holes in metal that can occur when gas bubbles are trapped as the molten metal in an ingot mold solidifies. Many of these blowholes are clean on the interior and are welded shut into sound metal during the first rolling or forging of the ingot. However, some do not weld and can appear as seams or laminations in finished products.

(3) Segregation is a nonuniform distribution of various chemical constituents that can occur in a metal when an ingot or casting solidifies. Segregation can occur anywhere in the metal and is normally irregular in shape. However, there is a tendency for some constituents in the metal to concentrate in the liquid that solidifies last.

(4) Porosity is holes in a material's surface or scattered throughout the material, caused by gases being liberated and trapped as the material solidifies.

(5) Inclusions are impurities, such as slag, oxides, sulfides, etc., that occur in ingots and castings. Inclusions are commonly caused by incomplete refining of the metal ore or the incomplete mixing of deoxidizing materials added to the molten metal in the furnace.

(6) Shrinkage cracks can occur in castings due to stresses caused by the metal contracting as it cools and solidifies.

c. Primary Processing Flaws. Flaws which occur while working the metal down by hot or cold deformation into useful shapes such as bars, rods, wires, and forged shapes are primary processing flaws. Casting and welding are also considered primary processes although they involve molten metal, since they result in a semi-finished product. The following are brief descriptions of some primary processing flaws:

(1) Seams are surface flaws, generally long, straight, and parallel to the longitudinal axis of the material, which can originate from ingot blowholes and cracks, or be introduced by drawing or rolling processes.

(2) Laminations are formed in rolled plate, sheet, or strip when blowholes or internal fissures are not welded tight during the rolling process and are enlarged and flattened into areas of horizontal discontinuities.

(3) Cupping is a series of internal metal ruptures created when the interior metal does not flow as rapidly as the surface metal during drawing or extruding processes. Segregation in the center of a bar usually contributes to the occurrence.

(4) Cooling cracks can occur in casting due to stresses resulting from cooling, and are often associated with changes in cross sections of the part. Cooling cracks can also occur when alloy and tool steel bars are rolled and subsequently cooled. Also, stresses can occur from uneven cooling which can be severe enough to crack the bars. Such cracks are generally longitudinal, but not necessarily straight. They can be quite long, and usually vary in depth along their length.

(5) Flakes are internal ruptures that can occur in metal as a result of cooling too rapidly. Flaking generally occurs deep in a heavy section of metal. Certain alloys are more susceptible to flaking than others.

(6) Forging laps are the result of metal being folded over and forced into the surface, but not welded to form a single piece. They can be caused by faulty dies, oversized dies, oversized blanks, or improper handling of the metal in the die. They can occur on any area of the forging.

(7) Forging bursts are internal or external ruptures that occur when forging operations are started before the material to be forged reaches the proper temperature throughout. Hotter sections of the forging blank tend to flow around the colder sections causing internal bursts or cracks on the surface. Too rapid or too severe a reduction in a section can also cause forging bursts or cracks.

(8) A hot tear is a pulling apart of the metal that can occur in castings when the metal contracts as it solidifies.

(9) A cold shut is a failure of metal to fuse. It can occur in castings when part of the metal being poured into the mold cools and does not fuse with the rest of the metal into a solid piece.

(10) Incomplete weld penetration is a failure of the weld metal to penetrate completely through a joint before solidifying.

(11) Incomplete weld fusion occurs in welds where the temperature has not been high enough to melt the parent metal adjacent to the weld.

(12) Weld undercutting is a decrease in the thickness of the parent material at the toe of the weld caused by welding at too high a temperature.

(13) Cracks in the weld metal can be caused by the contraction of a thin section of the metal cooling faster than a heavier section or by incorrect heat or type of filler rod. They are one of the more common types of flaws found in welds.

(14) Weld crater cracks are star shaped cracks that can occur at the end of a weld run.

(15) Cracks in the weld heat-affected zone can occur because of stress induced in the material adjacent to the weld by its expansion and contraction from thermal changes.

(16) A slag inclusion is a nonmetallic solid material that becomes trapped in the weld metal or between the weld metal and the base metal.

(17) Scale is an oxide formed on metal by the chemical action of the surface metal with oxygen from the air.

d. Secondary Processing or Finishing Flaws. This category includes those flaws associated with the various finishing operations, after the part has been rough-formed by rolling, forging, casting or welding. Flaws may be introduced by heat treating, grinding, and similar processes. The following are brief descriptions of some secondary processing or finishing flaws.

(1) Machining tears can occur when working a part with a dull cutting tool or by cutting to a depth that is too great for the material being worked. The metal does not break away clean, and the tool leaves a rough, torn surface which contains numerous short discontinuities that can be classified as cracks.

(2) Heat treating cracks are caused by stresses setup by unequal heating or cooling of portions of a part during heat treating operations. Generally, they occur where a part has a sudden change of section that could cause an uneven cooling rate, or at fillets and notches that act as stress concentration points.

(3) Grinding cracks are thermal type cracks similar to heat treating cracks and can occur when hardened surfaces are ground. The overheating created by the grinding can be caused by the wheel becoming glazed so that it rubs instead of cutting the surface; by using too little coolant; by making too heavy a cut; or by feeding the material too rapidly. Generally, the cracks are at right angles to the direction of grinding and in severe cases a complete network of cracks can appear. Grinding cracks are usually shallow and very sharp at their roots, which makes them potential sources of fatigue failure.

(4) Etching cracks can occur when hardened surfaces containing internal residual stresses are etched in acid.

(5) Plating cracks can occur when hardened surfaces are electroplated. Generally, they are found in areas where high residual stresses remain from some previous operation involving the part.

e. In-Service Flaws. These flaws are formed after all fabrication has been completed and the aircraft, engine, or related component has gone into service. These flaws are attributable to aging effects caused by either time, flight cycles, service operating conditions, or combinations of these effects. The following are brief descriptions of some in-service flaws.

(1) Stress corrosion cracks can develop on the surface of parts that are under tension stress in service and are also exposed to a corrosive environment, such as the inside of wing skins, sump areas, and areas between two metal parts of faying surfaces.

(2) Overstress cracks can occur when a part is stressed beyond the level for which it was designed. Such overstressing can occur as the result of a hard landing, turbulence, accident, or related damage due to some unusual or emergency condition not anticipated by the designer, or because of the failure of some related structural member.

(3) Fatigue cracks can occur in parts that have been subjected to repeated or changing loads while in service, such as riveted lap joints in aircraft fuselages. The crack usually starts at a highly-stressed area and propagates through the section until failure occurs. A fatigue crack will start more readily where the design or surface condition provides a point of stress concentration. Common stress concentration points are: fillets; sharp radii; or poor surface finish, seams, or grinding cracks.

(4) Unbonds, or disbonds, are flaws where adhesive attaches to only one surface in an adhesive-bonded assembly. They can be the result of crushed, broken, or corroded cores in adhesive-bonded structures. Areas of unbonds have no strength and place additional stress on the surrounding areas making failure more likely.

(5) Delamination is the term used to define the separation of composite material layers within a monolithic structure. Ultrasonic is the primary method used for the detection of delamination in composite structures.

5-6. SELECTING THE NDI METHOD.

The NDI method and procedure to be used for any specific part or component will generally be specified in the aircraft or component manufacturer’s maintenance or overhaul manuals, SSID’s, SB’s, or in AD’s.

NOTE: Some AD’s refer to SB’s which may, in turn, refer to manufacturer’s overhaul or maintenance manuals.

a. Appropriate Method. The appropriate NDI method may consist of several separate inspections. An initial inspection may indicate the presence of a possible flaw, but other inspections may be required to confirm the original indication. Making the correct NDI method selection requires an understanding of the basic principles, limitations, and advantages and disadvantages of the available NDI methods and an understanding of their comparative effectiveness and cost.

b. Other Factors. Other factors affecting the inspection are:

(1) The critical nature of the component;

(2) The material, size, shape, and weight of the part;

(3) The type of defect sought;

(4) Maximum acceptable defect limits in size and distribution;

(5) Possible locations and orientations of defects;

(6) Part accessibility or portability; and

(7) The number of parts to be inspected.

c. Degree of Inspection. The degree of inspection sensitivity required is an important factor in selecting the NDI method. Critical parts that *cannot* withstand small defects and could cause *catastrophic failure* require the use of the more sensitive NDI methods. Less critical parts and general hardware generally require less-sensitive NDI methods.

d. Material Safety Data Sheets (MSDS). The various materials used in NDI may contain chemicals, that if improperly used, can be hazardous to the health and safety of operators and the safety of the environment, aircraft, and engines. Information on safe handling of materials is provided in MSDS. MSDS, conforming to Title 29 of the Code of Federal Regulations (29 CFR), part 1910, section 1200, or its equivalent, must be provided by the material supplier to any user and must be prepared according to FED-STD-313.

e. Advantages and Disadvantages. Table 5-1 provides a list of the advantages and disadvantages of common NDI methods. Table 5-1, in conjunction with other information in the AC, may be used as a guide for evaluating the most appropriate NDI method when the manufacturer or the FAA has not specified a particular NDI method to be used.

5-7. TYPES OF INSPECTIONS. Nondestructive testing methods are techniques used both in the production and in-service environments without damage or destruction of the item under investigation. Examples of NDI methods are as follows:

a. Visual inspection

b. Magnetic particle

c. Penetrants

d. Eddy current

e. Radiography

f. Ultrasonic

g. Acoustic emission

h. Thermography

i. Holography

j. Shearography

k. Tap testing

TABLE 5-1. Advantages and disadvantages of NDI methods.

METHOD	ADVANTAGES	DISADVANTAGES
VISUAL	Inexpensive Highly portable Immediate results Minimum training Minimum part preparation	Surface discontinuities only Generally only large discontinuities Misinterpretation of scratches
DYE PENETRANT	Portable Inexpensive Sensitive to very small discontinuities 30 min. or less to accomplish Minimum skill required	Locate surface defects only Rough or porous surfaces interfere with test Part preparation required (removal of finishes and sealant, etc.) High degree of cleanliness required Direct visual detection of results required
MAGNETIC PARTICLE	Can be portable Inexpensive Sensitive to small discontinuities Immediate results Moderate skill required Detects surface and subsurface discontinuities Relatively fast	Surface must be accessible Rough surfaces interfere with test Part preparation required (removal of finishes and sealant, etc.) Semi-directional requiring general orientation of field to discontinuity Ferro-magnetic materials only Part must be demagnetized after test.
EDDY CURRENT	Portable Detects surface and subsurface discontinuities Moderate speed Immediate results Sensitive to small discontinuities Thickness sensitive Can detect many variables	Surface must be accessible to probe Rough surfaces interfere with test Electrically conductive materials Skill and training required Time consuming for large areas
ULTRASONIC	Portable Inexpensive Sensitive to very small discontinuities Immediate results Little part preparation Wide range of materials and thickness can be inspected	Surface must be accessible to probe Rough surfaces interfere with test Highly sensitive to sound beam - discontinuity orientation High degree of skill required to set up and interpret Couplant usually required
X-RAY RADIOGRAPHY	Detects surface and internal flaws Can inspect hidden areas Permanent test record obtained Minimum part preparation	Safety hazard Very expensive (slow process) Highly directional, sensitive to flaw orientation High degree of skill and experience required for exposure and interpretation Depth of discontinuity not indicated
ISOTOPE RADIOGRAPHY	Portable Less expensive than X-ray Detects surface and internal flaws Can inspect hidden areas Permanent test record obtained Minimum part preparation	Safety hazard Must conform to Federal and State regulations for handling and use Highly directional, sensitive to flaw orientation High degree of skill and experience required for exposure and interpretation Depth of discontinuity not indicated

5-8.—5-14. [RESERVED.]

SECTION 2. VISUAL INSPECTION

5-15. GENERAL. Visual inspection is the oldest and most common form of NDI for aircraft. Approximately 80 percent of all NDI procedures are accomplished by the direct visual methods. This inspection procedure may be greatly enhanced by the use of appropriate combinations of magnifying instruments, borescopes, light sources, video scanners, and other devices discussed in this AC. Visual inspection provides a means of detecting and examining a wide variety of component and material surface discontinuities, such as cracks, corrosion, contamination, surface finish, weld joints, solder connections, and adhesive disbonds. Visual inspection is widely used for detecting and examining aircraft surface cracks, which are particularly important because of their relationship to structural failures. Visual inspection is frequently used to provide verification when defects are found initially using other NDI techniques. The use of optical aids for visual inspection is beneficial and recommended. Optical aids magnify defects that cannot be seen by the unaided eye and also permit visual inspection in inaccessible areas.

5-16. SIMPLE VISUAL INSPECTION AIDS. It should be emphasized that the eye-mirror-flashlight is a critical visual inspection process. Aircraft structure and components that must be routinely inspected are frequently located beneath skin, cables, tubing, control rods, pumps, actuators, etc. Visual inspection aids such as a powerful flashlight, a mirror with a ball joint, and a 2 to 10 power magnifying glass are essential in the inspection process.

a. Flashlights. Flashlights used for aircraft inspection should be suitable for industrial use and, where applicable, safety approved by the Underwriters Laboratory or equivalent agency as suitable for use in hazardous atmospheres such as aircraft fuel tanks. Military Specification MIL-F-3747E, flashlights: plastic case, tubular (regular, explosion-proof, explosion-proof heat resistant, traffic directing, and inspection-light), provides requirements for flashlights suitable for use in aircraft inspection. However, at the present time, the flashlights covered by this specification use standard incandescent lamps and there are no standardized performance tests for flashlights with the brighter bulbs: Krypton, Halogen, and Xenon. Each flashlight manufacturer currently develops its tests and provides information on its products in its advertising literature. Therefore, when selecting a flashlight for use in visual inspection, it is sometimes difficult to directly compare products. The following characteristics should be considered when selecting a flashlight: foot-candle rating; explosive atmosphere rating; beam spread (adjustable, spot, or flood); efficiency (battery usage rate); brightness after extended use; and rechargeable or standard batteries. (If rechargeable, how many hours of continuous use and how long is required for recharging?) If possible, it would be best to take it apart and inspect for quality of construction and to actually use the flashlight like it would be used in the field. Inspection flashlights are available in several different bulb brightness levels:

(1) Standard incandescent (for long-battery life).

(2) Krypton (for 70 percent more light than standard bulbs).

(3) Halogen (for up to 100 percent more light than standard bulbs).

(4) Xenon (for over 100 percent more light than standard bulbs).

b. Inspection Mirrors. An inspection mirror is used to view an area that is not in the normal line of sight. The mirror should be of the appropriate size to easily view the component, with the reflecting surface free of dirt, cracks, worn coating, etc., and a swivel joint tight enough to maintain its setting.

c. Simple Magnifiers. A single converging lens, the simplest form of a microscope, is often referred to as a simple magnifier. Magnification of a single lens is determined by the equation M = 10/f. In this equation, "M" is the magnification, "f" is the focal length of the lens in inches, and "10" is a constant that represents the average minimum distance at which objects can be distinctly seen by the unaided eye. Using the equation, a lens with a focal length of 5 inches has a magnification of 2, or is said to be a two-power lens.

5-17. BORESCOPES. These instruments are long, tubular, precision optical instruments with built-in illumination, designed to allow remote visual inspection of internal surfaces or otherwise inaccessible areas. The tube, which can be rigid or flexible with a wide variety of lengths and diameters, provides the necessary optical connection between the viewing end and an objective lens at the distant, or distal tip of the borescope. Rigid and flexible borescopes are available in different designs for a variety of standard applications and manufacturers also provide custom designs for specialized applications. Figure 5-1 shows three typical designs of borescopes.

a. Borescopes Uses. Borescopes are used in aircraft and engine maintenance programs to reduce or eliminate the need for costly teardowns. Aircraft turbine engines have access ports that are specifically designed for borescopes. Borescopes are also used extensively in a variety of aviation maintenance programs to determine the airworthiness of difficult-to-reach components. Borescopes typically are used to inspect interiors of hydraulic cylinders and valves for pitting, scoring, porosity, and tool marks; inspect for cracked cylinders in aircraft reciprocating engines; inspect turbojet engine turbine blades and combustion cans; verify the proper placement and fit of seals, bonds, gaskets, and subassemblies in difficult to reach areas; and assess Foreign Object Damage (FOD) in aircraft, airframe, and powerplants. Borescopes may also be used to locate and retrieve foreign objects in engines and airframes.

b. Optical Designs. Typical designs for the optical connection between the borescope viewing end and the distal tip are:

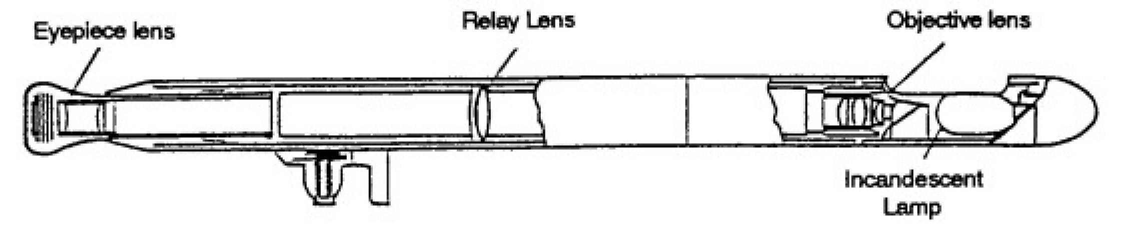
(1) A rigid tube with a series of relay lenses;

(2) A flexible or rigid tube with a bundle of optical fibers; and

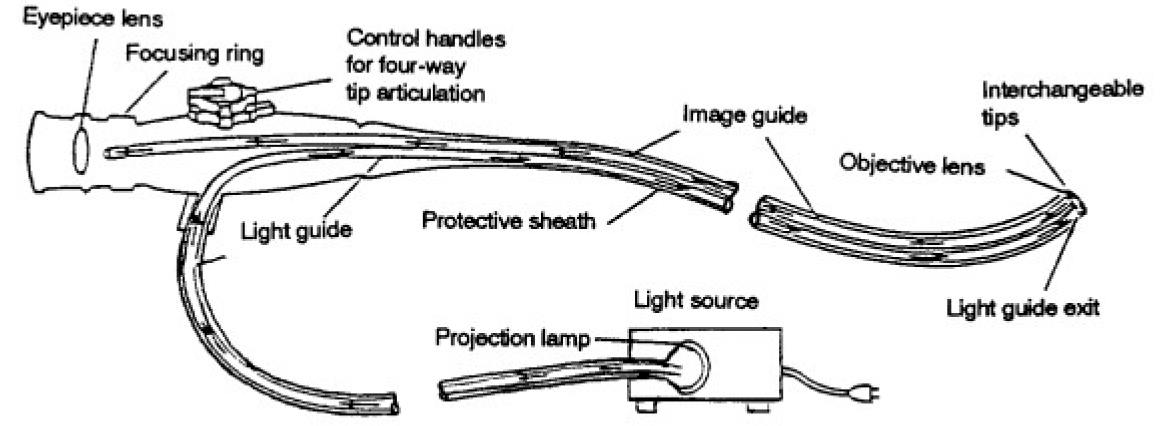
(3) A flexible or rigid tube with wiring that carries the image signal from a Charge Couple Device (CCD) imaging sensor at the distal tip.

These designs can have either fixed or adjustable focusing of the objective lens at the distal tip. The distal tip may also have prisms and mirrors that define the direction and field of view. A fiber optic light guide with white light is generally used in the illumination system, but ultraviolet light can also be used to inspect surfaces treated with liquid fluorescent penetrant or to inspect for contaminants that fluoresce. Some borescopes with long working lengths use light-emitting diodes at the distal tip for illumination.

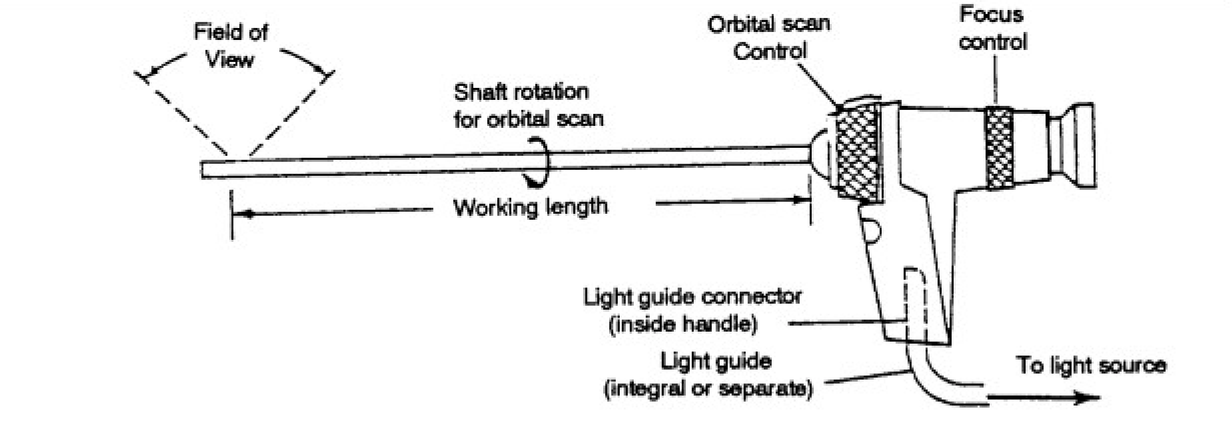
5-18. VISUAL INSPECTION PROCEDURES. Corrosion can be an extremely critical defect. Therefore, NDI personnel should be familiar with the appearance of common types of corrosion and have training and



(a) A rigid borescope with a lamp at the distal end.



(b) A flexible fiberscope with a light source.



(c) A rigid borescope with a light guide bundle in the shaft.

FIGURE 5-1. Typical borescope designs.

experience on corrosion detection on aircraft structure and engine materials. (Reference: AC 43-4A, Corrosion Control for Aircraft, for additional information on corrosion.

a. Preliminary Inspection. Perform a preliminary inspection of the overall general area for cleanliness, presence of foreign objects, deformed or missing fasteners, security of parts, corrosion, and damage. If the configuration or location of the part conceals the area to be inspected, use visual aids such as a mirror or borescope.

b. Corrosion Treatment. Treat any corrosion found during preliminary inspection after completing a visual inspection of any selected part or area.

NOTE: Eddy current, radiography, or ultrasonic inspection can determine the loss of metal to corrosion.

c. Lighting. Provide adequate lighting to illuminate the selected part or area.

d. Personal Comfort. Personal comfort (temperature, wind, rain, etc.) of the inspector can be a factor in visual inspection reliability.

e. Noise. Noise levels while conducting a visual inspection are important. Excessive noise reduces concentration, creates tension, and prevents effective communication. All these factors will increase the likelihood of errors.

f. Inspection Area Access. Ease of access to the inspection area has been found to be of major importance in obtaining reliable visual inspection results. Access consists of the act of getting into an inspection position (primary access) and doing the visual inspection (secondary access). Poor access can affect the inspector's interpretation of discontinuities, decision making, motivation, and attitude.

g. Precleaning. Clean the areas or surface of the parts to be inspected. Remove any contaminates that might hinder the discovery of existing surface indications. Do not remove the protective finish from the part or area prior to inspection. Removal of the finish may be required at a later time if other NDI techniques are required to verify any visual indications of flaws that are found.

h. Inspection. Carefully inspect the area for discontinuities, using optical aids as required. An inspector normally should have available suitable measuring devices, a flashlight, and a mirror.

(1) Surface cracks. When searching for surface cracks with a flashlight, direct the light beam at a 5 to 45 degree angle to the inspection surface, towards the face. (See figure 5-2.) Do not direct the light beam at such an angle that the reflected light beam shines directly into the eyes. Keep the eyes above the reflected light beam during the inspection. Determine the extent of any cracks found by directing the light beam at right angles to the crack and tracing its length. Use a 10-power magnifying glass to confirm the existence of a suspected crack. If this is not adequate, use other NDI techniques, such as penetrant, magnetic particle, or eddy current to verify cracks.

(2) Other surface discontinuities. Inspect for other surface discontinuities, such as: discoloration from overheating; buckled, bulging, or dented skin; cracked, chafed, split, or dented tubing; chafed electrical wiring; delaminations of composites; and damaged protective finishes.

i. Recordkeeping. Document all discrepancies by written report, photograph, and/or video recording for appropriate evaluation. The full value of visual inspection can be realized only if records are kept of the discrepancies found on parts inspected. The size and shape of the discontinuity and its location on the part should be recorded along with other pertinent information, such as rework performed or disposition. The inclusion on a report of some visible record of the discontinuity makes the report more complete.

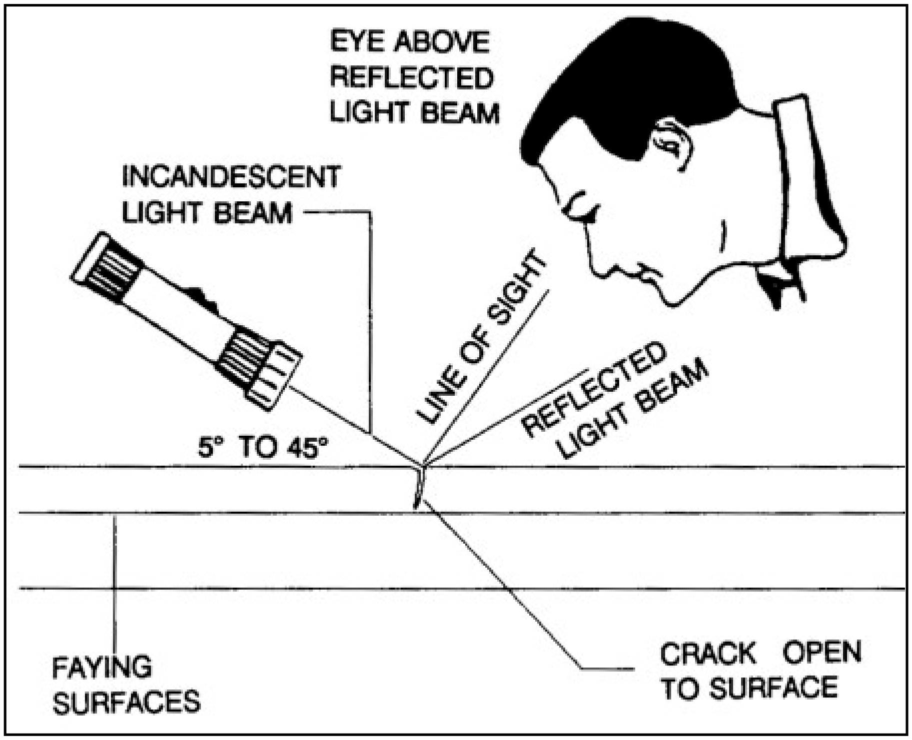


FIGURE 5-2. Using a flashlight to inspect for cracks.

5-19.—5-24. [RESERVED.]

SECTION 3. EDDY CURRENT INSPECTION

5-25. EDDY CURRENT INSPECTION. Eddy current is used to detect surface cracks, pits, subsurface cracks, corrosion on inner surfaces, and to determine alloy and heat-treat condition.

a. Eddy Current Instruments. A wide variety of eddy current test instruments are available. The eddy current test instrument performs three basic functions: generating, receiving, and displaying. The generating portion of the unit provides an alternating current to the test coil. The receiving section processes the signal from the test coil to the required form and amplitude for display. Instrument outputs or displays consist of a variety of visual, audible, storage, or transfer techniques utilizing meters, video displays, chart recorders, alarms, magnetic tape, computers, and electrical or electronic relays.

b. Principles of Operations. Eddy currents are induced in a test article when an alternating current is applied to a test coil (probe). The alternating current in the coil induces an alternating magnetic field in the article which causes eddy currents to flow in the article. (See figure 5-3.)

(1) Flaws in or thickness changes of the test-piece influence the flow of eddy currents and change the impedance of the coil accordingly. (See figure 5-4.) Instruments display the impedance changes either by impedance plane plots or by needle deflection.

(2) Figure 5-5 shows typical impedance plane display and meter display instrument responses for aluminum surface cracks, subsurface cracks, and thickness.

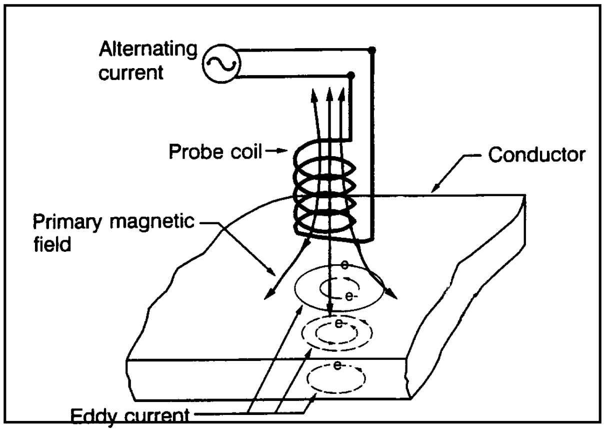


FIGURE 5-3. Generating an eddy current.

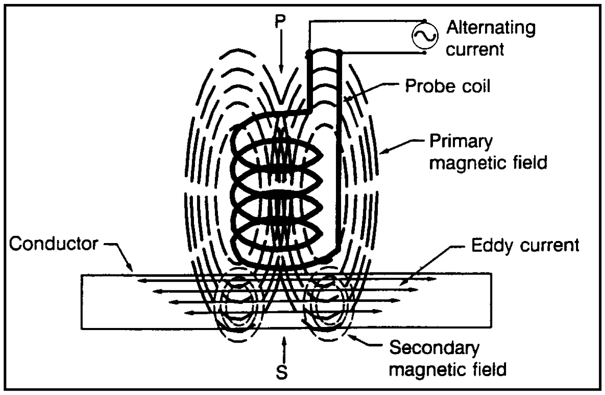


FIGURE 5-4. Detecting an eddy current.

5-26. EDDY CURRENT COILS AND PROBES. A wide variety of eddy current coils and probes is available. Coils and probes are not always interchangeable between various types of instruments and, for best results, should be matched to a specific instrument and frequency range. Special probe holders can be fabricated to facilitate eddy current inspection of contoured or shaped parts including part edges.

5-27. FIELD APPLICATION OF EDDY CURRENT INSPECTION. Eddy current techniques are particularly well-suited for detection of service-induced cracks in the field.

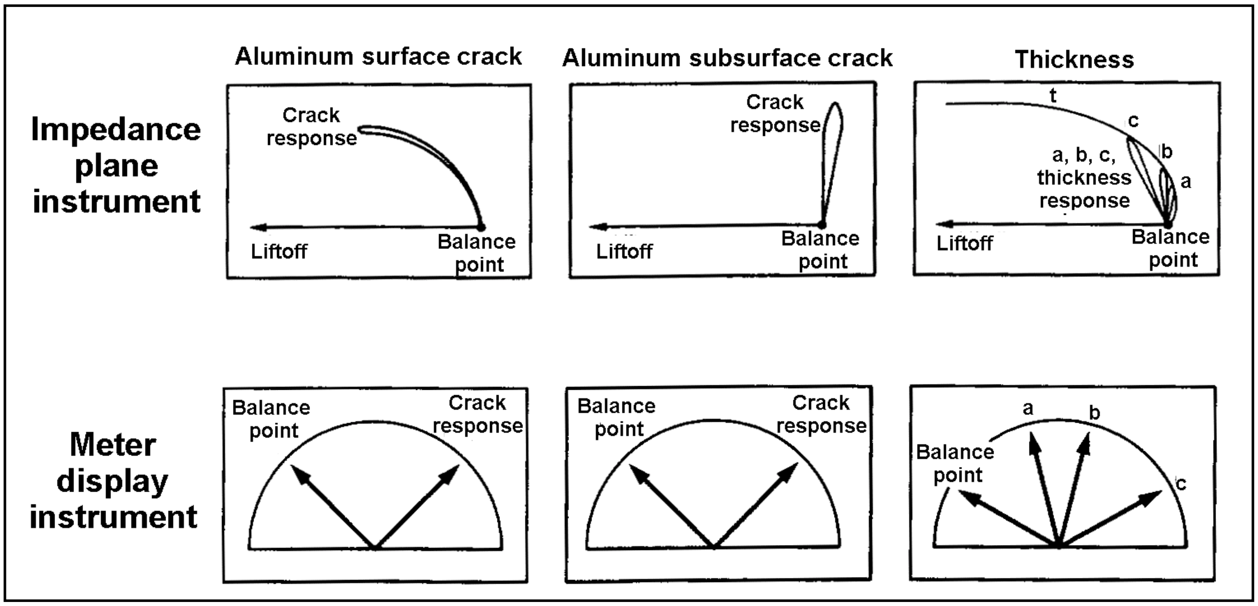


FIGURE 5-5. Typical instrument displays.

Service-induced cracks in aircraft structures are generally caused by fatigue or stress corrosion. Both types of cracks initiate at the surface of a part. If this surface is accessible, a high-frequency eddy current inspection can be performed with a minimum of part preparation and a high degree of sensitivity. If the surface is less accessible, such as in a subsurface layer of structure, low-frequency eddy current inspection can usually be performed. Eddy current inspection can usually be performed without removing surface coatings such as primer, paint, and anodic films. Eddy current inspection has the greatest application for inspecting small localized areas where possible crack initiation is suspected rather than for scanning broad areas for randomly-oriented cracks. However, in some instances it is more economical to scan relatively large areas with eddy current rather than strip surface coatings, inspect by other methods, and then refinish.

5-28. SURFACE INSPECTION. Eddy current inspection techniques are used to inspect for surface cracks such as those shown in figure 5-6.

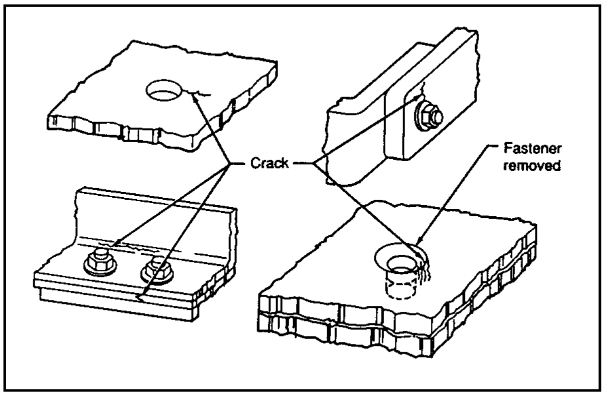


FIGURE 5-6. Typical surface cracks.

a. Equipment Requirements. The following are typical eddy current equipment requirements for surface crack inspections.

(1) Instruments must meet the liftoff and sensitivity requirements of the applicable NDI procedures. The frequency requirement is generally 100 Hz to 200 kHz.

(2) Many types of probes are available such as: flat-surface; spring-loaded; pencil; shielded pencil; right-angle pencil; or fastener hole probes.

(3) A reference standard is required for the calibration of Eddy Current test equipment. A reference standard is made from the same material as that which is to be tested. A reference standard contains known flaws or cracks and could include items such as: a flat surface notch, a fastener head, a fastener hole, or a countersink hole.

5-29. SUBSURFACE INSPECTION.

Eddy current inspection techniques are used to inspect for subsurface cracks such as those shown in figure 5-7. The following are typical eddy current equipment requirements for subsurface crack inspections.

a. Use a variable frequency instrument with frequency capability from 100 Hz to 500 MHz.

b. The probe used would be a low-frequency; spot, ring, or sliding probe.

c. Use a reference standard appropriate for the inspection being performed.

5-30. CORROSION INSPECTION.

Eddy current inspection is used to detect the loss of metal as a result of corrosion. An estimation of material loss due to corrosion can be made by comparison with thickness standards. Figure 5-8 shows typical structural corrosion that may be detected by the use of eddy current inspection. Remove all surface corrosion before performing the eddy current corrosion inspection. The following are typical eddy current equipment requirements for corrosion inspection.

a. Use a variable frequency instrument with frequency capability from 100 Hz to 40 kHz.

b. Use a shielded probe with coil diameter between 0.15 and 0.5 inch and designed to operate at the lower frequencies.

c. A reference standard made from the same alloy, heat treatment, and thickness as the test structure will be required.

5-31. ESTABLISHING EDDY CURRENT INSPECTION PROCEDURES. When establishing eddy current inspection procedures, where no written procedures are available, the following factors must be considered: type of material to be inspected; accessibility of the inspection area; material or part geometry, the signal-to-noise ratio, test system; lift-off effects, location and size of flaws to be detected; scanning pattern; scanning speed; and reference standards. All of these factors are interrelated. Therefore, a change in one of the factors may require changes in other factors to maintain the same level of sensitivity and reliability of the eddy current inspection procedure. Written procedures should elaborate on these factors and place them in their proper order.

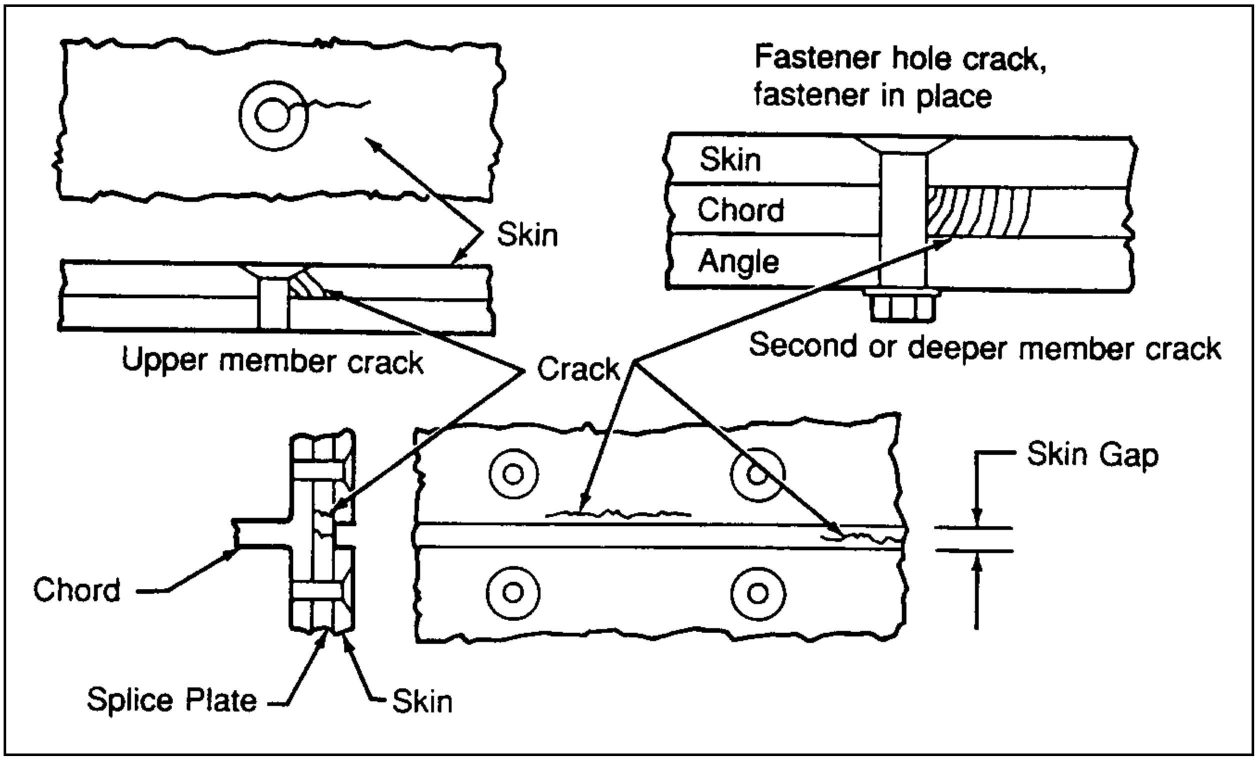


FIGURE 5-7. Typical subsurface cracks.

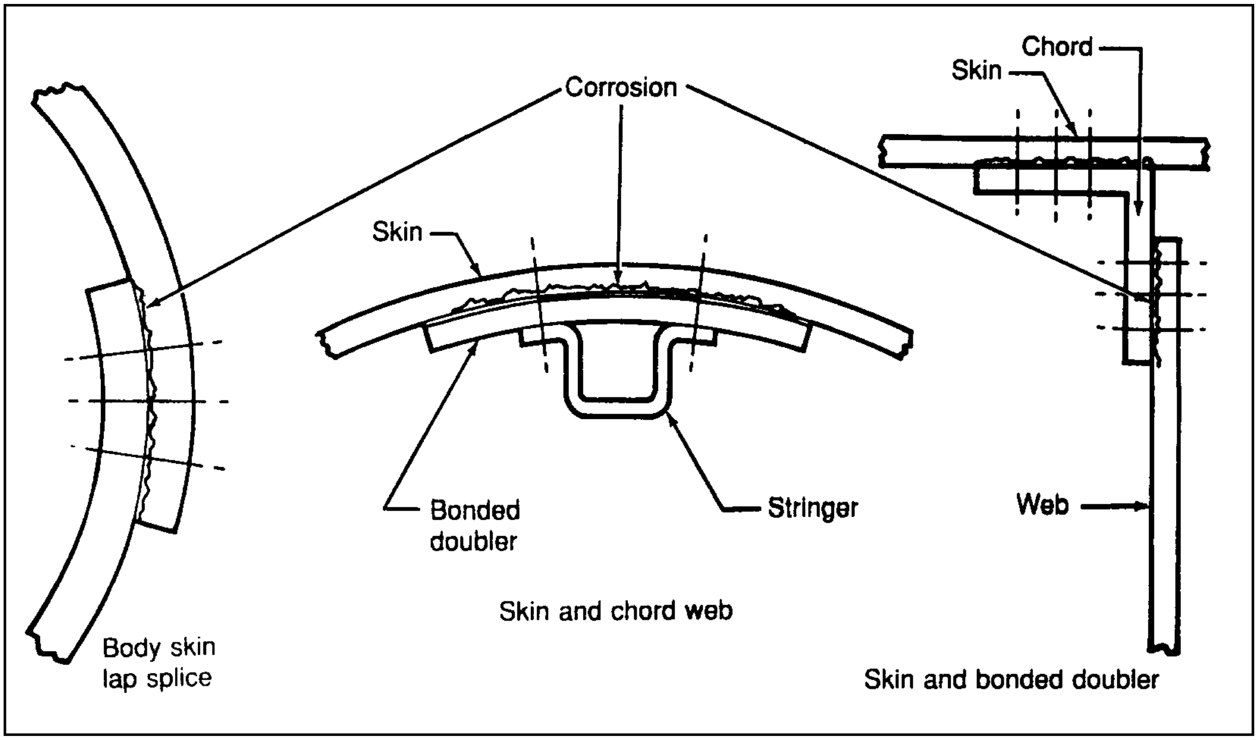


FIGURE 5-8. Typical structural corrosion.

5-32.—5-39. [RESERVED.]

SECTION 4. MAGNETIC PARTICLE INSPECTION

5-40. GENERAL. Magnetic particle inspection is a method for detecting cracks, laps, seams, voids, pits, subsurface holes, and other surface, or slightly subsurface, discontinuities in ferro-magnetic materials. Magnetic particle inspection can be used only on ferro-magnetic materials (iron and steel). It can be performed on raw material, billets, finished and semi-finished materials, welds, and in-service assembled or disassembled parts. Magnetic particles are applied over a surface either dry, as a powder, or wet, as particles in a liquid carrier such as oil or water.

Common uses for magnetic particle inspection are; final inspection, receiving inspection, in-process inspection; and quality control, maintenance, and overhaul.

5-41. PRINCIPLES OF OPERATION. Magnetic particle inspection uses the tendency of magnetic lines of force, or flux, of an applied field to pass through the metal rather than through the air. A defect at or near the metal's surface distorts the distribution of the magnetic flux and some of the flux is forced to pass out through the surface. (See figure 5-9.) The field strength is increased in the area of the defect and opposite magnetic poles form on either side of the defect. Fine magnetic particles applied to the part are attracted to these regions and form a pattern around the defect. The pattern of particles provides a visual indication of a defect. (See figure 5-10.)

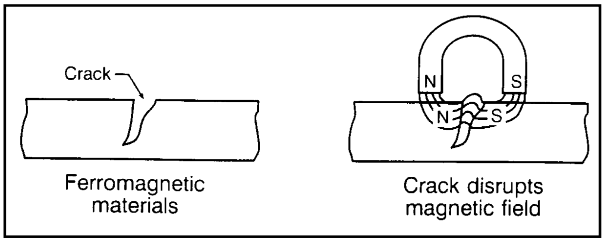


FIGURE 5-9. Magnetic field disrupted.

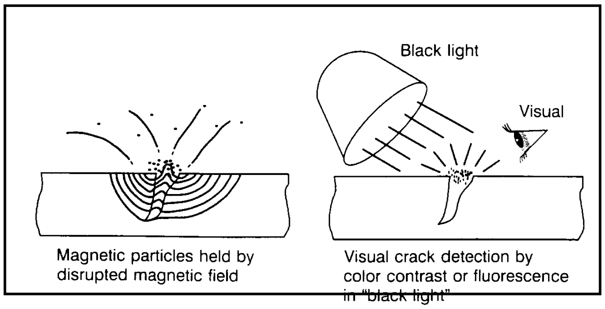


FIGURE 5-10. Crack detection by magnetic particle inspection.

a. To locate a defect, it is necessary to control the direction of magnetization, and flux lines must be perpendicular to the longitudinal axes of expected defects. Examination of critical areas for defects may require complete disassembly. Two methods of magnetization, circular and longitudinal, are used to magnetize the part and induce perpendicular flux paths. Parts of complex configuration may require local magnetization to ensure proper magnetic field direction and adequate removal of surface coatings, sealants, and other similar compounds. Possible adverse influence of the applied or residual magnetic fields on delicate parts such as instruments, bearings, and mechanisms may require removal of these parts before performing the inspection.

b. Certain characteristics inherent in the magnetic particle method may introduce errors in examination results. Nonrelevant errors are caused by magnetic field distortions due to intentional design features, such as:

(1) Sharp radii, less than 0.10 inch radius, in fillets;

(2) Thread roots, keyways, and drilled holes; and

(3) Abrupt changes in geometry or in magnetic properties within the part.

c. Operators must understand nonrelevant error indications and recognize them during examination. Proper analysis of indications in these regions will require considerable skill and experience, and supplemental methods may be required before a final evaluation can be made. Special techniques for examination of these areas are given in subsequent paragraphs.

5-42. APPLICATIONS. Use magnetic particle inspection on any well-cleaned surface that is accessible for close visual examination. Typical parts deserving magnetic particle examination are: steel fasteners and pins; critical structural elements; linkages; landing gear components; splice and attach fittings; and actuating mechanisms.

a. During field repair operations, disassembly is often not necessary, except when the parts have critical areas or delicate installed components. However, for overhaul operations, a more thorough and critical examination may be obtained with stationary equipment in a shop environment with completely disassembled, and thoroughly cleaned and stripped parts.

b. Magnetic rubber examination material is useful for in-field service examinations of fastener holes in areas where the accessibility is limited or restricted, where particle suspensions may cause unwanted contamination, when a permanent record is desired, and when the examination area cannot be observed visually.

5-43. ELECTRICAL MAGNETIZING EQUIPMENT. Stationary equipment in the range of 100 to 6000 amperes is normal for use within the aerospace industry for overhaul operations. Mobile equipment with similar amperage outputs is available for field examination of heavy structures, such as landing gear cylinders and axles. Small parts and local areas of large components can be adequately checked with the use of small, inexpensive permanent magnets or electromagnetic yokes. In procuring magnetizing equipment, the maximum rated output should be greater than the required examination amperage. Actual current flow through a complex part may be reduced as much as 20 percent by the resistance load of the rated output.

5-44. MATERIALS USED IN MAGNETIC PARTICLE INSPECTION. The particles used in magnetic particle inspection are finely divided ferro-magnetic materials that have been treated with color or fluorescent dyes to improve visibility against the various surface backgrounds of the parts under inspection. Magnetic particles, particle-suspension vehicles, and cleaners are required for conducting magnetic particle inspection. Requirements for magnetic particle inspection materials, other than cleaners, are contained in the aerospace industry standard, ASTM-E1444, Inspection, Magnetic Particle (as revised). A certification statement which will certify that the material meets applicable specification requirements will generally be received when a magnetic particle inspection material is purchased. Magnetic particle inspection materials for use on a specific part or component will generally be specified by the aircraft or component manufacturer or the FAA in documents such as; maintenance or overhaul manuals, AD’s, SSID’s, or manufacturer’s SB’s. However, if the magnetic particle inspection materials are not specified for the specific part or component to be inspected, it is recommended that personnel use materials meeting the aircraft or component manufacturers’ specifications or materials meeting the requirements of ASTM-E1444. Other FAA engineering-approved materials may also be used. Table 5-2 provides a partial listing of commonly accepted standards and specifications for magnetic particle inspection.

TABLE 5-2. Listing of commonly accepted standards and specifications for magnetic particle inspection.

NUMBER	TITLE
ASTM STANDARDS	
ASTM A275/A275 M-96	Standard Test Method for Magnetic Particle Examination of Steel Forgings. 1995
ASTM A456/A456 M Rev. A.	Standard Specification for Magnetic Particle Examination of Large Crankshaft Forgings. 1995
ASTM D96	Standard Test Methods for Water and Sediment in Crude Oils by Centrifuge Method (Field Procedure). 1988
ASTM E125-63 (1993)	Standard Reference Photographs for Magnetic Particle Indications on Ferrous Castings. (Revised 1993) 1963
ASTM E1316-95C	Standard Terminology for Nondestructive Examination. 1995 (Replaces ASTM E269).
SAE-AMS SPECIFICATIONS	
AMS 2300G	Premium Aircraft-Quality Steel Cleanliness Magnetic Particle Inspection Procedure. 1991 (Revised 1995)
MAM 2300A	Premium Aircraft Quality Steel Cleanliness Magnetic Particle Inspection Procedure Metric (SI) Measurement. 1992
AMS 2303C	Aircraft Quality Steel Cleanliness Martensitic Corrosion Resistant Steels Magnetic Particle Inspection Procedure. 1993
MAM 2303A	Aircraft Quality Steel Cleanliness Martensitic Corrosion Resistant Steels Magnetic Particle Inspection Procedure Metric (SI) Measurement. 1993
AMS 2641	Vehicle, Magnetic Particle Inspection Petroleum Base. 1988
AMS 3040B	Magnetic Particles, Nonfluorescent, Dry Method. 1995
AMS 3041B	Magnetic Particles, Nonfluorescent, Wet Method, Oil Vehicle, Ready-To-Use. 1988
AMS 3042B	Magnetic Particles, Nonfluorescent, Wet Method, Dry Powder. 1988
AMS 3043A	Magnetic Particles, Nonfluorescent, Wet Method, Oil Vehicle, Aerosol Packaged. 1988
AMS 3044C	Magnetic Particles, Fluorescent, Wet Method, Dry Powder. 1989
AMS 3045B	Magnetic Particles, Fluorescent, Wet Method, Oil Vehicle Ready-to-Use. 1989
AMS 3046B	Magnetic Particles, Fluorescent, Wet Method, Oil Vehicle, Aerosol Packaged. 1989
U.S. GOVERNMENT SPECIFICATIONS	
DOD-F-87935	Fluid, Magnetic Particle Inspection, Suspension. 1993
Mil-Std-271F	Requirements for Nondestructive Testing Methods. 1993
Mil-Std-410E	Nondestructive Testing Personnel Qualifications and Certifications. 1991
MIL-HDBK-728/1	Nondestructive Testing. 1985
MIL-HDBK-728/4A	Magnetic Particle Testing. 1993
OTHER PUBLICATIONS	
SNT-TC-1A	American Society for Nondestructive Testing. Recommended Practice . 1992 (Personnel Qualification and Certification in Nondestructive Testing and Recommended Training Courses) Note: Updated every 4 years - 1996 edition due in early 1997.
ATA No. 105	Air Transport Association of America. Guidelines for Training and Qualifying Personnel in Nondestructive Testing Methods, (Revision 4 1993)
ASM Handbook, Volume 17	Nondestructive Evaluation and Quality Control. 1989

5-45. PREPARATION OF SURFACE.

a. Remove protective coatings according to the manufacturer's instructions if necessary. Unless otherwise specified, magnetic particle examination should not be performed with coatings in place that could prevent the detection of surface defects in the ferro-magnetic substrate. Such coatings include paint or chromeplate thicker than 0.003 inch, or ferromagnetic coatings such as electroplated nickel thicker than 0.001 inch.

b. Parts should be free of grease, oil, rust, scale, or other substances which will interfere with the examination process. If required, clean by vapor degrease, solvent, or abrasive means per the manufacturer's instructions. Use abrasive cleaning only as necessary to completely remove scale or rust. Excessive blasting of parts can affect examination results.

c. Exercise extreme care to prevent any cleaning material or magnetic particles from becoming entrapped where they cannot be removed. This may require extracting components such as bushings, bearings, or inserts from assemblies before cleaning and magnetic particle examination.

d. A water-break-free surface is required for parts to be examined by water suspension methods. If the suspension completely wets the surface, this requirement is met.

e. Magnetic particle examination of assembled bearings is not recommended because the bearings are difficult to demagnetize. If a bearing cannot be removed, it should be protected from the magnetic particle examination materials and locally magnetized with a magnetic yoke to limit the magnetic field across the bearing.

5-46. METHODS OF EXAMINATION. Magnetic particle examination generally consists of: the application of magnetic particles; magnetization; determination of field strength; special examination techniques; and demagnetization and post-examination cleaning. Each of these steps will be described in the following paragraphs.

5-47. APPLICATION OF MAGNETIC PARTICLES. The magnetic particles used can be nonfluorescent or fluorescent (dependent on the examination required) and are applied suspended in a suitable substance. Fluorescent particles are preferred due to their higher sensitivity.

a. Wet Continuous Method. Unless otherwise specified, use only the wet continuous method. In the wet continuous method, the particle suspension is liberally applied to wet all surfaces of the part. The magnetizing current is applied at the instant the suspension is diverted from the part. Apply two shots of magnetizing current, each at least 1/2 second long.

(1) Wet suspensions of fluorescent particles, either in water or oil, should be used for most overhaul and in-service examinations except where the material, size, or shape of the part prohibits its use.

(2) Water, with a suitable rust inhibitor and wetting agent, may be used as a liquid vehicle, provided that magnetic examination equipment is designed for use or is satisfactorily converted for use with water.

b. Dry Continuous Method. This method is not recommended for use on aerospace components because of its lower sensitivity level.

c. Residual Magnetization Method. In this method, the part is magnetized and the magnetizing current is then cut off. If the amperage has been correctly calculated and quality indicator has verified the technique, then one shot will correctly magnetize the part. The magnetic particles are applied to the part after the magnetization. This method is dependent upon the retentiveness of the part, the strength of the applied field, the direction of magnetization, and the shape of the part.

5-48. MAGNETIZATION.

a. Circular. Circular magnetization is induced in the part by the central-conductor method or the direct-contact method. (See figure 5-11.)

(1) Indirect Induction (central-conductor method). Pass the current through a central conductor that passes through the part. When several small parts are examined at one time, provide sufficient space between each piece to permit satisfactory coverage (with particles), magnetization, and examination.

(2) Direct Induction (contact method). Pass current through the part mounted horizontally between contact plates. As an example, circular magnetization of a round steel bar would be produced by placing the ends of the steel bar between the heads of the magnetic inspection machine and passing a current through the bars. Magnetic particles applied either during or after passage of the current, or after passage of the current in magnetically-retentive steels, would disclose discontinuities parallel to the axis of the bar.

NOTE: Exercise extreme caution to prevent burning of the part at the electrode contact areas. Some causes of overheating and arcing are: insufficient contact area, insufficient contact pressure, dirty or coated contact areas, electrode removal during current flow, and too high an amperage setting.

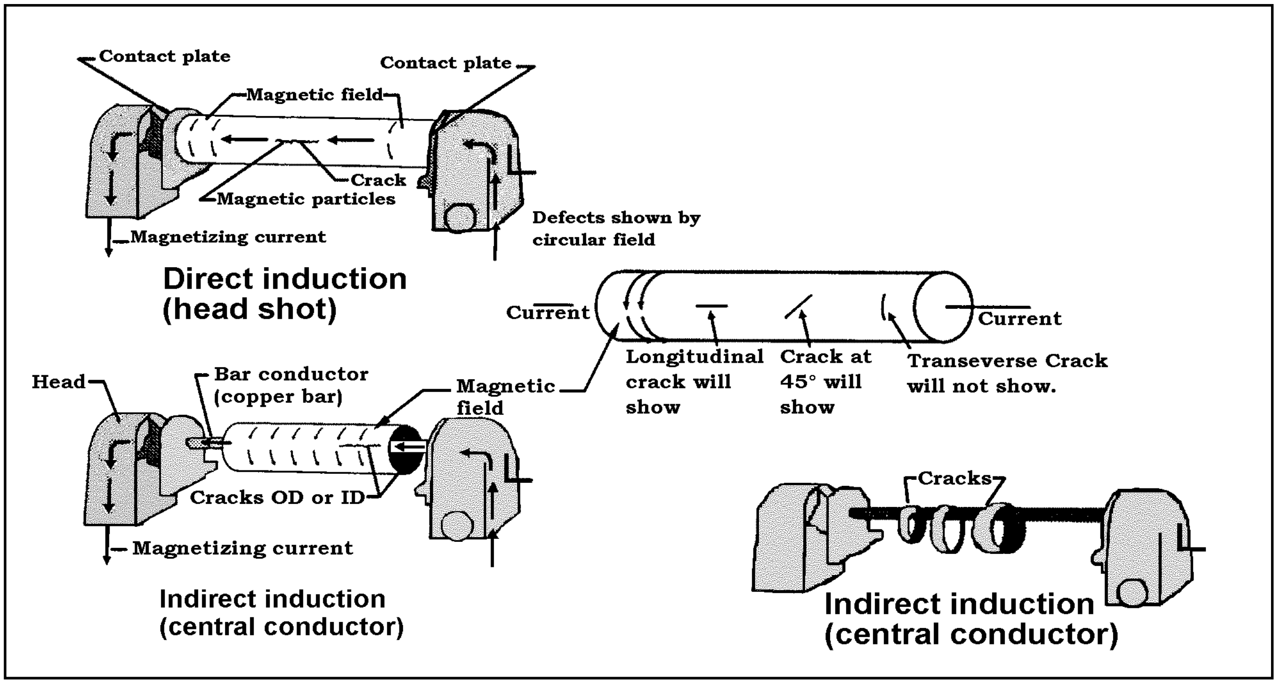


FIGURE 5-11. Circular magnetization.

b. Longitudinal. Longitudinal magnetization is induced in a part by placing the part in a strong magnetic field, such as the center of a coil or between the poles of an electromagnetic yoke. (See figure 5-12.) When using a coil, optimum results are obtained when the following conditions are met.

(1) The part to be examined is at least twice as long as it is wide.

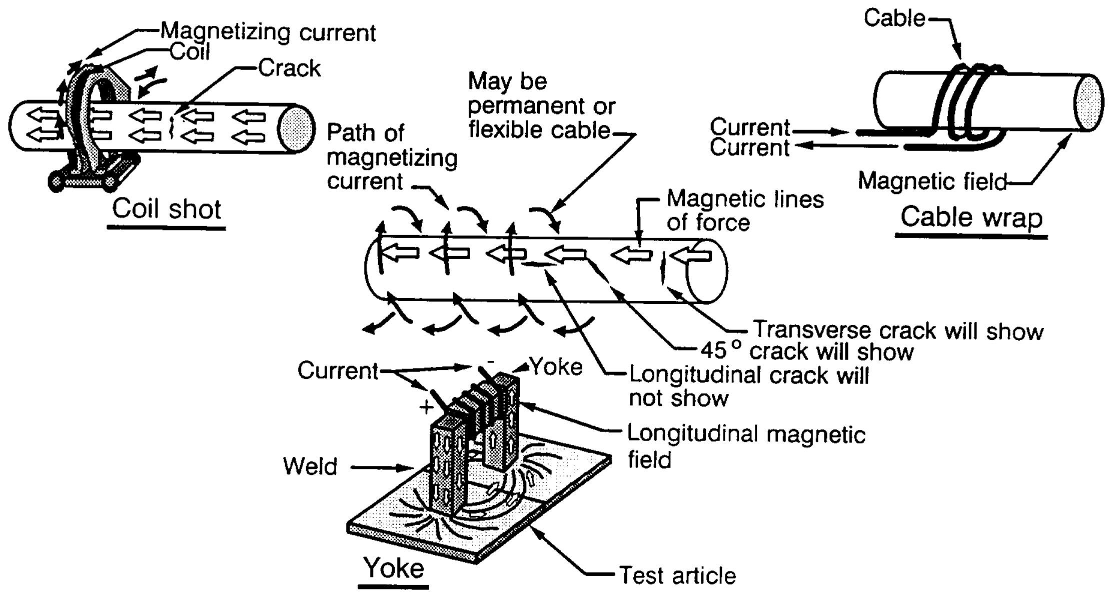
(2) The long axis of the part is parallel to the axis of the coil opening.

(3) The area of the coil opening is at least 10 times the cross-sectional areas of the part.

(4) The part is positioned against the inner wall of the coil.

(5) Three to five turns are employed for hand-held coils formed with cables.

(6) For the 10-to-1 fill factor, the effective region of inspection is 1 coil radius on either side of the coil with 10 percent overlap. (Refer to ASTME-1444.)



COIL SHOT
The usual way to longitudinally magnetize a part is to place the part lengthwise inside the bottom of the coil. Multiple inspections are necessary on long parts because the effective field extends only 6 to 9 inches on either side of the coil.

CABLE WRAP
Cable wrapping a coil around large or heavy parts is a common practice. Cable length must be kept as short as practical to minimize cable-resistance loss and aid in obtaining higher current amperages. Normally, three to five turns are sufficient.

YOKE
Essentially a yoke is a temporary horseshoe magnet. It is made of low-retentivity iron that is magnetized by a small coil wound around its horizontal bar. Yokes are recommended for parts subject to arc burns and for spot inspection of large parts.

FIGURE 5-12. Longitudinal magnetization.

(7) The intensity of the longitudinal shots is kept just below the level at which leakage fields develop across sharp changes of section, such as radii under bolt heads, threads, and other sharp angles in parts. This does not apply when checking chrome-plated parts for grinding cracks.

(a) For example, longitudinal magnetization of a round steel bar would be produced by placing the DC coil around the bar. After application of the magnetic particles, either during or subsequent to magnetization, discontinuities perpendicular to the longitudinal axis of the bar would be disclosed.

(b) When a yoke is used, the portion of the part between the ends of the yoke completes the path of the magnetic lines of force. This results in a magnetic field between the points of contact.

c. Permanent Magnets and Electromagnetic Yoke. The stability of the magnetic field generated by permanent magnets requires some agitation of the oxide particles within the field. The wet method is considered most satisfactory. Use a well-agitated plastic squirt bottle for the most effective application of the magnetic particle suspension. When the direction of possible cracks in a suspect area is not known, or would not necessarily be normal to the lines of force between the poles of the magnet, reposition the magnet to the best advantage and recheck. Usually, two shots, 90 degrees apart are required. The part must be demagnetized between each magnetization when the field direction is changed unless the next shot is at least 10 percent stronger than the previous shot, if this is the case demagnetization is not necessary.

5-49. DETERMINATION OF FIELD STRENGTH. Factors such as part size, shape, magnetic properties of the material, and the method of magnetization will affect the field strength induced within a part by a given applied magnetizing force. The factors vary considerably, making it difficult to establish rules for magnetizing during examination. Technique requirements are best determined on actual parts having known defects.

a. A magnetization indicator, such as a Quantitative Quality Indicator (QQI), should be used to verify that adequate magnetic flux strength is being used. It effectively indicates the internally-induced field, the field direction, and the quality of particle suspension during magnetization.

b. The level of magnetization required for detection of service-related defects in most cases can be lower than that required for material and manufacturing control. Contact the manufacturer for correct specifications.

> **NOTE: If the examination must be performed with less current than is desired because of part size or equipment limitations, the lower field strength can be partially accommodated by reducing the area of examination for each magnetization, or the examination can be supplemented by using electromagnetic yokes. Examine only 4 inches on either side of a coil instead of 6, or apply additional magnetization around the periphery of a hollow cylinder when using an internal conductor.**

5-50. SPECIAL EXAMINATION TECHNIQUES.

a. Magnetic Rubber. Magnetic rubber formulations using finely divided magnetic particles in a silicone rubber base are used for the inspection of screw, bolt, or other bore holes, which are not easily accessible. The liquid silicone rubber mixture is poured into holes in magnetic parts to be inspected.

Curing time for silicone rubbers varies from about 30 minutes and up depending upon the particular silicone rubber, the catalyst, and the amount of catalyst used to produce the curing reaction.

b. Curing. While curing is taking place, the insides of the hole must be maintained in the required magnetized state. This can be accomplished using a permanent magnet, a DC yoke, an electromagnet, or some other suitable means. Whatever method of magnetization is used, the leakage fields at any discontinuities inside the holes must be maintained long enough to attract and hold in position the magnetic particles until a partial cure takes place. A two-step magnetizing procedure has been developed.

(1) The first magnetization is accomplished for a short time in one direction followed by a second at 90 degrees to the first for the same length of time. This procedure must be repeated for whatever period of time is needed until the cure prevents particle mobility. Magnetization in two directions 90 degrees apart ensures formation of indications at discontinuities in all directions inside the holes.

(2) After curing, the rubber plugs, which are exact replicas of the holes, are removed and visibly examined for indications which will appear as colored lines against the lighter colored background of the silicone rubber. Location of any discontinuities or other surface imperfections in the holes can be determined from the location of the indications on the plugs. The magnetic rubber inspection method is covered in detail in Air Force Technical Order 33B-1-1, section XI.

c. Critical Examination for Sharp Radii Parts. A critical examination is required for cracks in sharp radii; such as threaded parts, splines, gear teeth roots, and abrupt changes in sections, that cause obscuring and nonrelevant indications during normal examination practices. The procedure provided herein is the most sensitive method for detecting the early beginnings of in-service fatigue cracks in the sharp, internal radii of ferro-magnetic parts. Magnetic particle examination equipment may be used; however, alternating fields are not reliable to provide the necessary high level of residual magnetism. Optical aids are necessary to realize the maximum sensitivity provided by this magnetic particle procedure. Low-power (10x-30x) binocular microscopes are recommended. As a minimum, pocket magnifiers of 7 to 10 power may be used with the following procedure.

(1) Thoroughly clean the part at the sharp radii and fillets where soils, greases, and other contaminants tend to accumulate and at other places where they might be overlooked during a casual or hasty examination.

(2) The residual method should be used as an aid in particular problem areas, even though it is not considered the best practice in most of the instances. The conventional wet continuous methods should be used initially for overall examination and the residual technique should be applied only for supplemental, local examination of the sharp radii. It should not be applied except in those cases where nonrelevant indications have proven to be a problem in the initial examination.

(3) Methods of magnetization should be done according to standard procedures; however, alternating fields should not be used, and the level of magnetizing force imposed should usually be increased above the normal levels to ensure a higher residual field within the part.

(4) Following magnetization, apply particles in liquid suspension. The application should be liberal and in a manner to cause maximum particle buildup. Immersion of small parts such as rod end fittings in a container of suspension, which has just been stirred for about 30 seconds, is an excellent method.

(5) Check for the presence of particle accumulation in the sharp radii. It is necessary that the level of magnetization and the particle application result in the formation of nonrelevant indications. Lack of indications will require remagnetization to a higher level, more care in applying the particles, or both.

(6) Wash the parts in a clean suspension vehicle only enough to remove the weakly-held particle accumulations causing the nonrelevant indications. Particles at true cracks will be more strongly held and will persist if the washing is gently done. This can be accomplished by flowing or directing a stream of liquid vehicle over the part, or for a small component, by gently stirring in a container of the vehicle. Closely observe the removal of the nonrelevant particle accumulations in the region to be examined to avoid excessive washing. If washing is prolonged beyond the minimum needed to remove the nonrelevant indications, the small defect indications may also be washed away. A few trials will help to develop the best method and time required for washing.

(7) Check for crack indications with optical magnification and ample lighting. The smaller indications that are attainable by this procedure cannot be reliably seen or evaluated with the unaided eye.

5-51. DEMAGNETIZATION AND POST-EXAMINATION CLEANING. Parts should be magnetized longitudinally last before demagnetizing.

NOTE: Circular magnetism cannot be read with a field meter since it is an internal magnetic field. However, if the last shot, was a coil shot the meter can read it if a magnetic field is present.

a. Demagnetization. Demagnetize between successive magnetization of the same part, to allow finding defects in all directions, and whenever the residual magnetism interferes with the interpretation of the indications. Also, demagnetize all parts and materials after completion of magnetic particle examination. Test all parts at several locations and parts for residual magnetism of complex configuration at all significant changes in geometry. Repeat demagnetization if there is any appreciable deflection of the field indicator needle.

(1) AC method. Hold the part in the AC demagnetizing coils and then move the part slowly and steadily through the coils and approximately 3 to 4 feet past the coils. Repeat this process until the part loses its residual magnetism. Rotate and tumble parts of complex configuration as they are passed through the coils.

(2) DC method. Place the part in the same relative position as when magnetized and apply reversing DC current. Gradually reduce the current to zero and repeat the process until the residual magnetic field is depleted.

b. Post-Examination Cleaning.

(1) When oil suspensions are used, solvent clean or remove the part until all magnetic particles and traces of oil are removed.

(2) When parts or materials have been examined using water suspension methods, completely remove the water by any suitable means, such as an air blast, to ensure that the parts are dried immediately after cleaning. Thoroughly rinse the part with a detergent-base cleaner until all magnetic particles are removed. Then rinse in a solution of water and rust inhibitor.

(3) For cadmium-plated parts an air-water vapor blast may be used to remove any remaining magnetic particle residue.

(4) After final cleaning and drying, use temporary protective coatings, when necessary, to prevent corrosion.

(5) After magnetic particle examination has been completed, restore any removed finishes according to the manufacturer's repair manual.

NOTE: Visible penetrant is often used interchangeably by NDI personnel with fluorescent penetrant. However, the chemical within most common red dye penetrants will neutralize the fluorescence of the chemicals used in that method. Therefore, a thorough cleaning of all magnetic particles is mandatory.

5-52.—5-59. [RESERVED.]

SECTION 5. PENETRANT INSPECTION

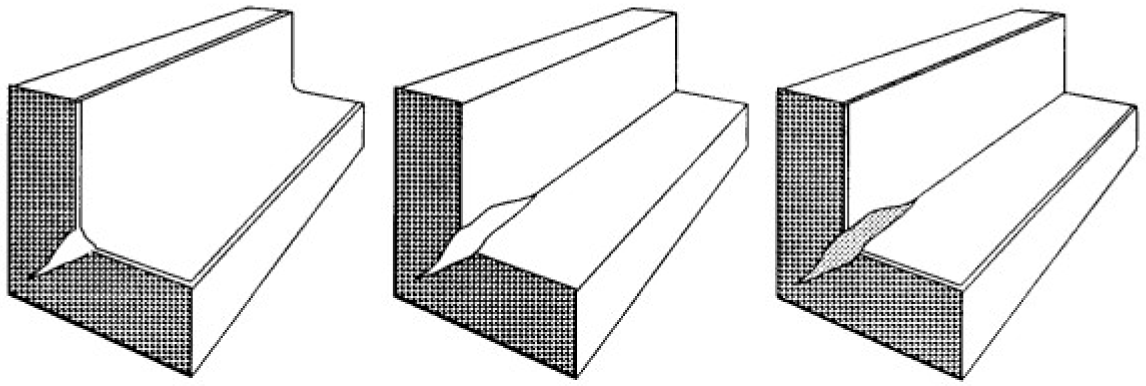
5-60. GENERAL. Penetrant inspection is used on nonporous metal and nonmetal components to find material discontinuities that are open to the surface and may not be evident to normal visual inspection. The part must be clean before performing a penetrant inspection. The basic purpose of penetrant inspection is to increase the visible contrast between a discontinuity and its background. This is accomplished by applying a liquid of high penetrating power that enters the surface opening of a discontinuity. Excess penetrant is removed and a developer material is then applied that draws the liquid from the suspected defect to reveal the discontinuity. The visual evidence of the suspected defect can then be seen either by a color contrast in normal visible white light or by fluorescence under black ultraviolet light. (See figure 5-13.)

a. The penetrant method does not depend upon ferro-magnetism like magnetic particle inspection, and the arrangement of the discontinuities is not a factor. The penetrant method is effective for detecting surface defects in nonmagnetic metals and in a variety of nonmetallic materials. Penetrant inspection is also used to inspect items made from ferromagnetic steels and its sensitivity is generally greater than that of magnetic particle inspection. Penetrant inspection is superior to visual inspection but not as sensitive as other advanced forms of tests for detection of in-service surface cracks.

b. The major limitations of the penetrant inspection is that it can detect only those discontinuities that are open to the surface; some other method must be used for detecting subsurface defects. Surface roughness or porosity can limit the use of liquid penetrants. Such surfaces can produce excessive background indications and interfere with the inspection. Penetrant inspection can be used on most airframe parts and assemblies accessible to its application. The basic steps to perform penetrant inspections are briefly described in the following paragraphs.

5-61. EQUIPMENT USED IN THE PENETRANT INSPECTION PROCESS. Equipment varies from simple aerosol cans used in portable systems to fully automated computer-controlled systems. Whether fluorescent or visible penetrants are used, different penetrant bases are available but may require different cleaning methods. Water-washable penetrants can often be removed by a simple water washing process, whereas oil-base penetrants may require special solvents for removal. Some oil-base penetrants have emulsifiers, either added to the penetrant before it is applied or added afterwards, that allow water washing to be used. Developers used, can be applied either by a wet or dry bath. Therefore, each penetrant inspection process may require different cleaning facilities and procedures. (See table 5-3.)

5-62. BASIC STEPS TO PERFORM PENETRATION INSPECTION. Table 5-4 shows a general process, in the procedures flow sheet, for commonly used penetrant inspection processes. It is important to ensure that parts are thoroughly cleaned and dried before doing penetrant inspection. All surfaces to be inspected should be free of contaminants, paint, and other coatings that could prevent penetrant from entering discontinuities. Table 5-5 shows applications of various methods of precleaning for penetrant inspection.



(A) PENETRANT, APPLIED TO SURFACE, SEEPS INTO DISCONTINUITY

(B) PENETRANT, REMOVED FROM SURFACE, BUT DISCONTINUITY REMAINS FULL

(C) DEVELOPER, ACTS AS A BLOTTER, TO DRAW THE PENETRANT OUT OF SURFACE DISCONTINUITY AND PRODUCE A VISIBLE INDICATION

FIGURE 5-13. Penetrant and developer action.

TABLE 5-3. Classification of penetrant inspection materials covered by MIL-I-25135E.

PENETRANT SYSTEMS	DEVELOPERS	SOLVENT REMOVERS
Type I Fluorescent Dye Type II Visible Dye Type III Visible and Fluorescent Dye (dual mode)	Form a Dry Powder Form b Water Soluble Form c Water Suspendible Form d Nonaqueous Form e Specific Application	Class (1) Halogenated (chlorinated) Class (2) Nonhalogenated (nonchlorinated) Class (3) Specific Application
Method A Water Washable Method B Post emulsifiable, Lipophilic Method C Solvent Removable Method D Post Emulsifiable, Hydrophilic		
Sensitivity Level 1/2 Ultralow Sensitivity Level 1 Low Sensitivity Level 2 Medium Sensitivity Level 3 High Sensitivity Level 4 Ultrahigh		

TABLE 5-4. Fluorescent and visible penetrant inspection general processing procedures flowsheet.

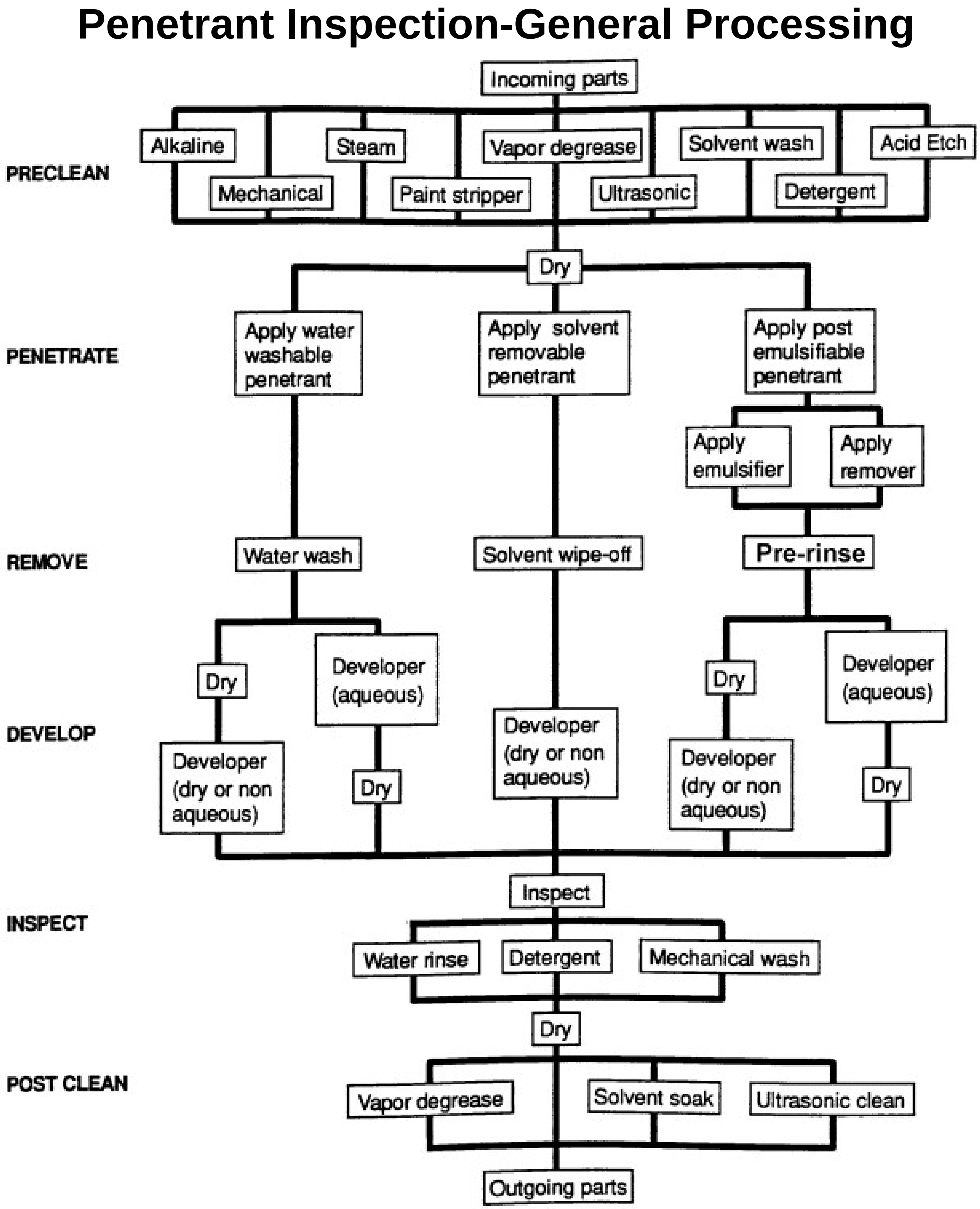


TABLE 5-5. Pre-cleaning methods for penetrant inspection.

METHOD	USE
Mechanical Methods	
Abrasive tumbling	Removing light scale, burrs, welding flux, braze stopoff, rust, casting mold, and core material; should not be used on soft metals such as aluminum, magnesium, or titanium.
Dry abrasive grit blasting	Removing light or heavy scale, flux, stopoff, rust, casting mold and core material, sprayed coatings, carbon deposits: In general, any brittle deposit. Can be fixed or portable (may peen metal over defect).
Wet abrasive grit blast	Same as dry except, where deposits are light, better surface and better control of dimensions are required.
Wire brushing	Removing light deposits of scale, flux, and stopoff (may mask defect by displacing metal).
High pressure water and steam	Ordinarily used with an alkaline cleaner or detergent; removing typical machine shop contamination, such as cutting oils, polishing compounds, grease, chips, and deposits from electrical discharge machining; used when surface finish must be maintained.
Ultrasonic cleaning	Ordinarily used with detergent and water or with a solvent; removing adhering shop contamination from large quantities of small parts.
Chemical Methods	
Alkaline cleaning	Removing braze stopoff, rust, scale, oils, greases, polishing material, and carbon deposits; ordinarily used on large articles where hand methods are too laborious; also used on aluminum for gross metal removal.
Acid cleaning	Strong solutions for removing heavy scale; mild solutions for light scale; weak (etching) solutions for removing lightly smeared metal.
Molten salt bath cleaning	Conditioning and removing heavy scale; not suitable for aluminum, magnesium, or titanium.
Solvent Methods	
Solvent wiping	Same as for vapor degreasing except a hand operation; may employ nonhalogenated (nonchlorinated) solvents; used for localized low-volume cleaning.

CAUTION: Improper cleaning methods can cause severe damage or degradation of the item being cleaned. Personnel must select and apply cleaning processes in accordance with aircraft, engine, propeller, or appliance manufacturer's recommendations.

5-63. CLEANERS AND APPLICATIONS. Use a cleaner to remove contaminants from parts prior to the application of penetrant inspection materials. After the inspection is completed, penetrant inspection material residues are removed. The following cleaners are commonly used during the penetrant inspection process.

a. Detergents. Detergent cleaners are water-based chemicals called surfactants, which surround and attach themselves to particles of contaminants allowing them to be washed away.

b. Solvents. Solvents dissolve contaminants such as oils, greases, waxes, sealants, paints, and general organic matter so they can easily be wiped away or absorbed on a cloth. They are also used to remove Method C penetrant material prior to developer application.

c. Alkalies. Alkaline cleaners are water solutions of chemicals that remove contaminants by chemical action or displacement rather than dissolving the contaminant.

d. Paint Removers. The general types of removers used for conventional paint coatings are solvent, bond release, and disintegrating.

e. Salt Baths. Molten salt baths are used in removing heavy, tightly-held scale and oxide from low alloy steels, nickel, and cobalt-base alloys, and some types of stainless steel. They cannot be used on aluminum, magnesium, or titanium alloys.

f. Acids. Solutions of acids or their salts are used to remove rust, scale, corrosion products, and dry shop contamination. The type of acid used and its concentration depends on the part material and contaminants to be removed.

g. Etching Chemicals. Etching chemicals contain a mixture of acids or alkalies plus inhibitors. They are used to remove a thin layer of surface material, usually caused by a mechanical process, that may seal or reduce the opening of any discontinuities. The type of etching solution used depends on the part material and condition.

h. Penetrant Application. Apply the penetrant by spraying, brushing, or by completely submerging the part in a container of penetrant. Wait the recommended amount of time after the penetrant has been applied to allow it to enter any discontinuities

(1) Removal of Excess Penetrant. Excess penetrant must be removed from the part's surface to prevent a loss of contrast between indications of discontinuities and the background during the inspection. Removal may require actually washing or spraying the part with a cleansing liquid, or may simply require wiping the part clean with a solvent-moistened cloth. The removal method is determined by the type of penetrant used.

(2) Drying. If removal of the excess penetrant involves water or other cleaning liquids, drying of the part may be required prior to developer application. When drying is required, the time can be decreased by using ovens or ventilation systems.

i. Developer Application. Apply developer after excess penetrant is removed and, where required, the surface is dried. Apply the developer in a thin uniform layer over the surface to be inspected. Developer acts like a blotter to assist the natural capillary action bleed-out of the penetrant from discontinuities and to spread the penetrant at discontinuity surface edges to enhance bleed-out indications. After the developer is applied, allow sufficient time for the penetrant to be drawn out of any discontinuities. Follow the manufacturer's recommendations.

j. Inspection for Discontinuities. After the penetrant has sufficiently developed, visually inspect the surface for indications from discontinuities. Evaluate each indication observed to determine if it is within acceptable limits. Visible penetrant inspection is performed in normal visible white light, whereas fluorescent penetrant inspection is performed in black (ultraviolet) light.

k. Post-Cleaning. Remove inspection material residues from parts after completion of penetrant inspection. This residue could interfere with subsequent part processing, or if left on some alloys, it could increase their susceptibility to hydrogen embrittlement, intergranular corrosion, and stress corrosion during service.

5-64. TECHNICAL STANDARDS. Two of the more generally accepted aerospace industry standards are the MIL-I-25135E, Inspection Materials, Penetrants (see table 5-6) and ASTM-E-1417. The penetrant materials specification (MIL-I-25135E) is used to procure penetrant materials and the process control specification (MIL-STD-6866) is used to establish minimum requirements for conducting a penetrant inspection. Table 5-6 provides a partial listing of commonly-accepted standards and specifications for penetrant inspection.

TABLE 5-6. Listing of commonly accepted standards and specifications for penetrant inspection.

NUMBER	TITLE
ASTM STANDARDS	
ASTM-E-165	Standard Practice for Liquid Penetrant Inspection Method
ASTM -E-270	Standard Definitions of Terms Relating to Liquid Penetrant Inspection
ASTM -E-1135	Standard Method for Comparing the Brightness of Fluorescent Penetrants
ASTM -E-1208	Standard Method for Fluorescent Liquid Penetrant Examination Using the Lipophilic Post-Emulsification Process
ASTM -E-1209	Standard Method for Fluorescent Penetrant Examination Using the Water Washable Process
ASTM -E-1210	Standard Method for Fluorescent Penetrant Examination Using the Hydrophilic Post-Emulsification Process
ASTM -E-1219	Standard Method for Fluorescent Penetrant Examination Using the Solvent Removable Process
ASTM -E-1220	Standard Method for Visible Penetrant Examination Using the Solvent Removable Method
ASTM -E-2512	Compatibility of Materials with Liquid Oxygen (Impact-Sensitivity Threshold Technique)
SAE-AMS SPECIFICATIONS	
AMS-2647	Fluorescent Penetrant Inspection - Aircraft and Engine Component Maintenance
US GOVERNMENT SPECIFICATIONS	
MIL-STD-271	Requirements for Nondestructive Testing
MIL-STD-410	Nondestructive Testing Personnel Qualifications and Certifications
MIL-STD-1907	Inspection, Liquid Penetrant and Magnetic Particle, Soundness Requirements for Materials, Parts and Welds
MIL-STD-6866	Inspection, Liquid Penetrant
MIL-STD-728/1	Nondestructive Testing
MIL-STD-728/3	Liquid Penetrant Testing
MIL-STD-25135E	Inspection Materials, Penetrants
QPL-25135	Qualified Products List of Materials Qualified Under MIL-I-25135
T.O. 33B-1-1	U.S. Air Force/Navy Technical Manual, Nondestructive Testing Methods
OTHER PUBLICATIONS	
SNT-TC-1A	Personnel Qualification and Certification in Nondestructive Testing and Recommended Training Courses
ATA No. 105	Guidelines for Training and Qualifying Personnel in Nondestructive Methods,
Metals Handbook, Ninth Edition, Volume 17	Nondestructive Evaluation, and Quality Control

5-65.—5-72. [RESERVED.]

SECTION 6. RADIOGRAPHY (X-RAY) INSPECTION

5-73. GENERAL. Radiography (x-ray) is an NDI method used to inspect material and components, using the concept of differential adsorption of penetrating radiation. Each specimen under evaluation will have differences in density, thickness, shapes, sizes, or absorption characteristics, thus absorbing different amounts of radiation. The unabsorbed radiation that passes through the part is recorded on film, fluorescent screens, or other radiation monitors. Indications of internal and external conditions will appear as variants of black/white/gray contrasts on exposed film, or variants of color on fluorescent screens. (See figure 5-14.)

5-74. LIMITATIONS. Compared to other nondestructive methods of inspection, radiography is expensive. Relatively large costs and space allocations are required for a radiographic laboratory. Costs can be reduced considerably when portable x-ray or gamma-ray sources are used in film radiography and space is required only for film processing and interpretation. Operating costs can be high because sometimes as much as 60 percent of the total inspection time is spent in setting up for radiography. With real-time radiography, operating costs are usually much lower, because setup times are shorter and there are no extra costs for processing or interpretation of film.

5-75. FILM OR PAPER RADIOGRAPHY. In film or paper radiography, a two-dimensional latent image from the projected radiation is produced on a sheet of film or paper that has been exposed to the unabsorbed radiation passing through the test piece. This technique requires subsequent development of the exposed film or paper so that the latent image becomes visible for viewing.

5-76. REAL-TIME RADIOGRAPHY. A two-dimensional image that can be immediately displayed on a viewing screen or television monitor. This technique converts unabsorbed radiation into an optical or electronic signal which can be viewed immediately or can be processed with electronic or video equipment.

5-77. ADVANTAGE OF REAL-TIME RADIOGRAPHY OVER FILM RADIOGRAPHY. The principal advantage of real-time radiography over film radiography is the opportunity to manipulate the test piece during radiographic inspection. This capability allows the inspection of internal mechanisms and enhances the detection of cracks and planar defects by allowing manipulation of the part to achieve the best orientation for flaw detection. Part manipulation during inspection also simplifies three-dimensional dynamic imaging for the determination of flaw location and size. In film radiography, depth parallel to the radiation beam is not recorded. Consequently, the position of a flaw within the volume of a test piece cannot be determined exactly with a single radiograph. To determine flaw location and size more exactly with film radiography, other film techniques; such as stereo-radiography, triangulation, or simply making two or more film exposures with the radiation beam being directed at the test piece from a different angle for each exposure, must be used.

5-78. COMPUTED TOMOGRAPHY (CT). CT is another important radiological technique with enhanced flaw detection and location capabilities. Unlike film and real-time radiography, CT involves the generation of cross-sectional views instead of a planar

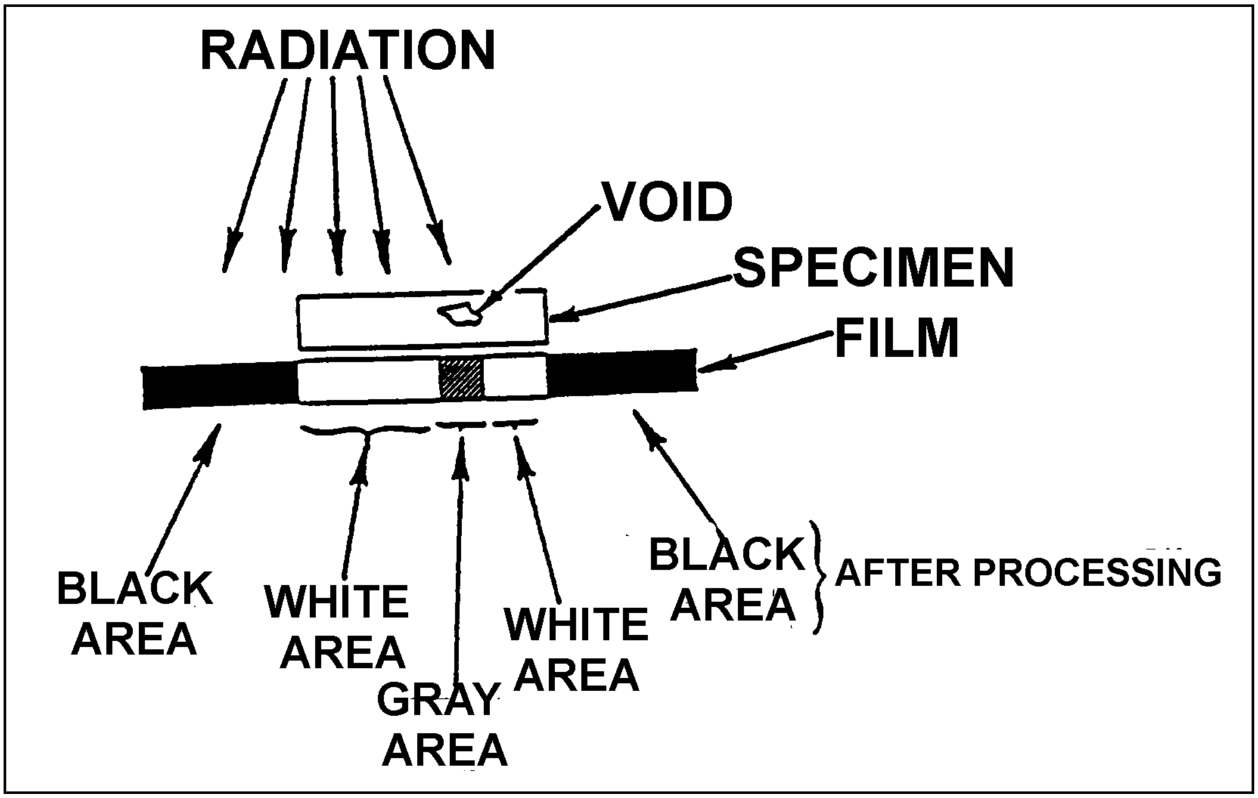


FIGURE 5-14. Radiography.

projection. The CT image is comparable to that obtained by making a radiograph of a physically sectioned thin planar slab from an object. This cross-sectional image is not obscured by overlying and underlying structures and is highly sensitive to small differences in relative density. Computed tomography images are also easier to interpret than radiographs.

5-79. USES OF RADIOGRAPHY. Radiography is used to detect the features of a component or assembly that exhibit a difference in thickness or density as compared to surrounding material. Large differences are more easily detected than small ones. In general, radiography can detect only those features that have an appreciable thickness in a direction along the axis of the radiation beam. Therefore, the ability of radiography to detect planar discontinuities, such as cracks, depends on proper orientation of the test piece during inspection. Discontinuities which have measurable thickness in all directions, such as voids and inclusions, can be detected as long as they are not too small in relation to section thickness. In general, features that exhibit a 2 percent or more difference in radiation adsorption compared to the surrounding material can be detected.

5-80. COMPARISON WITH OTHER NDI METHODS. Radiography and ultrasonic are the two generally-used, nondestructive inspection methods that can satisfactorily detect flaws that are completely internal and located well below the surface of the test part. Neither method is limited to the detection of specific types of internal flaws. However, radiography is more effective when the flaws are not planar, while ultrasonic is more effective when flaws are planar. In comparison to other generally-used NDI methods (e.g., magnetic particle, liquid penetrant, and eddy current inspection), radiography has the following advantages.

a. The ability to inspect for both internal and external flaws.

b. The ability to inspect covered or hidden parts or structures.

c. The ability to detect significant variations in composition.

d. Provides a permanent recording of raw inspection data.

5-81. FLAWS. Certain types of flaws are difficult to detect by radiography. Cracks cannot be detected unless they are essentially along the axis of the radiation beam. Tight cracks in thick sections may not be detected at all, even when properly oriented. Minute discontinuities such as: inclusions in wrought material, flakes, microporosity, and microfissures may not be detected unless they are sufficiently segregated to yield a detectable gross effect. Delaminations are nearly impossible to detect with radiography. Because of their unfavorable orientation, delaminations do not yield differences in adsorption that enable laminated areas to be distinguished from delaminated areas.

5-82. FIELD INSPECTION. The field inspection of thick sections can be a time-consuming process, because the effective radiation output of portable sources may require long exposure times of the radiographic film. This limits field usage to sources of lower activity that can be transported. The output of portable x-ray sources may also limit field inspection of thick sections, particularly if a portable x-ray tube is used. Portable x-ray tubes emit relatively low-energy (300 kev) radiation and are limited in the radiation output. Both of these characteristics of portable x-ray tubes combine to limit their application to the inspection of sections having the adsorption equivalent of 75 mm (3 inches) of steel maximum. Portable linear accelerators and betatrons that provide high-energy (> 1 MeV) x-rays can be used for the radiographic field inspection of thicker sections.

5-83. SAFETY. Radiographic safety requirements can be obtained from; the OEM's manual, FAA requirements, cognizant FAA ACO engineers, and radiation safety organizations such as the Nuclear Regulatory Commission (NRC). Information in radiation safety publications can be used as a guide to ensure that radiation exposure of personnel involved in radiographic operations is limited to safe levels, and to afford protection for the general public.

5-84.—5-88. [RESERVED.]

SECTION 7. ULTRASONIC INSPECTION

5-89. GENERAL. Ultrasonic inspection is an NDI technique that uses sound energy moving through the test specimen to detect flaws. The sound energy passing through the specimen will be displayed on a Cathode Ray Tube (CRT), a Liquid Crystal Display (LCD) computer data program, or video/camera medium. Indications of the front and back surface and internal/external conditions will appear as vertical signals on the CRT screen or nodes of data in the computer test program. There are three types of display patterns; "A" scan, "B" scan, and "C" scan. Each scan provides a different picture or view of the specimen being tested. (See figure 5-15.)

5-90. SOUND REFLECTION. The amount of reflection that occurs when a sound wave strikes an interface depends largely on the physical state of the materials forming the interface and to a lesser extent on the specific physical properties of the material. For example: sound waves are almost completely reflected at metal/gas interfaces; and partial reflection occurs at metal/liquid or metal/solid interfaces.

5-91. ULTRASONIC INSPECTION TECHNIQUES. Two basic ultrasonic inspection techniques are employed: pulse-echo and through-transmission. (See figure 5-16.)

a. Pulse-Echo Inspection. This process uses a transducer to both transmit and receive the ultrasonic pulse. The received ultrasonic pulses are separated by the time it takes the sound to reach the different surfaces from which it is reflected. The size (amplitude) of a reflection is related to the size of the reflecting surface. The pulse-echo ultrasonic response pattern is analyzed on the basis of signal amplitude and separation.

b. Through-Transmission Inspection. This inspection employs two transducers, one to generate and a second to receive the ultrasound. A defect in the sound path between the two transducers will interrupt the sound transmission. The magnitude (the change in the sound pulse amplitude) of the interruption is used to evaluate test results. Through-transmission inspection is less sensitive to small defects than is pulse-echo inspection.

5-92. FLAW DETECTION. Ultrasonic inspection can easily detect flaws that produce reflective interfaces. Ultrasonic inspection is used to detect surface and subsurface discontinuities, such as: cracks, shrinkage cavities, bursts, flakes, pores, delaminations, and porosity. It is also used to measure material thickness and to inspect bonded structure for bonding voids. Ultrasonic inspection can be performed on raw material, billets, finished, and semi-finished materials, welds, and in-service assembled or disassembled parts. Inclusions and other nonhomogeneous areas can also be detected if they cause partial reflection or scattering of the ultrasonic sound waves or produce some other detectable effect on the ultrasonic sound waves. Ultrasonic inspection is one of the more widely-used methods of NDI.

5-93. BASIC EQUIPMENT. Most ultrasonic inspection systems include the following basic equipment; portable instruments (frequency range 0.5 to 15 MHz), transducers (longitudinal and shear wave), positioners, reference standards, and couplant.

a. Ultrasonic Instruments. A portable, battery-powered ultrasonic instrument is used for field inspection of airplane structure. (See figure 5-17.) The instrument generates an

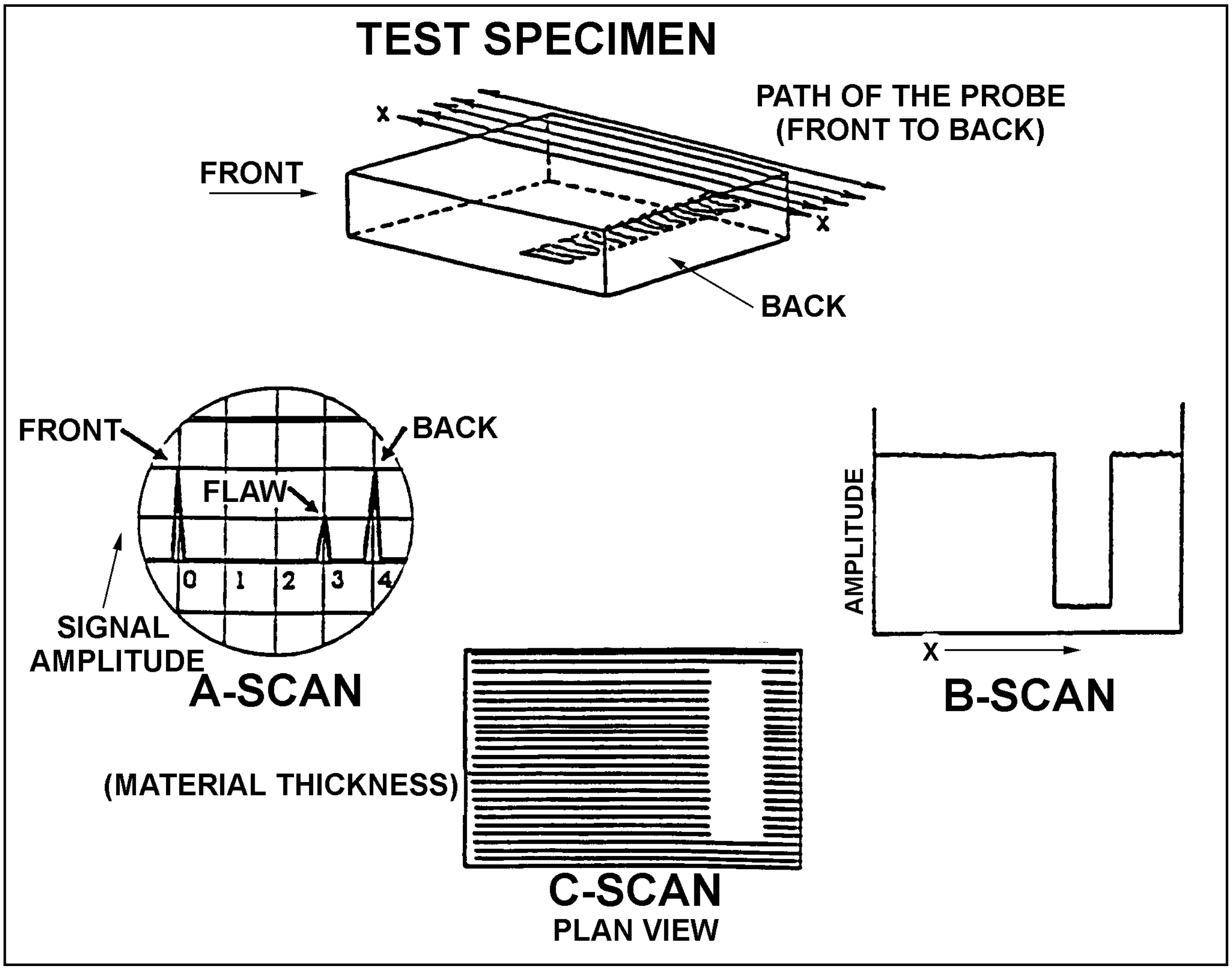


FIGURE 5-15. Ultrasound.

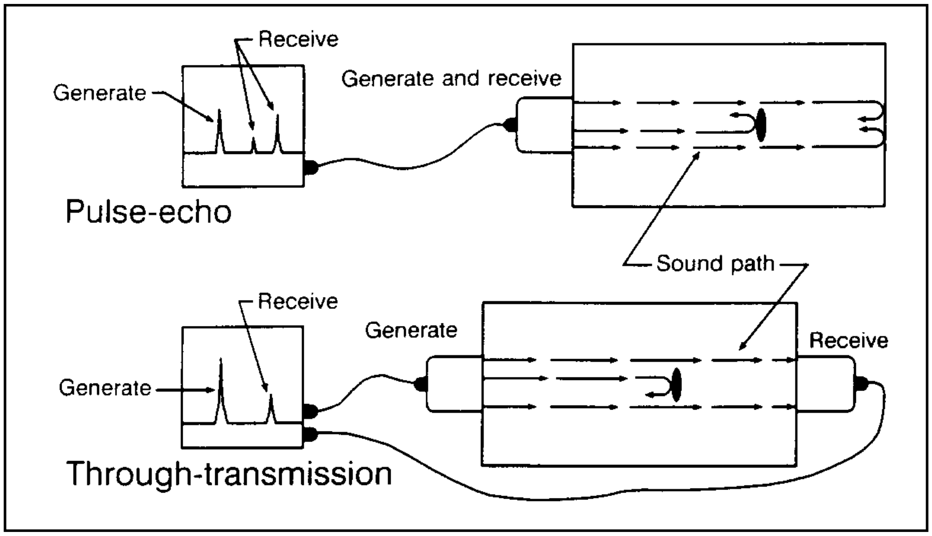


FIGURE 5-16. Pulse-echo and through-transmission ultrasonic inspection techniques.

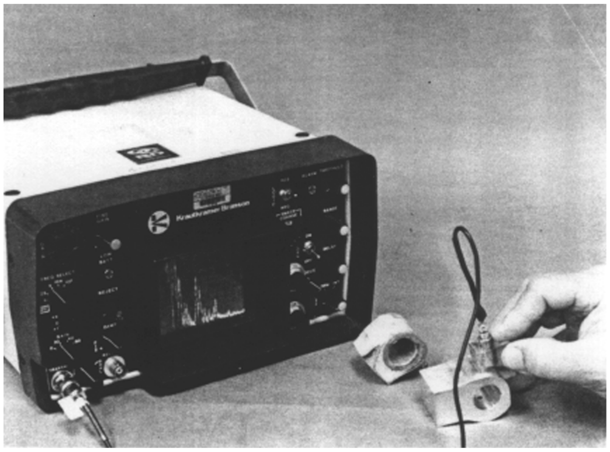


FIGURE 5-17. Typical portable ultrasonic inspection instrument.

ultrasonic pulse, detects and amplifies the returning echo, and displays the detected signal on a cathode ray tube or similar display. Piezoelectric transducers produce longitudinal or shear waves, which are the most commonly used wave forms for aircraft structural inspection.

b. Positioning Fixtures. To direct ultrasound at a particular angle, or to couple it into an irregular surface, transducer positioning fixtures and sound-coupling shoes are employed. (See figure 5-18.) Shoes are made of a plastic material that has the necessary sound-transmitting characteristics. Positioning fixtures are used to locate the transducer at a prescribed point and can increase the sensitivity of the inspection. (See figure 5-19.) If a transducer shoe or positioning fixture is required, the inspection procedure will give a detailed description of the shoe or fixture.

c. Reference Standards. Reference standards are used to calibrate the ultrasonic instrument (see figure 5-20), reference standards serve two purposes to provide an ultrasonic response pattern that is related to the part being inspected, and to establish the required inspection sensitivity. To obtain a representative response pattern, the reference standard configuration is the same as that of the test structure, or is a configuration that provides an ultrasonic response pattern representative of the test structure. The reference standard contains a simulated defect (notch) that is positioned to provide a calibration signal representative of the expected defect. The notch size is chosen to establish inspection sensitivity (response to the expected defect size). The inspection procedure gives a detailed description of the required reference standard.

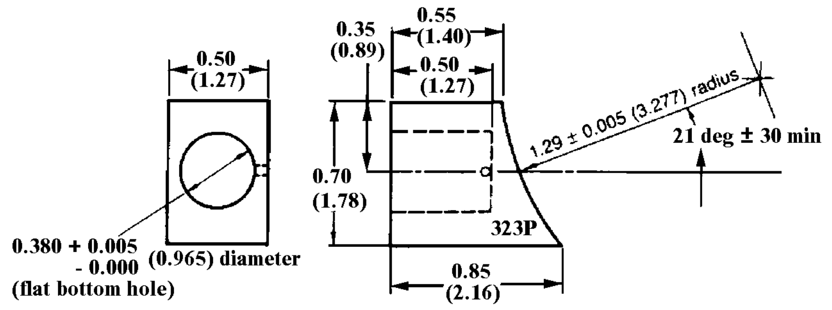
d. Couplants. Inspection with ultrasonics is limited to the part in contact with the transducer. A layer of couplant is required to couple the transducer to the test piece because ultrasonic energy will not travel through air. Some typical couplants used are: water, glycerin, motor oils, and grease.

5-94. INSPECTION OF BONDED STRUCTURES. Ultrasonic inspection is finding increasing application in aircraft bonded construction and repair. Detailed techniques for specific bonded structures should be obtained from the OEM's manuals, or FAA requirements. In addition, further information on the operation of specific instruments should be obtained from the applicable equipment manufacturer manuals.

a. Types of Bonded Structures. Many configurations and types of bonded structures are in use in aircraft. All of these variations complicate the application of ultrasonic inspections. An inspection method that works well on one part or one area of the part may not be applicable for different parts or areas of the same part. Some of the variables in the types of bonded structures are as follows.

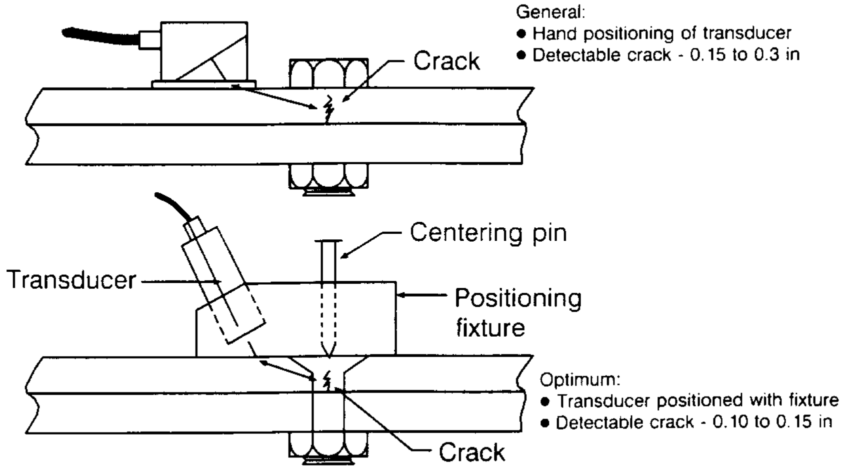
(1) Top skin material is made from different materials and thickness.

(2) Different types and thickness of adhesives are used in bonded structures.



Note:
All dimensions in inches followed by centimeters in parentheses.

FIGURE 5-18. Example of position fixture and shoe.



General:
- Hand positioning of transducer
- Detectable crack - 0.15 to 0.3 in

Optimum:
- Transducer positioned with fixture
- Detectable crack - 0.10 to 0.15 in

FIGURE 5-19. Example of the use if a transducer positioning fixture.

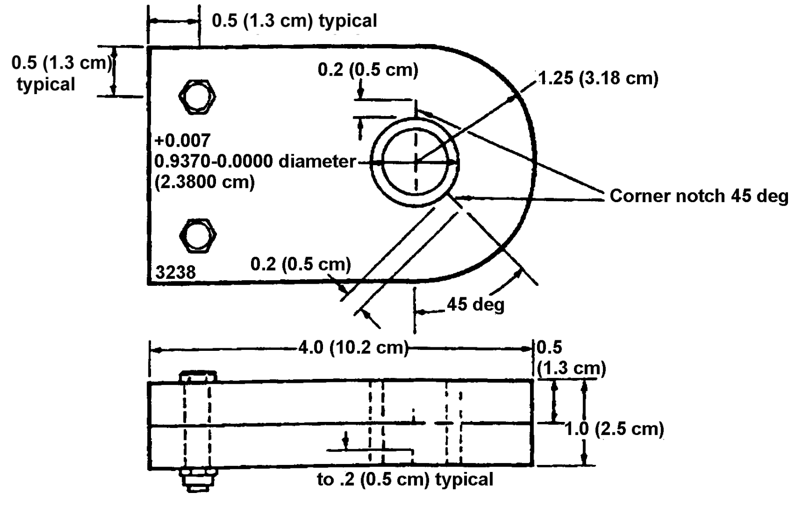


FIGURE 5-20. Example of a typical reference standard.

(3) Underlying structures contain differences in; core material, cell size, thickness, and height, back skin material and thickness, doublers (material and thickness), closure member attachments, foam adhesive, steps in skins, internal ribs, and laminates (number of layers, layer thickness, and layer material).

(4) The top only or top and bottom skin of a bonded structure may be accessible.

b. Application of Ultrasonic Inspection. Application to bonded structures must be examined in detail because of the many inspection methods and structural configurations. The advantages and limitations of each inspection method should be considered, and reference standards (representative of the structure to be inspected) should be ultrasonically inspected to verify proposed techniques.

c. Internal Configuration. Complete information on the internal configuration of the bonded test part must be obtained by the inspector. Drawings should be reviewed, and when necessary, radiographs of the test part should be taken. Knowledge of details such as the location and boundaries of doublers, ribs, etc., is required for valid interpretation of ultrasonic inspection results. The boundaries of internal details should be marked on the test part using a grease pen or other easily removable marking.

d. Reference Standards. Standards can be a duplicate of the test part except for the controlled areas of unbond. As an option, simple test specimens, which represent the varied areas of the test part and contain controlled areas of unbond, can be used. Reference standards must meet the following requirements.

(1) The reference standard must be similar to the test part regarding material, geometry, and thickness. This includes containing: closure members, core splices, stepped skins, and internal ribs similar to the test part if bonded areas over or surrounding these details are to be inspected.

(2) The reference standard must contain bonds of good quality except for controlled areas of unbond fabricated as explained below.

(3) The reference standard must be bonded using the adhesive and cure cycle prescribed for the test part.

e. Types of Defects. Defects can be separated into five general types to represent the various areas of bonded sandwich and laminate structures as follows:

(1) Type I. Unbonds or voids in an outer skin-to-adhesive interface.

(2) Type II. Unbonds or voids at the adhesive-to-core interface.

(3) Type III. Voids between layers of a laminate.

(4) Type IV. Voids in foam adhesive or unbonds between the adhesive and a closure member at core-to-closure member joints.

(5) Type V. Water in the core.

f. Fabrication of NDI Reference Standards. Every ultrasonic test unit should have sample materials that contain unbonds equal to the sizes of the minimum rejectable unbonds for the test parts. Information on minimum rejectable unbond sizes for test parts should be obtained from the OEM’s manuals, FAA requirements, or the cognizant FAA Aircraft Certification Office (ACO) engineer. One or more of the following techniques can be used in fabricating reference defects; however, since bonding materials vary, some of the methods may not work with certain materials.

(1) Standards for Types I, II, III, and IV unbonds can be prepared by placing discs of 0.006 inch thick (maximum) Teflon sheets over the adhesive in the areas selected for unbonds. For Type II unbonds, the Teflon is placed between the core and adhesive. The components of the standard are assembled and the assembly is then cured.

(2) Types I, II, and III standards can also be produced by cutting flat-bottomed holes of a diameter equal to the diameter of the unbonds to be produced. The holes are cut from the back sides of bonded specimens, and the depths are controlled to produce air gaps at the applicable interfaces. When using this method, patch plates can be bonded to the rear of the reference standard to cover and seal each hole.

(3) Type II standards can be produced by locally undercutting (before assembly) the surface of the core to the desired size unbond. The depth of the undercut should be sufficient to prevent adhesive flow causing bonds between the undercut core and the skin.

(4) Type IV standards can be produced by removing the adhesive in selected areas prior to assembly.

(5) Type V standards can be produced by drilling small holes in the back of the standard and injecting varying amounts of water into the cells with a hypodermic needle. The small holes can then be sealed with a small amount of water-resistant adhesive.

g. Inspection Coverage. Examples of several different configurations of bonded structure along with suggested inspection coverages with standard ultrasonic test instruments are shown in figure 5-21. In many cases, access limitations will not permit application of the suggested inspections in all of the areas shown. The inspection coverages and suggested methods contained in figure 5-21 and table 5-7 are for reference only. Details of the inspection coverage and inspections for a particular assembly should be obtained from the OEM's manuals, or other FAA-approved requirements.

h. Inspection Methods. Table 5-8 lists the various inspection methods for bonded structures along with advantages and disadvantages of each inspection method.

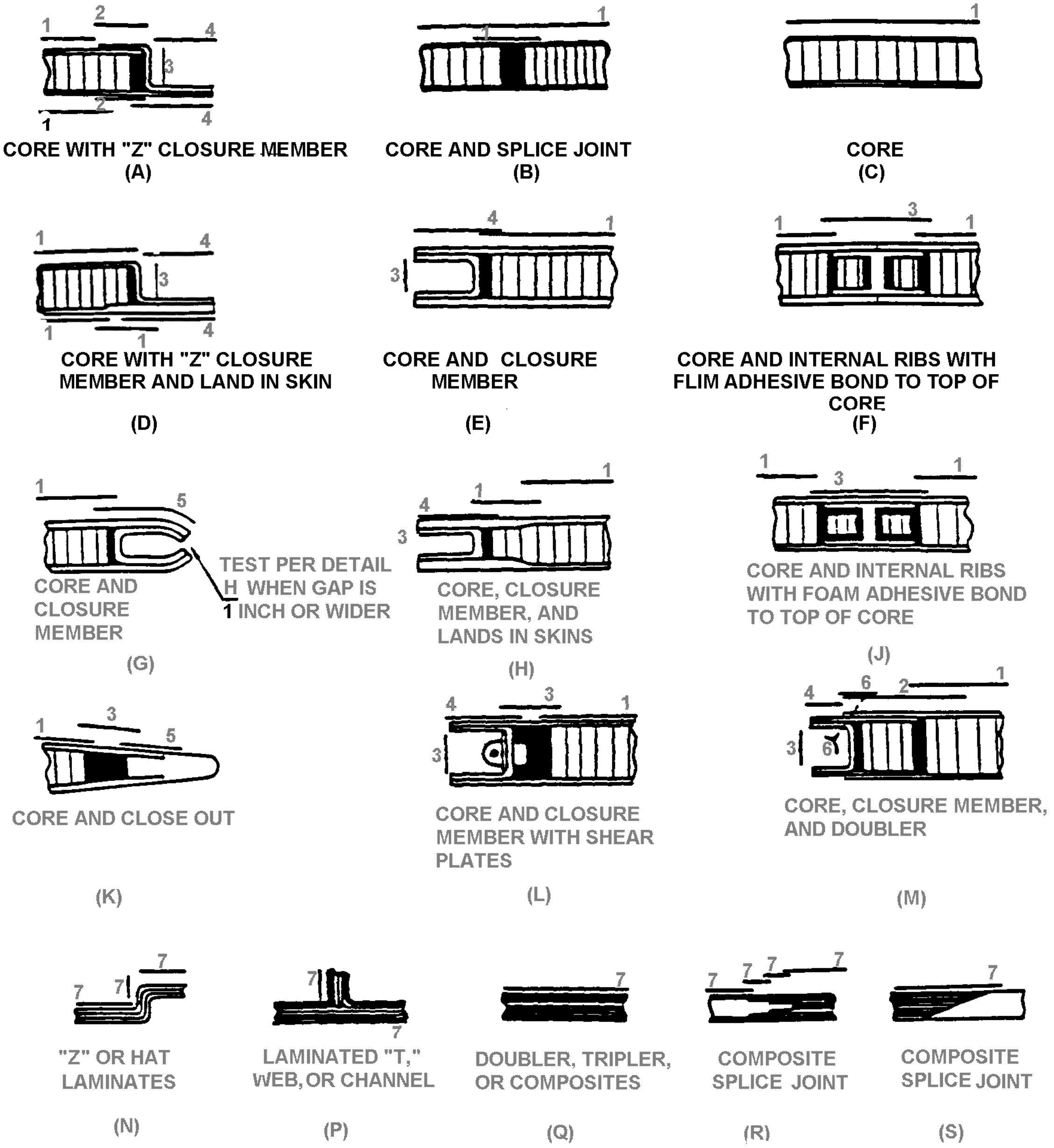
5-95. BOND TESTING INSTRUMENTS. Standard ultrasonic inspection instruments can be used for bond testing as previously noted; however, a wide variety of bond testing instruments are available for adaptation to specific bonded structure inspection problems.

a. General Principle. Two basic operating principles are used by a variety of bond testers for single-sided bond inspection.

(1) Ultrasonic resonance. Sound waves from a resonant transducer are transmitted into and received from a structure. A disbond in the structure will alter the sound wave characteristics, which in turn affect the transducer impedance.

(2) Mechanical impedance. Low-frequency, pulsed ultrasonic energy is generated into a structure. Through ultrasonic mechanical vibration of the structure, the impedance or stiffness of the structure is measured, analyzed, and displayed by the instrumentation.

b. Operation. In general, operation of the adhesive bond test instruments noted is similar. The test probe is moved over the surface in smooth overlapping strokes. The direction of the stroke with regard to the surface is generally immaterial; however, when using the Sondicator models, the direction of the stroke becomes critical when the test probe is



CORE WITH "Z" CLOSURE MEMBER (A)

CORE AND SPLICE JOINT (B)

CORE (C)

CORE WITH "Z" CLOSURE MEMBER AND LAND IN SKIN (D)

CORE AND CLOSURE MEMBER (E)

CORE AND INTERNAL RIBS WITH FLIM ADHESIVE BOND TO TOP OF CORE (F)

CORE AND CLOSURE MEMBER (G)

TEST PER DETAIL H WHEN GAP IS 1 INCH OR WIDER

CORE, CLOSURE MEMBER, AND LANDS IN SKINS (H)

CORE AND INTERNAL RIBS WITH FOAM ADHESIVE BOND TO TOP OF CORE (J)

CORE AND CLOSE OUT (K)

CORE AND CLOSURE MEMBER WITH SHEAR PLATES (L)

CORE, CLOSURE MEMBER, AND DOUBLER (M)

"Z" OR HAT LAMINATES (N)

LAMINATED "T," WEB, OR CHANNEL (P)

DOUBLER, TRIPLER, OR COMPOSITES (Q)

COMPOSITE SPLICE JOINT (R)

COMPOSITE SPLICE JOINT (S)

NOTES:

1. THE NUMBERED LINES SURROUNDING EACH VIEW INDICATE THE SCAN PLANES. THE NUMBER ON EACH LINE IS USED TO DETERMINE THE ACCEPTABLE INSPECTION METHODS BY REFERRING TO TABLES.
2. WHERE SURFACES ARE SYMMETRICAL, THE COVERAGE ILLUSTRATED SHALL BE CONSIDERED TYPICAL FOR BOTH SIDES.
3. SHADED AREAS REPRESENT FOAM ADHESIVE. (▬)
4. WHEN THE SAME METHOD(S) ARE SPECIFIED IN MORE THAN ONE SCAN PLANE, CALIBRATION SHALL BE VERIFIED FOR EACH PLANE.

FIGURE 5-21. Examples of bonded structure configurations and suggested inspection coverage.

TABLE 5-7. Acceptable ultrasonic inspection methods associated with the example bonded structure configurations shown in figure 5-21.

NUMBER	ACCEPTABLE METHODS
1	Either (a) Pulse-echo straight or angle beam, on each side or (b) Through-transmission.
2	Pulse-echo, straight beam, on each skin.
3	Refer to 1 for methods. If all these methods fail to have sufficient penetration power to detect reference defects in the reference standard, then the ringing method, applied from both sides, should be used. Otherwise, the ringing method is unacceptable.
4	Either (a) Ringing, on each skin of the doubler. or (b) Through-transmission or (c) Damping.
5	Ringing.
6	Through-transmission. Dotted Line represents beam direction.
7	Either (a) Through-transmission or (b) Damping.

NOTE

A variety of ultrasonic testing methods and instruments are available for adaptation to specific inspection problems. Other bond inspection instruments can be used if detailed procedures are developed and proven on the applicable reference standards for each configuration of interest. Some representative instruments, which can be used for the inspection of bonded structures are; the Sondicator, Harmonic Bond Tester, Acoustic Flaw Detector, Audible Bond Tester, Fokker Bond Tester, 210 Bond Tester, and Bondascope 2100.

TABLE 5-8. Ultrasonic inspection methods for bonded structures.

INSPECTION METHOD				
	THROUGH-TRANSMISSION	PULSE-ECHO	RINGING	DAMPING
Advantages	Applicable to structures with either thick or thin facing sheets. Applicable to structures with multiple layers bonded over honeycomb core. Detects unbonds on either side Detects broken, crushed, and corroded core. In some cases water in core can be detected.	Applicable to structures with either thick or thin facing sheets. Determines which side is unbonded. Detects small unbonds. Detects broken, crushed, and corroded core. In some cases water in core can be detected.	Applicable to complex shapes. Detects small near surface unbonds (larger than diameter of search unit).	Applicable to structures with either thick or thin facing sheets. Applicable to multiple-layered (more than two layers) structures. Detects unbonds on either side. Detects small unbonds (larger than diameter of receiving search unit).
Disadvantages	Access to both sides of part is required. Does not determine layer position of unbonds. Alignment of search units is critical. Couplant is required. Inspection rate is slow.	Inspection from both sides required, does not detect far side unbonds. Applicable only to skin-to-honeycomb core structures. Reduced effectiveness on structures with multiple skins over honeycomb core. Couplant required.	Applicable only to near surface unbonds, works best on unbonds between top sheet and adhesive, may miss other unbonds. Reduced effectiveness on thick skins. Couplant required.	Applicable only to doublers and laminate-type structures. Access to both sides required. Does not determine layer positions of unbonds. Couplant required.

operated near a surface edge. Edge effects on vibration paths give a test reading that may be misinterpreted. To avoid edge effects, the test probe should be moved so that the inspection path follows the surface edge, giving a constant edge for the test probe to inspect. Edge effects are more pronounced in thicker material. To interpret meter readings correctly, the operator should determine whether there are variations in the thickness of the material.

c. Probe Sending Signal. With the exception of the Sondicator models, the test probes of the testers emit a sending signal that radiates in a full circle. The sending signal of the Sondicator probe travels from one transducer tip to the other. For this reason, the test probe should be held so that the transducer tips are at right angles to the inspection path. When inspecting honeycomb panels with a Sondicator model, the transducer tips should be moved consistently in the direction of the ribbon of the honeycomb or at right angles to the ribbon so that a constant subsurface is presented.

5-96. THICKNESS MEASUREMENTS. Ultrasonic inspection methods can be used for measurement of material thickness in aircraft parts and structures.

a. Applications. Ultrasonic thickness measurements are used for many applications, such as: checking part thickness when access to the back side is not available; checking large panels in interior areas where a conventional micrometer cannot reach; and in maintenance inspections for checking thickness loss due to wear and/or corrosion.

b. Pulse-Echo Method. The most commonly used ultrasonic thickness measurement method. The ultrasonic instrument measures time between the initial front and back surface signals or subsequent multiple back reflection signals. Since the velocity for a given material is a constant, the time between these signals is directly proportional to the thickness. Calibration procedures are used to obtain direct readout of test part thickness.

c. Thickness Measurement Instrument Types. Pulse-echo instruments designed exclusively for thickness measurements are generally used in lieu of conventional pulse-echo instruments; however, some conventional pulse-echo instruments also have direct thickness measurement capabilities. Conventional pulse-echo instruments without direct thickness measuring capabilities can also be used for measuring thickness by using special procedures.

d. Thickness Measurement Ranges. Dependent upon the instrument used and the material under test, material thickness from 0.005 inches to 20 inches (or more) can be measured with pulse-echo instruments designed specifically for thickness measuring.

5-97. LEAK TESTING. The flow of a pressurized gas through a leak produces sound of both sonic and ultrasonic frequencies. If the gas leak is large, the sonic frequency sound it produces can probably be detected with the ear or with such instruments as stethoscopes or microphones; however, the ear and these instruments have limited ability to detect and locate small leaks. Ultrasonic leak detectors are frequently used to detect leaks that cannot be detected by the above methods, because they are very sensitive to ultrasonic energy and, under most conditions, background noise at other frequencies does not affect them.

a. Standard Method. A standard method of testing for leaks using ultrasonics is provided in ASTM E 1002. The method covers procedures for calibration, location, and estimated measurements of leakage by the ultrasonic technique (sometimes called ultrasonic translation).

b. Detection Distance. Ultrasonic energy in the relatively low-frequency range of 30-50 KHz travels easily through air; therefore, an ultrasonic leak detector can detect leakage with the probe located away from the leak. The maximum detection distance depends on the leakage rate.

c. Typical Applications. Some typical applications for the ultrasonic leak detector on aircraft are: fuel system pressurization tests, air ducts and air conditioning systems, emergency evacuation slides, tire pressure retention, electrical discharge, oxygen lines and valves, internal leaks in hydraulic valves and actuators, fuel cell testing, identifying cavitation in hydraulic pumps, arcing in wave guides, cabin and cockpit window and door seals, and cabin pressurization testing.

5-98.—5-104. [RESERVED.]

SECTION 8. TAP TESTING

5-105. GENERAL. Tap testing is widely used for a quick evaluation of any accessible aircraft surface to detect the presence of delamination or debonding.

a. The tap testing procedure consists of lightly tapping the surface of the part with a coin, light special hammer with a maximum of 2 ounces (see figure 5-22), or any other suitable object. The acoustic response is compared with that of a known good area.

b. A "flat" or "dead" response is considered unacceptable. The acoustic response of a good part can vary dramatically with changes in geometry, in which case a standard of some sort is required. The entire area of interest must be tapped. The surface should be dry and free of oil, grease, and dirt. Tap testing is limited to finding relatively shallow defects in skins with a thickness less than .080 inch. In a honeycomb structure, for example, the far side bondline cannot be evaluated, requiring two-side access for a complete inspection. This method is portable, but no records are produced. The accuracy of this test depends on the inspector's subjective interpretation of the test response; therefore, only qualified personnel should perform this test.

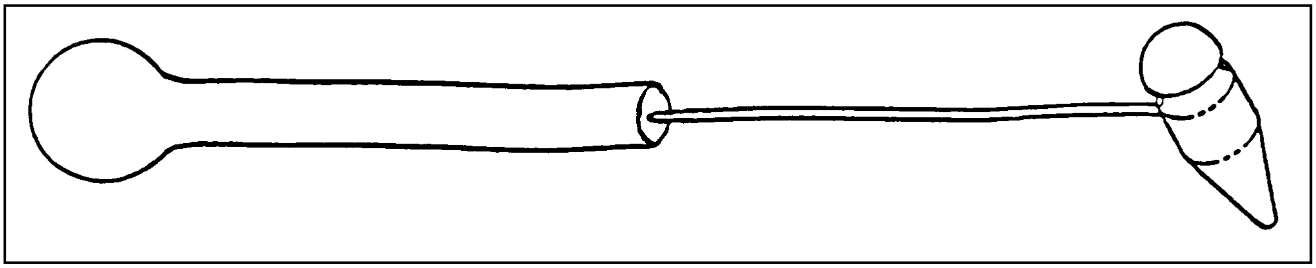


FIGURE 5-22. Sample of special tap hammer.

5-106.—5-111. [RESERVED.]

SECTION 9. ACOUSTIC-EMISSION

5-112. GENERAL. Acoustic-Emission is an NDI technique that involves the placing of acoustical-emission sensors at various locations on the aircraft structure and then applying a load or stress. The level of stress applied need not reach general yielding, nor does the stress generally need to be of a specific type. Bending stress can be applied to beamed structures, torsional stress can be applied to rotary shafts, thermal stresses can be applied with heat lamps or blankets, and pressure-induced stress can be applied to pressure-containment systems such as the aircraft fuselage. The materials emit sound and stress waves that take the form of ultrasonic pulses that can be picked up by sensors. Cracks and areas of corrosion in the stressed airframe structure emit sound waves (different frequencies for different size defects) which are registered by the sensors. These acoustic-emission bursts can be used both to locate flaws and to evaluate their rate of growth as a function of applied stress. Acoustic-emission testing has an advantage over other NDI methods in that it can detect and locate all of the activated flaws in a structure in one test. Acoustic-emission testing does not now provide the capability to size flaws, but it can greatly reduce the area required to be scanned by other NDI methods.

5-113. APPLICATIONS. A wide variety of structures and materials, such as: wood, plastic, fiberglass, and metals can be inspected by the acoustic-emission technique by applying stress on the test material. The emission-producing mechanism in each type of material may differ, but characteristic acoustic-emissions are produced and can be correlated to the integrity of the material. Acoustic-emission technology has been applied quite successfully in monitoring proof tests of pressure vessels and tests of fiber-reinforced plastic structures of all kinds. There are now ASTM standards and ASME codes applying to its use in testing gas cylinders and both metal and fiber-reinforced plastic vessels, tanks, and piping.

For a welded structure such as a pressure vessel, acoustic-emission testing works well with relatively simple instrumentation. However, slight movement of bolted or riveted joints can also generate acoustic signals. Thus a complex structure may have many acoustic sources besides flaws in its components. These unwanted emission sources greatly complicate acoustic-emission tests of complex structures. The difficulties are not prohibitive, but they put a premium on the intelligent use of signal processing and interpretation. Therefore, because of the complexity of aircraft structures, application of acoustic-emission testing to aircraft has required a new level of sophistication, both in testing techniques and data interpretation. Research and testing programs are currently in progress to determine the feasibility of acoustic-emission testing on several different types of aircraft.

5-114.—5-119. [RESERVED.]

SECTION 10. THERMOGRAPHY

5-120. GENERAL. Thermography is an NDI technique that uses radiant electromagnetic thermal energy to detect flaws. The presence of a flaw is indicated by an abnormal temperature variant when the item is subjected to normal heating and cooling conditions inherent to the in-service life, and/or when artificially heated or cooled. The greater the material's resistance to heat flow, the more readily the flow can be identified due to temperature differences caused by the flaw.

5-121.—5-126. [RESERVED.]

SECTION 11. HOLOGRAPHY

5-127. GENERAL. Holography is an NDI technique that uses visible light waves coupled with photographic equipment to create a three-dimensional image. The process uses two laser beams, one called a reference beam and the other called an object beam. The two laser beams are directed to an object, between beam applications the component is stressed. The beams are then compared and recorded on film, or other electronic recording medium, creating a double image. Indications of applied stresses or defects are shown as virtual images with a system of fringe lines overlaying the part. Holography is most commonly used for rapid assessment of surface flaws in composite structures.

5-128.—5-133. [RESERVED.]

SECTION 12. SHEAROGRAPHY

5-134. GENERAL. Shearography was developed for strain measurements. The process now provides a full-field video strain gauge, in real time, over large areas. It is an enhanced form of holography, which requires the part to be under stress. A laser is used for illumination of the part while under stress. The output takes the form of an image processed video display. This technique has been used effectively in locating defects, such as disbonds and delaminations, through multiple bondlines. It is capable of showing the size and shape of subsurface anomalies when the test part is properly stressed. Shearography has been developed into a useful tool for NDI. It can be used easily in a hangar environment, while meeting all laser safety concerns. Other applications include the testing of honeycomb structures, such as flaps and control surfaces. Shearography offers a great increase in the speed of inspection by allowing on-aircraft inspections of structures without their removal, as well as inspections of large areas in just seconds.

5-135.—5-140. [RESERVED.]