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Chapter 1. INTRODUCTION

1. PURPOSE. This Advisory Circular reviews the basic principles underlying nondestructive testing. The information contained herein implements data currently available. It is hoped that interested parties will be stimulated by this publication and seek additional information in more extensive works on nondestructive testing.

a. One of the major dangers encountered in presenting data on nondestructive testing techniques is that the reader may be given the impression that a technique is a panacea for all problem solutions.

b. Let it be clear that each of the techniques to be discussed has application to certain requirements, but no one technique universally obviates the need for any of the others.

c. The most efficient testing system may include all known nondestructive techniques; however, until appropriate techniques for all applications have been developed, no system of evaluation can be completely efficient.

2. CANCELLATION. AC 20-61, dated April 29, 1969, Nondestructive Testing For Aircraft, is cancelled.

3. TYPES OF INSPECTION. This circular is divided into the commonly known types of inspections as follows: (See Appendix 1 for more detailed listing.)

a. ***Visual inspection*** is the most common form of examination, and consists of viewing the area with the eye, aided by magnifying glass, borescope, light source, etc.

b. ***Radiographic inspection*** will show internal and external structural details of all types of parts and materials. It is a nondestructive test method and is used for the inspection of airframe structure inaccessible or unsatisfactory for the application of other nondestructive test methods. It is accomplished by passing the X-ray or Gamma ray through the part of assembly being tested to expose a radiographic film. The processed film shows the structural details of the part or assembly by variations in film density. Interpretation of the radiograph will indicate defects or damage.

c. ***Magnetic particle inspection*** will indicate surface or near-surface defects in ferro-magnetic parts. It is a nondestructive test method and may be performed on assembled or disassembled parts. The test is accomplished by inducing a magnetic field in the part and applying a dry powder or liquid suspension of iron oxide particles. Local magnetic poles formed by defects in the part attract the oxide particles so they may be viewed and evaluated by color contrast or fluorescence under "black light." (See Appendix 3.)

d. ***Ultrasonic inspection*** is a nondestructive test method suitable for the inspection of most metals, plastics, and ceramics for surface or subsurface defects. Ultrasonic inspection requires at least one surface of the part to be accessible in the vicniity of the area in question. The inspection of airframe structure is accomplished by inducing the ultrasound into the part by a contacting probe and picking up reflections of this sound from within the part. The detected ultrasonic reflections are electronically displayed on an oscilloscope tube and interpreted for indications of defects.

e. ***Dye penetrant inspection*** is used to detect small cracks or discontinuities open to the surface and which may not be evident by normal visual inspection. Penetrant inspection can be used on most airframe parts and assemblies accessible for its application. The inspection is performed by applying a liquid which penetrates into surface defects. Excessive penetrating liquid is removed and suitable developers applied to draw the penetrant from the surface defects so that visual indications are obtained by color contrast or fluorescence of the penetrant under the influence of "black light." (See Appendix 3.)

f. *Eddy current inspection* is used to detect surface or near-surface cracks in most metals, and to separate metals or alloys and their heat treat conditions. It can be applied to airplane parts or assemblies where the defective area is accessible to contact by the eddy current probe. The inspection is performed by inducing eddy currents into a part and electronically observing variations in the induced field. The character of observed field change is interpreted to determine the nature of the defective condition.

4. INSPECTION ILLUSTRATIONS. Usually, inspection illustrations are provided by the manufacturer in manuals or service bulletins to cover each area of the aircraft that requires inspection. Areas are indexed on the major index charts and on the illustrated structure index. Each shows location of area, type of inspection, and directs the inspector to the inspection illustration for that area. This illustration shows the general area for inspection, the method of performing the inspection such as the type of dye penetrant to be used, type of film, kv. setting and exposure time for X-ray, or the type of optical equipment that may be used in a visual inspection. It also indicates the preparation of the part, such as cleaning, paint removal, corrosion removal, etc. When a particular type inspection has been completed, reference is made to a next step inspection. For example, if a visual examination has been performed, it may be necessary to confirm any suspected or visible cracks with a dye penetrant check.

5. COMMON FAILURES. The type of failures or defects the inspection personnel will encounter during the nondestructive inspection program follow. It is essential that the inspection personnel be skilled and well-trained in the field of nondestructive inspection to enable them to make sound decisions. Inexperienced personnel should not attempt to interpret the results of the nondestructive inspections. Misinterpretation can result in serviceable parts being rejected and defective parts being accepted.

a. *Fatigue cracks* only occur in parts that have been in service under repeated stress reversals or stress variations. The crack 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, such as fillets, poor surface finish, seams, grinding cracks, and from fastener holes that have poor surface finish or sharp burrs.

b. *Heat-treat cracks* are caused by faulty heat-treat processing of parts. They can be caused during the heating or quenching cycle or may be an enlargement of a fault existing from a previous operation. They generally occur in a sudden change of section which could cause an uneven cooling rate, or at fillets and notches which act as stress concentration points.

c. *Grinding or plating cracks*—

(1) Grinding cracks are caused by faulty grinding, and are quite critical as they generally occur on surfaces which are highly stressed. They are distinguished by very fine and sharp cracks at right angles to the grinding marks.

(2) Plating cracks are found only in areas where high residual stresses remain from some previous operation, such as hardening. When such parts are plated, the operation may cause those stresses to crack the surface.

d. *Discontinuity is an interruption* in the normal physical structure configuration of a part such as cracks, forging laps, folds, seams, porosity, etc. A discontinuity may or may not affect the usefulness of the part.

e. *Inclusions are impurities* embedded in the material in the forming stage. The inclusions can be deep in the part or near the surface. Normally, they will have no effect on the strength of the part, but when they occur in areas of high stress or in certain special locations or direction they may be cause for rejection of the part.

f. *Corrosion*. Almost all metals are subject to corrosion. The use of corrosive-resistant metals, such as aluminum clad sheet, minimize airframe corrosion. Many other factors contribute to the amount and degree of corrosion, such as the geographic location and fabrication process. Geographically, corrosion is caused by the presence of salts in moist air, or by some other abetment to corrosion present in the chemical content of the water or elements in the metal. Corrosion caused by fabrication is dependent on such factors as protective coating, the type of metal used, treatment of parts, and dissimilar metal contacts. Stress corrosion is another common cause for cracking in metals.

6. INSPECTION TECHIQUES—ADVANTAGES AND DISADVANTAGES.

a. *The various types of nondestructive inspections for aircraft application* are described briefly. The advantages and disadvantages of each type are described in Table 1. These should be studied by personnel who are about to make an inspection of an area that is not covered in the specific inspection illustrations, or if the particular inspection equipment called for in the illustration is not available. The information should be used as a guide in choosing the best method, or best alternative method for the area, or equipment that is available.

b. *Inspection access and provisions.* The majority of the parts requiring inspection will be accessible from inside the airplane, or will be on the wings or empennage. The points for inspection in the fuselage will generally be underneath the soundproofing material. To locate these areas, the inspection team should have a good knowledge of the frame stations and stiffener positions (frame stations may be stenciled on soundproofing). Many areas to be inspected will be very difficult to get at and may necessitate removing doors or panels which are part of the structure.

c. *Inaccessible inpection problems.* In some cases, the method of inspecting an area will depend on the accessibility; it may be desirable to inspect by X-ray but not possible to get the unit near, or obtain the correct angle, for exposing the film. Also, it might be desirable to inspect an item by magnetic particle but not possible to get the coils around it, or probes to the part. The means of accessibility to the part will determine the best method for the inspection of it.

7. SELECTING THE INSPECTION METHOD. The method of inspection for the area will depend on several factors: accessibility, portability, type of defect sought, material of the part, and degree of sensitivity required. A typical example of determining which inspection method to use follows:

a. *Example.* In the lower wing skin, a fastener hole is found to have a fatigue crack radiating from it, the fastener is removed; a penetrant inspection is performed to determine the length of the crack on the surface, a section of the skin containing the hole and crack is cut out—(5/8" diameter section). It is required to check the skin around the cutout to determine that all of the crack has been removed. The following methods were considered: X-ray, eddy current, ultrasonics, and dye penetrant.

(1) The penetrant method was considered unsuitable because of the "smeared" nature of the saw-cut surface and excessive bleed back from the skin to doubler faying surface.

(2) X-ray was considered in evaluating the test standards, but was not considered feasible for the wing inspection because its sensitivity to a small tight crack is not as good as ultrasonics or eddy current.

(3) Ultrasonic was considered; however, it was rejected because it is less sensitive to small cracks of the size and type sought than eddy current inspection, and would require the preparation of a special transducer holder to obtain maximum sensitivity in suspected area.

(4) Eddy current was chosen as the best means for inspection because the inspection can be performed quickly with standard equipment and will obtain a high degree of sensitivity.

8. INSPECTION OF AIRPLANE. When an inspection of the airplane is to be performed, the airplane must be prepared to suit the type inspection being performed. For most methods of inspection, no special preparation is necessary, except in areas near or in fuel cells where the airplane would have to be defueled. In some areas parts of the structure may have to be removed to gain access to the area for inspection. For X-ray inspection, the plane may have to be defueled, X-ray tube leveled, and the area properly roped off with red rotating beacon lights at each corner to keep unauthorized personnel at a safe distance. After inspection, care must be taken to restore the airplane to original configuration, such as

TABLE 1. Comparisons of various inspection methods.

Method	*Advantages*	*Disadvantages*
Visual	1. Cheapness. 2. Portability. 3. Immediate results. 4. Minimum special skill. 5. Minimum part preparation.	1. Suitable only for surfaces which can be viewed. 2. Generally detects only larger defects. 3. Misinterpretation of cracks and scratches.
Radio-graphic X-ray	1. Ability to inspect for both internal and surface defects. 2. Ability to inspect parts covered or hidden by other parts or structure. 3. Permanent test record obtained. 4. Minimum part preparation required.	1. Most expensive. 2. Airplane may have to be defueled. 3. Area must be cleared of other personnel to avoid X-ray exposure. 4. Test method is highly directional, depends on crack/X-ray source orientation. 5. High degree of skill required for varied technique development and radiographic interpretation.
Radio-graphic Isotopes	1. It is portable. 2. Needs less area to gain access for energy source. 3. Can accommodate thicker material sources. 4. Less expensive than X-ray.	1. Must conform to Atomic Energy Commission regulations for handling and use.
Eddy Current	1. Portable. 2. Moderate cost. 3. Immediate results. 4. Sensitive to small indication. 5. Little part preparation.	1. Essentially a surface inspection. 2. Surface to be inspected must be accessible to contact by the eddy current probe. 3. Rough surfaces interfere with test sensitivity. 4. Suitable for inspection of metals only. 5. No permanent test record. 6. Considerable skill and familiarity required in handling test equipment. 7. Time consuming to scan large areas.
Ultra-sonic	1. Suitable for surface and subsurface defects. 2. Sensitive to small defects. 3. Immediate test results. 4. Little part preparation. 5. Wide range of material thicknesses can be inspected.	1. Surface of part to be inspected must be accessible to sonic probe. 2. Rough surfaces interfere with test results. 3. No permanent test record. 4. Test method is directional depending on sound beam—defect orientation. 5. High degree of skill and experience required to set up and interpret results for varied test conditions.
Dye Penetrant	1. Cheapness. 2. Portable. 3. High sensitivity. 4. Immediate results. 5. Minimum skill required to perform.	1. Can only inspect surface of parts accessible to penetrant application. 2. Defects must be open to surface. 3. Part preparation, such as removal of finishes and sealant required. 4. No permanent test results. 5. Direct visual detection of results required. 6. Requires a high degree of cleanliness for satisfactory inspection.
Magnetic Particle	1. Semiportable. 2. Sensitive to small indications. 3. Detects surface and near-surface defects. 4. Sensitive to inclusions as well as cracks. 5. Moderate skill required to perform.	1. Only suitable for ferro-magnetic material. 2. Part must be physically and visually accessible to perform test. 3. Removal of most surface coatings and sealant required. 4. Inspection is semidirectional requiring a general orientation of field to defect. 5. No permanent test results unless the indications from dry powder technique are recorded by pressing "scotch" tape on the surface. 6. Not usable in areas where a strong magnetic field may damage instruments. 7. Part must be demagnetized after inspection.

proper torquing of bolts, using the same type rivets as original, etc. If the area has been sealed (fuel or otherwise) it must be resealed as original, and if the part has been cleaned, the original finish must be replaced. Magnaflux inspections require demagnetization of the parts after inspection.

9. INSPECTION OF PARTS.

a. ***For X-ray inspection*** no preparation of the part is necessary, except for making provisions for holding the film behind the part being inspected.

b. ***Eddy current inspection*** requires that good contact be made with the part and the test coil; freshly machined parts need no preparation; mildly corroded parts need light rubbing with emery cloth; heavily corroded or painted parts need cleaning locally for placing the test coil.

c. ***Ultrasonic inspection*** of parts requires no surface treatment, except for the removal of loose paint and thick or loose scale. A part with severe surface irregularities will not give accurate readings. The surface should provide a good, smooth contact for the probe.

d. ***Magnetic particle and dye penetrant inspection*** requires absolute cleanliness of the part or area being inspected. The cleaning technique to be used will be determined by what sort of soil conditions are present, also if the part is plated, painted, or has a protective coat. Scale and rust must be removed completely from the part before inspection. The removal of coatings such as paint, rust, and scale must be accomplished by a method that does not affect the defect or discontinuity that may be present. Do not use shot blast, sand blast, grit blast, pressure blast, liquid honing, emery cloth, sand paper, steel wire brush, or metal scraper. These will cover up defects by peening or cold working the surface, particularly on soft metals. After inspection has been performed, the original protective finish must be restored to the part or area.

Chapter 2. RADIOGRAPHIC INSPECTION

10. GENERAL. Radiographic inspection of the structure is recommended if the suspected structural area may be hidden or not easily accessible. This type of inspection is not recommended as an exploratory technique for general inspection. In most instances when radiographic techniques are used, the suspected location and orientation of the failure will be known from previous experience. Information available should provide inspectors with the necessary setup and exposure data for shooting most of the areas of the aircraft. These instructions should provide good radiographic views based upon the best orientation to detect a failure.

11. AIRCRAFT PREPARATION. Due to the hazardous nature of radiographic radiation, it is necessary to isolate the aircraft and to keep unauthorized personnel at a safe distance. The aircraft may be defueled and properly marked with warning signs or roped off. In most instances no disassembly of the aircraft will be required; however, X-ray tube leveling will be required. The individual inspection requirements will generally dictate the configuration and attitude of the aircraft.

12. RADIOGRAPHIC EQUIPMENT. For all inspection requirements of this section, the basic radiographic equipment must be portable. Consequently, any approved portable equipment is acceptable provided it is calibrated and the rating is compatible with the inspection requirements. The requirements for associated items of equipment such as "geiger" counters, penetrometers, lead screens, dark room equipment, etc., will be found in MIL–STD–453.

13. INSPECTION TECHNIQUE. Each individual inspection required should provide radiation source and film orientation, also exposure requirements and setup geometry. In all instances, the recommended setup has proven the best orientation and exposure to detect damage in the most critical area. While every attempt has been made to provide the best inspection setup possible, additional setups or orientation should be considered if aircraft modifications or film interpretation warrant such action.

14. PRINCIPLES OF RADIOGRAPHY.

a. *General.* X-rays and gamma rays are radiations which have the ability to penetrate material opaque to visible light. These radiations on passage through material are absorbed to varying degrees which is dependent on the density and atomic number of the material. This phenomenon of absorption is used to render information that is recorded on a film. The following are general definitions:

(1) Gamma rays. Electromagnetic radiation of high-frequency waves (or short wave length) emitted by the nucleus of an atom during a nuclear reaction. Gamma rays are not deflected by electric or magnetic fields. They are identical in nature and properties to X-rays. Source will depreciate in intensity with time and thus exposure time must be recalculated periodically.

(2) X-rays. A form of radiant energy resulting from the bombardment of a suitable target by electrons produced in a vacuum by the application of high voltages.

b. *Concepts.* X-rays and gamma rays because of their unusual ability to penetrate material and disclose discontinuities have been applied to the industrial radiography inspection of castings, welds, metal fabrications, and nonmetallic products. Radiography has proven a successful maintenance tool with which to implement maintenance programs for inspection of aircraft.

(1) The three major steps concerned in radiography inspection are:

(a) Exposure of the material to X- or gamma radiation including preparation for exposure.

(b) Processing of the film.

(c) Interpretation of the radiograph.

c. ***Production of X-radiation.***

(1) General. X-radiation is produced when some forms of matter is struck by a rapidly moving, negatively charged particle called an electron. This condition can be produced by the following basic requirements:

(a) Source of electrons. If the appropriate material is heated sufficiently, some of the electrons will become agitated and boil off or escape from the material and surround it in the form of a cloud.

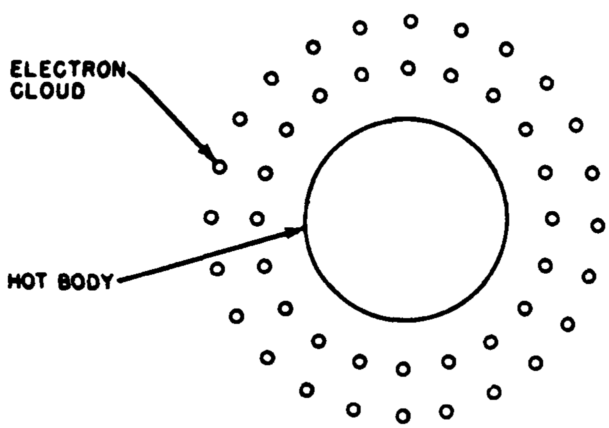


FIGURE 1.—Electron cloud around hot body.

(b) Directing and accelerating electrons. Unless some force pulls the cloud of electrons away, it will return to the emitting material. Movement of the electrons is essential and is brought about by the repelling and attracting forces inherent in electrical charges. A strong like charge is used to move the electrons which must be conducted in a vacuum (tube) to avoid collision with air molecules and resultant loss of energy.

(c) Bombardment. It is necessary that the moving electrons strike some substance. When electrons bombard the target, certain atomic disturbances occur within the target material releasing radiation known as X-rays.

d. ***Production of gamma radiation.***

(1) Natural sources. Radioactivity which is a phenomenon of spontaneous atomic disintegration is a property displayed by atoms of certain materials. The lack of stability of the atomic structure of the material probably causes the disintegration. The energy is released due to the unbalanced condition, in the form of gamma rays and is spontaneous.

(2) Artificial sources. Certain elements can be made radioactive by bombardment in an atomic pile. These elements are changed structurally and are known as isotopes of the original element. Among the common isotopes currently used in industry are those derived from elements Cobalt, Cesium, Iridium, and Thulium, and are referred to as Cobalt 60, Cesium 137, Iridium 192, and Thulium 170. The numerical designation indicates the weight of one atom of the particular radioisotope and differentiates from other isotopes of the same element or the parent element itself.

e. ***Radiation intensity.*** Quantity or number of rays available during a specific period ~~of~~ time must be determined. This is important since the time required to make a radiographic exposure is directly related to the radiation intensity. X-ray intensity is directly proportional to the tube current and is, in general, a function of the voltage raised to a power greater than 2.5. Gamma ray intensity is radiation emission as measured over a period of time at a fixed distance.

f. ***Effect of radiation on film.*** Film is basically a cellulose material with a photosensitive emulsion on both sides. A change occurs in the emulsion when exposed to X-rays or gamma rays since it is sensitive to certain wave lengths of electromagnetic radiation.

g. ***Film characteristics.*** There are many diverse applications in industrial radiography. To produce the optimum radiograph, there are several factors to consider in each application. The following headings encompass important areas of information on film characteristics of which the radiographer should have knowledge:

(1) Film density.

(2) Exposure.

(3) Film characteristic curves.

(4) Film speed.

(5) Technique charts.

(6) Radiographic screens—

(a) Lead foil screens.

(b) Fluorescent screens.

(c) Cassettes and film holder.

(7) Film processing and control.

(8) Film defects.

15. SAFETY.

a. *Personnel safety* is one of the most important considerations in the use of X-ray equipment. Radiation from X-ray units and radioisotope sources is destructive to living tissue, so adequate protective methods and detection devices must be used. Since the detrimental effects of excessive exposure are not immediately apparent, personnel frequently exposed to X-rays should have periodic blood counts and physical examinations.

b. *The National Bureau of Standards* has issued a number of handbooks on the subject of protection against radiation. These books can be obtained from the United States Department of Commerce.

c. *While the exposure is in process,* the operators and all personnel in the immediate vicinity must be protected.

d. *Three general types* of radiation monitoring devices are in general use.

(1) One type consists of a small, pencil-like ionization chamber which is given an electrostatic charge at the beginning of each day's work. As it is subjected to penetrating radiation, it discharges proportionately to the amount of radiation received. By inserting this chamber into an electrometer, the amount of radiation received between the time of charge and the time of reading can be determined.

(2) The second and most commonly used radiation monitoring device is the film badge, consisting of a holder, a filter, and special X-ray film. These film badges are distributed to the radiographic operator, assistants, and all persons who may be in the vicinity of an exposure area. After one or two weeks of exposure, the film is processed and the resultant density of the negative is read by means of a densitometer. By comparing the density of the film with a master guide, the radiation received by the badge wearer can be determined.

(3) A third type of radiation monitor uses either a large ionization chamber or geiger, proportional or scintillation counters in conjunction with an electronic rate meter. This type of instrument reads the radiation intensity being received at a given location at the time the instrument is in operation and is independent of time. These devices are useful for posting the areas of radiation hazard and for determining the safe distance from the exposure area at which the operators and personnel must remain.

e. *The assets and liabilities* of radiographic techniques are well established. It is important to show how some of the liabilities associated with radiographic techniques provided the stimulus for the development of new nondestructive techniques. Foremost among these liabilities is safety. Safety considerations require areas which must be shielded. There are, however, technical liabilities such as insensitivity and, in fact, ineffectiveness of radiographic techniques for many of today's needs. All of these liabilities and others not noted were sufficient to initiate the search for new and more efficient nondestructive evaluation tools.

16. INTERPRETING RADIOGRAPHIC FILM. Interpretation of radiographic films must be attempted only by qualified radiographic personnel. However, the qualified radiographic film reader must be aware of the necessity of the need for maximum film interpretation due to increased structural complexity and the differing failure characteristics of new materials. Further, the radiographic reader must possess a knowledge of the aircraft and engine structure.

a. *The most important phase of radiography* is the interpretation of the exposed film. The effort of the whole radiographic process is centered in this phase. Defects or flaws which are overlooked, not understood or improperly diagnosed can jeopardize the reliability of the material. A particular danger is the false sense of security imparted by inspection approval based on improper interpretation. At first impression, radiographic interpretation may seem simple but a closer analysis of the problem soon dispels this impression. This subject is too varied and complex and cannot be covered adequately in this Advisory Circular.

b. ***Description of radiographic process.*** The penetrating radiation passes through the object and produces an invisible image on the film. The processing of the film provides a radiograph or shadow picture of the object. More radiation passes through the object where the section is thin, and as a result, the corresponding area on the film is darker. The radiograph is read by comparing with the known design of the object and observing either the similarities or differences. (See Figure 2, diagram showing fundamental elements of radiographic exposure.)

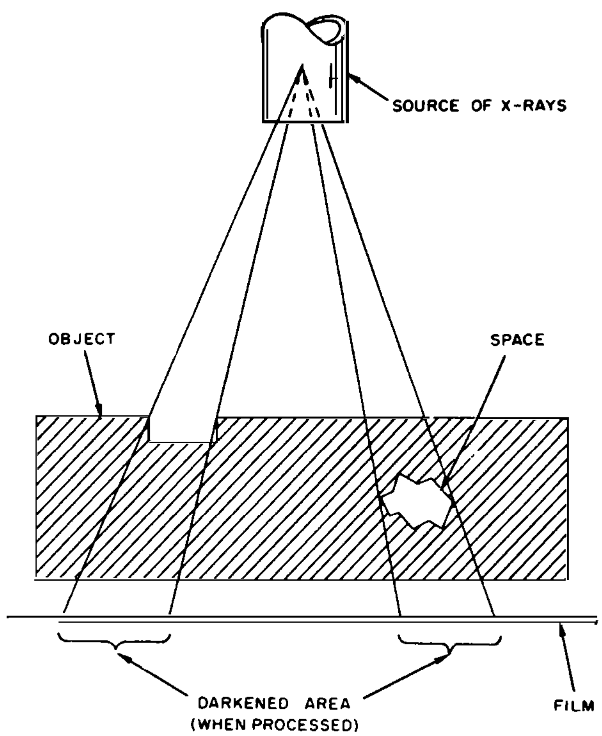


FIGURE 2.—Diagram of radiographic process.

c. ***Radiographic inspection*** has several inherent limitations. Since radiation travels in straight lines from the source, it must intercept a film at nearly right angles. This precludes efficient examination of items which have complex geometries. Such conditions can occur under circumstances wherein the film cannot be suitably oriented, or if suitably oriented, will be subject to the adverse effects of scattered radiation or image distortion.

(1) The information in a radiograph or plate is obtained by density differences brought about by differential absorption of the radiation. These density differences, must be oriented almost parallel to the direction in which the radiation is traveling. Discontinuities such as laminar-type flaws, will often be undetected because they do not present a sufficient density differential to the radiation. This limitation is countered to some extent since the orientation of fractures can be approximately predicted and the setup oriented accordingly.

(2) The nature of laminations precludes their ready detection, and radiographic inspection is seldom used to locate this type of flaw. Penetrating radiation is absorbed in direct proportion to the thickness of material. As material thickness is increased, the time required to obtain sufficient information on the film also increases.

(3) For a given energy (penetrating power) of X- or gamma radiation, there exists a thickness beyond which radiography is not feasible. Radiographic equipment of higher energy potential could be obtained; however, costs would increase markedly because of the barriers required to protect personnel from the harmful effects of the radiation as well as the basic cost of larger equipment.

d. ***Characteristics of X-ray and gamma ray.***

(1) X-ray and gamma ray are forms of electromagnetic radiation as are visible light, infrared waves, radio waves, and cosmic waves. The wave length, lambda (λ), of an electromagnetic radiation is expressed in units of length to suit the length of the waves, in meters (m.), centimeters (cm.), millimeters (mm.), microns ($1\mu = 1/1{,}000$ mm.), in millimicrons ($1m\mu = 1/1{,}000\ \mu$); or again for X-rays in angstrom units ($1A° = 1/10\ m\mu = 10^{-8}$ cm.), and also for X-ray and gamma ray in X units ($1X = 1/1{,}000$ A°). Figure 3 shows position of X-ray and gamma rays in the electromagnetic spectrum.

(2) Short wave lengths are the distinguishing characteristics of X-rays and gamma rays. Penetrating power, or energy, is dependent upon the wave length in an inverse relationship; i.e. the shorter the wave length, the higher the energy and the longer the wave length, the lower the energy. (A low energy X-ray is frequently noted as a "soft" X-ray.)

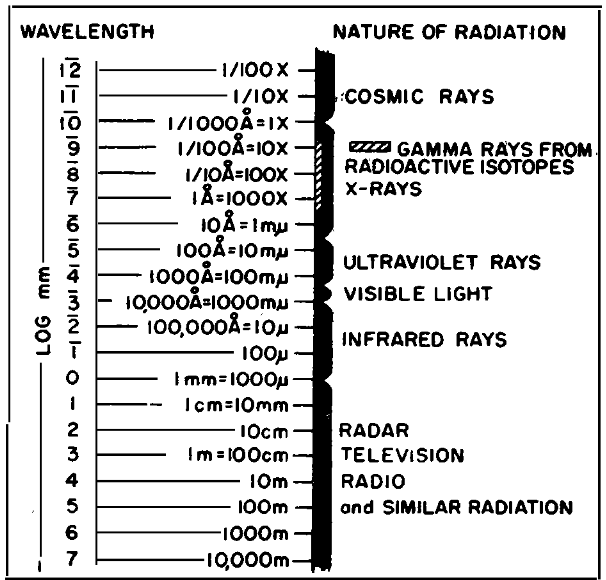


FIGURE 3.—Position of X-rays and Gamma rays in the electromagnetic spectrum.

Chapter 3. PENETRANT INSPECTION

17. GENERAL. Penetrant inspection is used to detect small cracks or discontinuities which cannot be found by normal visual inspection. Penetrant inspection may be used without limitation on most aircraft materials, and will give positive indications on any type of structure. The method depends on the ability of a highly penetrating liquid to seep into any discontinuity in the material to which it is applied. It may, therefore, be used to detect only surface defects and subsurface defects that have surface openings.

18. PENETRANT INSPECTION TECHNIQUE. Penetrant inspection of a part is done by coating its surface with a film of penetrating liquid, allowing time for the liquid to seep into any existing flaws, then removing the surface film. The penetrant remaining in the surface discontinuities is processed with a developer and examined under a suitable light. Penetrant inspections can be performed using water-washable, postemulsifiable, or solvent-removable penetrants. Each of these penetrants is available with fluorescent or visible dye properties.

a. ***Fluorescent and visible dye penetrants*** are not compatible. If one type has been used to inspect a part, be sure to clean the surface thoroughly before attempting to re-inspect using the other type. The process to be used in each application should be carefully selected according to the sensitivity required, the type of defect sought, and the equipment available. Also, some of these processes involve the use of water which, under circumstances such as the following may be undesirable:

(1) On rough surfaces such as castings.

(2) On materials where rust or corrosion will result from lack of rapid, complete drying.

(3) Under environmental conditions where sufficient water cannot be used or where low temperatures prevent rapid evaporation.

b. ***Inspection.*** It is important to remember that the penetrant must enter and fill the surface defect before an accurate indication of the defect can be obtained. The surface being inspected must be thoroughly clean and dry, and sufficient time must be allowed for the penetrant to fill the discontinuity completely. The time period will vary considerably, depending upon the type of penetrant used, type of material being inspected, sensitivity desired, and types of defects expected to be found. Care must be taken to ensure that none of the penetrant is washed out of the defect while the excess is being removed from the surface. A proper indication of the flaw depends upon the amount of penetrant drawn out of it by the developer, and spread on the surface. (See Figure 4.)

c. ***Precautions.***

(1) Keep penetrant and solvent off of clothes and skin. These chemicals cause irritation when in prolonged contact with the skin. Wear neoprene gloves to protect the hands and, if necessary, wash skin with soap and water as soon as possible.

(2) Wear safety glasses, goggles, or plastic face shield whenever there is risk of the solvent splashing.

(3) Provide adequate ventilation at all times; vapors arising from the penetrant or solvent may be toxic.

(4) Dry developer powders are considered harmless, but the inhaling of excessive amounts should be avoided.

(5) Most materials used in the portable, visible penetrant process are highly flamable; observe the manufacturer's recommended handling precautions at all times.

(6) Avoid looking directly at the black-light source. The liquid in the eyeball glows in black light and causes the viewer's sight to become

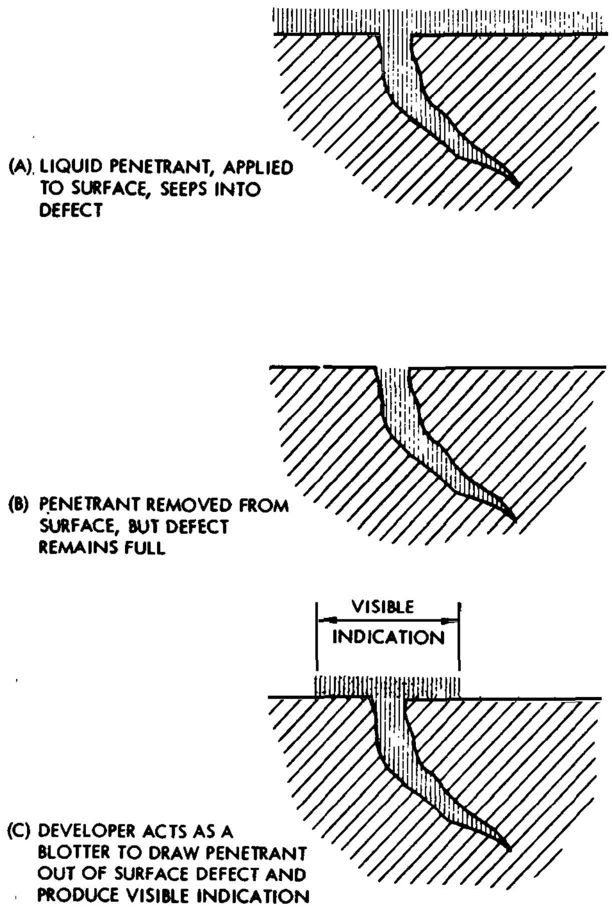


FIGURE 4.—Penetrant and developer action.

hazy. The effect is not harmful, and normal vision is restored after a momentary period of adjustment.

d. *Preparation of parts.* It is very important that the part be clean and free of foreign materials of all kinds, including moisture, that may clog surface discontinuities and, thereby, interfere with the efficient action of the penetrant. Paint, varnish, or similar coatings, as well as grease, dirt, and corrosion, must be completely removed to prevent the development of misleading indications. Plating should also be removed down to the bare metal if this can conveniently be done without camouflaging any surface defects. The surface condition of each individual part will determine the type of cleaning required. Refer to manufacturers instructions for information on part preparation. Reliable inspection of a part by any dye penetrant method depends upon the ability of the penetrant to seep into defects existing in the test surface.

e. *Water-washable, fluorescent penetrant inspection.*

(1) Water-washable penetrant method is the least sensitive of the three methods involving fluorescent penetrants. The method utilizes an oil-base penetrant to which has been added to emulsifier, to make it water washable, and a highly fluorescent dye. After an application of the penetrant, the test surface is washed to remove the surplus penetrant, and a developer is applied. Either a wet or a dry developer can be used. The dry powder type results in improved sensitivity and may be used where more critical inspection is required. In both instances, when viewed under black light, any discontinuities in the test surface glow with a bright yellow-green light against a dark background. The intensity of the fluorescence is related to the volume of penetrant retained in the surface flaw. The advantages and disadvantages of water-washable, fluorescent penetrant inspection are tabulated in Table 2.

TABLE 2. Characteristics of water-washable, fluorescent penetrant inspection.

Advantages	*Disadvantages*
Has fluorescence for greater visibility.	May be difficult to rerun parts.
Easily washed with water.	Anodizing may affect sensitivity.
Good for quantities of small parts.	Chromate finish may affect sensitivity.
Good on rough surfaces.	Requires inspection with black light in dark areas.
Good on keyways and threads.	Not reliable for detecting scratches and similar shallow surface conditions.
High speed, economy of time.	
Good on wide range of defects.	

(2) Postemulsification, fluorescent penetrant inspection utilizes an oil-base penetrant to which a highly fluorescent dye has been added. As the penetrant does not contain an emulsifier, it has the ability to seep into very fine surface defects. The surface film of penetrant is made water soluble by the application of an emulsifier in a separate operation. The sensitivity of the operation can be partially controlled by proper judgment of the time lapse between the application of the emulsifier and the rinsing operation. A developer is applied to the test surface after rinsing, and the surface is examined under black light. An existing defect will fluoresce brilliantly against a dark background. In addition to deep cracks, careful application of this technique makes possible the detection of shallow scratches, tool marks, and shallow imperfections that are wider than they are deep. The advantages and disadvantages of postemulsification fluorescent penetrant inspection are tabulated in Table 3.

TABLE 3. Characteristics of postemulsification fluorescent penetrant inspection.

Advantages	*Disadvantages*
Has fluorescence for greater visibility.	Application of emulsifier a separate operation.
High sensitivity in very fine defects.	Requires inspection with black light in dark areas.
Can show wide, shallow defects.	Sometimes difficult to wash penetrant from:
Easily washed with water after emulsification.	a. Threaded parts.
Short penetration time.	b. Keyways.
High production, especially with large parts.	c. Blind holes.
Can be used on anodized surfaces.	
Can be used on chromate surfaces.	
Parts can be rerun satisfactorily.	

(3) Solvent removable fluorescent penetrant inspection is especially useful for the detection of stress or intergranular corrosion, but may be used as a general inspection method on parts where the use of water is unsatisfactory or inconvenient.

(a) A solvent is used to remove the surface film of high-sensitivity penetrant, and the developer is a quick-drying, nonaqueous type. This developer, when applied in the form of a fine spray, forms a thin, uniform coating that provides the highest degree of inspection accuracy.

(b) Portable kits are available with all fluids contained in aerosol-type, pressurized cans. The kits are useful in field operations for inspecting primary structural members when available light is sufficiently limited to permit adequate indications under black light. The indications are similar to those obtained with other fluorescent penetrant inspection methods.

(4) Water-washable and postemulsification visible dye penetrant inspection methods utilize oil-base penetrants to which visible dye has been added. The inspections are performed under ordinary white light, and surface defects result in bright red indications against a white background. The procedures and relative advantages of the visible dye methods of inspection are basically similar to those using fluorescent dye penetrants.

(5) Solvent-removable, visible dye penetrant inspection procedure is the same as that used in the postemulsification visible dye method. After penetration, the excess surface film is removed by applying a solvent and wiping with clean absorbent rags or paper towels. A quick-drying, nonaqueous developer is then applied to the part to produce the usual bright red indications. The nonaqueous developer is the most highly sensitive developer available, but for best results, it should be applied in the form of a fine spray. This method of inspection will provide a high degree of accuracy when hand-applied procedures are employed. The method is therefore, ideally suited to field operations using portable inspection kits containing all necessary fluids in aerosol-type pressurized cans. The advantages and disadvantages of solvent-removable, visible dye penetrant inspection is tabulated in Table 4.

(6) Post-inspection treatment. After completion of any dye penetrant inspection process, if no repair action is required, all traces of inspec-

TABLE 4. Characteristics of solvent-removable visible dye penetrant inspection.

Advantages	*Disadvantages*
Can be used in portable kits.	Materials very flammable.
Does not require a special light source.	Removal of surface penetrant is slow.
Can be used on suspected local areas of large parts.	Expensive in man-hours.
Can be used on parts where contact with water is not permissible.	Indications are less visible than fluorescent indications.
Can be used on anodized surfaces.	Materials cannot be used in open tanks.
Ideal for operational components that cannot be disassembled.	Difficult to use on rough surfaces especially on cast magnesium.
Provides very high inspection accuracy.	
Best of all techniques on contaminated defects.	

tion material residues must be removed within 4 hours. Thoroughly clean the part or structure using any suitable, approved method. Dry the surface completely, and restore the original surface finish. If this is not practicable, apply a suitable alternate finish.

Chapter 4. MAGNETIC PARTICLE INSPECTION

19. GENERAL. Magnetic particle inspection is a method of detecting cracks or other flaws on the surface, or subsurface, of materials that are readily magnetized. This type of inspection will generally find usage with steel fasteners, landing gear components, and a few steel fittings such as found in engine or empennage attaching fittings. Magnetic particle inspection will provide excellent indications of all surface discontinuities provided the part is free from grease, oil, dirt, or loose scale or surface finish. Consequently, this type of inspection will generally apply to parts which are disassembled from the aircraft. Generally, DC current is used for surface defects and AC current is used for subsurface defects.

a. *Magnetic fields* are induced in ferro-magnetic parts when exposed to an electric current or field of the current. By controlling the direction of the magnetizing current, the lines of magnetic force can be induced at right angles to the discontinuity. Direction of the magnetic field is critical: (1) The lines of force should be at right angles to the longest dimension of the discontinuity if the best inspection results are to be obtained. (2) A general rule for magnetic field orientation is the "right-hand" rule. This rule states that if you grasp the article being magnetized with your right hand so that your thumb points in the direction of current flow, the lines of force in the magnetic field will be represented by your four fingers. (See Figure 5.)

b. Methods for applying magnetic fields to parts for inspection:

(1) Longitudinal magnetism is achieved by fixed current-carrying coils, or portable current-carrying cable coils which encircle the part and induce a longitudinal field. (See Figure 6.) The effective magnetic field extends from 6 to 9 inches from each end of the coil; long parts must be magnetized in sections which is accomplished by moving the part through the coil.

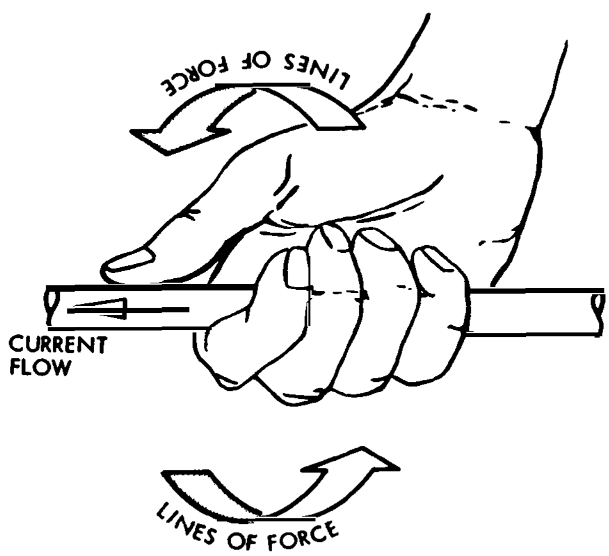


FIGURE 5.—The right hand rule.

(2) Circular magnetism is achieved by applying the electrical contacts at each end, or each side of the area being inspected and allowing the current to flow through. (See Figure 7.) Where the part is too large to apply end contacts the part can be magnetized with prod contacts, or clamp contacts. (See Figure 8.)

(3) An example of the use of a portable magnetic inspection unit is shown in Figure 9.

(4) Magnetic particles. During magnetization of the part the flaw or discontinuity is made visible by covering the area with magnetic particles which line themselves along the flaw or discontinuity. There are two types of magnetic particles for use in the magnetic inspection, the wet particles and dry particles.

(5) Wet particles consist of a suspension of magnetic particles in a light petroleum distillate or light oil. The particles are made of carefully selected magnetic materials of proper size, shape, magnetic permeability, and retentivity. They

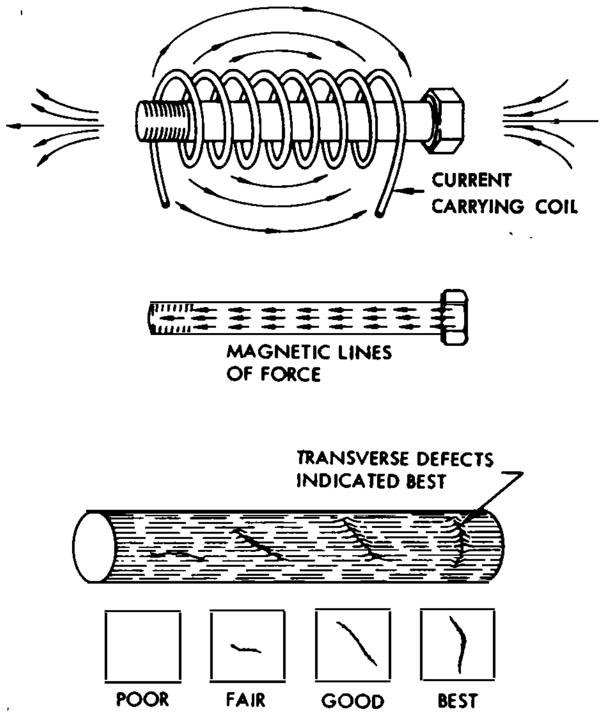


FIGURE 6.—Longitudinal magnetism.

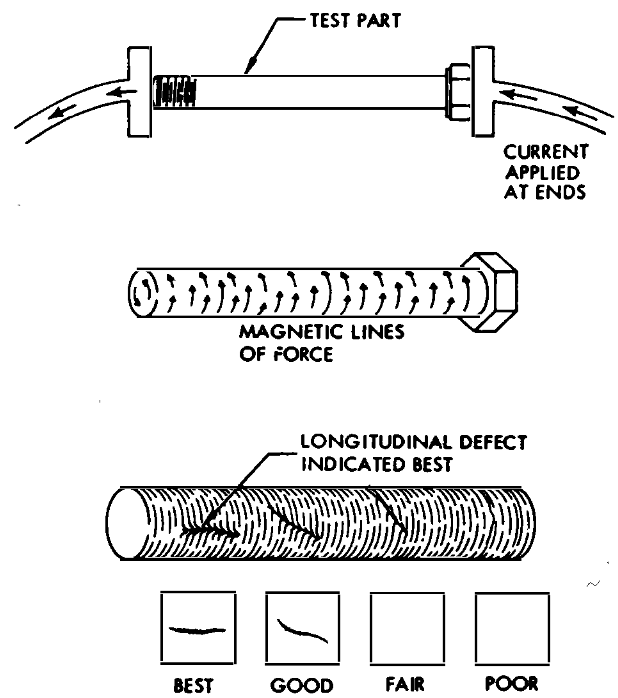


FIGURE 7.—Circular magnetism.

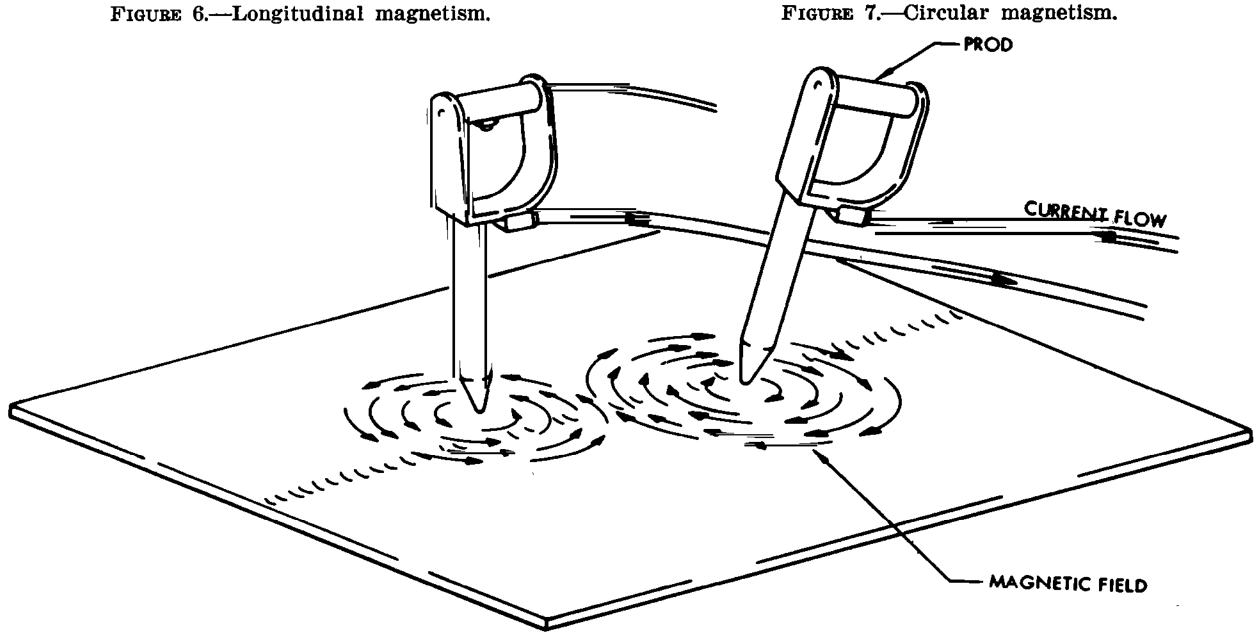


FIGURE 8.—Prod magnetization.

are colored, to give good contrast with the surface being inspected, or have fluorescent coating for viewing with a black-light source. Wet particles are applied by dipping or immersing the part in the solution, or by delivering it to the part through a hole.

(6) Dry particles are in powder form and can be obtained in a variety of colors, they are used with portable equipment. These types of particles are borne by air, and are applied using hand shakers, spray bulbs, shaking screens, or an air stream.

(7) Crack indications are detected by observing the particle pattern formed on the surface of the part being inspected. The approximate size and shape of the discontinuity is disclosed by this pattern. Fine discontinuities will develop more readily discernible indications when formed with the fluorescent magnetic particles. The advantages of the use of the wet or dry particles are as follows:

(a) Wet particles will give the best indications of fine surface cracks. They are used in stationary equipment, where the bath can be used until contaminated. Also, particles can be dispensed from small, portable shaker.

(b) Dry particles are best used on rough surfaces, and are used in portable equipment.

(8) Precautions. Parts must be free from grease, oil, rust, scale, paint, or other substances which will affect the magnetic particle inspection. Precautions must be observed during magnetic part inspection:

(a) If part being inspected is high-heat-treated steel, use only approved solvents.

(b) Keep cleaning fluids or magnetic particles out of areas where they could get entrapped.

(c) Dissimilar metals such as bushings, bearings, inserts, etc., must be removed prior to cleaning and inspection.

(d) Do not magnetize bearings.

(e) Avoid arc strikes during magnetization to preclude possible damage to critical items.

(9) Procedure for magnetic particle inspection:

(a) Clean the part per paragraph 18.b.(8).

(b) Magnetize the part. Equipment to magnetize the part will depend on material, location, and the type of defect being sought.

(c) Coat the magnetized area with magnetic particles and check for defects, surface or subsurface.

(d) After being magnetized for magnetic particle inspection materials retain some residual magnetism; upon completion of inspection the part must be demagnetized.

(e) Check part with a standard magnetic field indicator to assure complete demagnetization.

(f) Clean the part as follows:

1. If inspection has been made with the oil-suspension method, magnetic particle residue must be removed by solvent cleaning or vapor degreasing.

2. If inspection has been made with the water-suspension method, clean the part.

3. If the part is cadmium plated use an air-water vapor blast to remove residue.

(g) Dry the part and restore the original protective finish.

(10) Types of Equipment. There are many types of equipment available for performing magnetic particle inspection. They vary from small hand-held yokes, which consist of permanent magnets, or electromagnets energized from 115 volt AC lines to large, 10,000 amp. heavy-duty power units used for the inspection of large castings, weldments, or forgings. The choice of equipment that is used will depend on the equipment available at the time, and the place where the inspection is being performed.

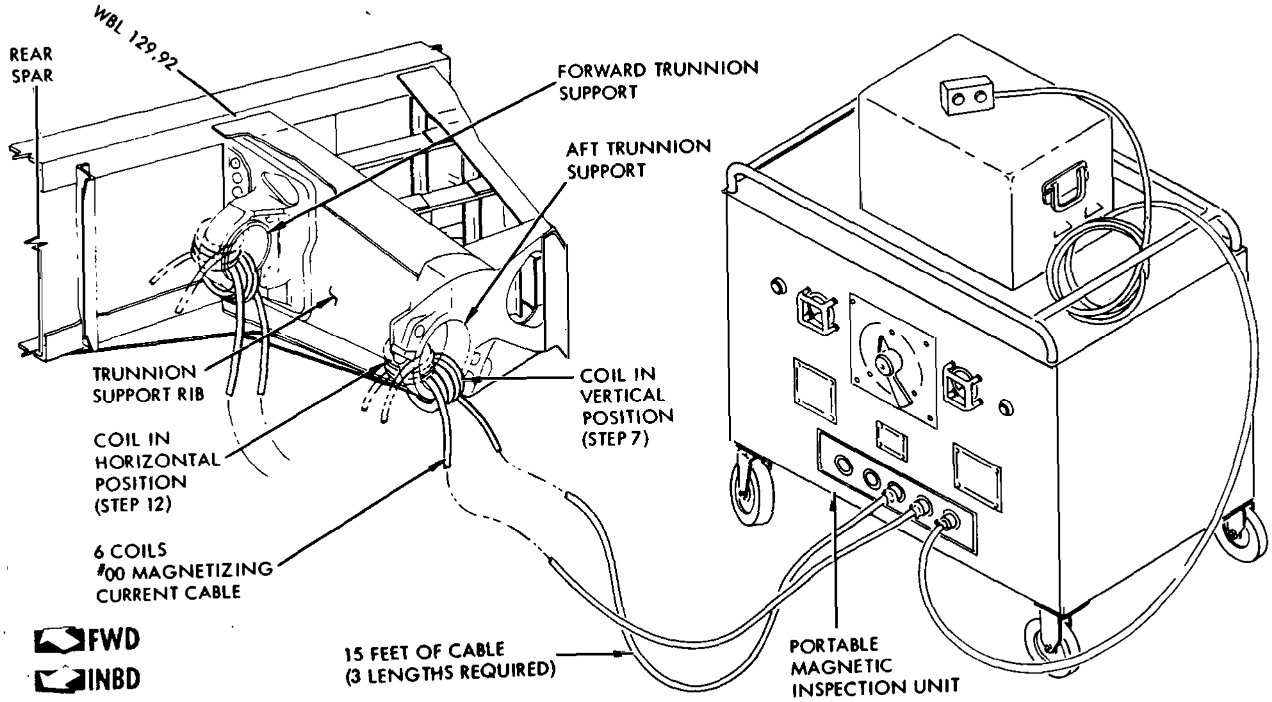


FIGURE 9.—Main landing gear trunnion support fittings inspection.

Chapter 5. EDDY CURRENT INSPECTION

20. GENERAL. Eddy current inspection is a nondestructive means for detecting discontinuities in a part. To initiate eddy currents in a part, an alternating current at a suitable frequency is supplied to the test coil. The coil carrying this current, in turn, induces a magnetic field of the same frequency in the part and causes eddy currents to flow. Variations in the magnitude of the eddy currents will affect this magnetic field, and when analyzed electronically will give information regarding structural change in the part, such as, flaws, discontinuities, thickness, alloy or heat treat of material. Eddy current inspection is used to locate defects both on the surface and subsurface. Adjustments on the electronic control enable the same instrument to detect variations in diameter, grade, and hardness.

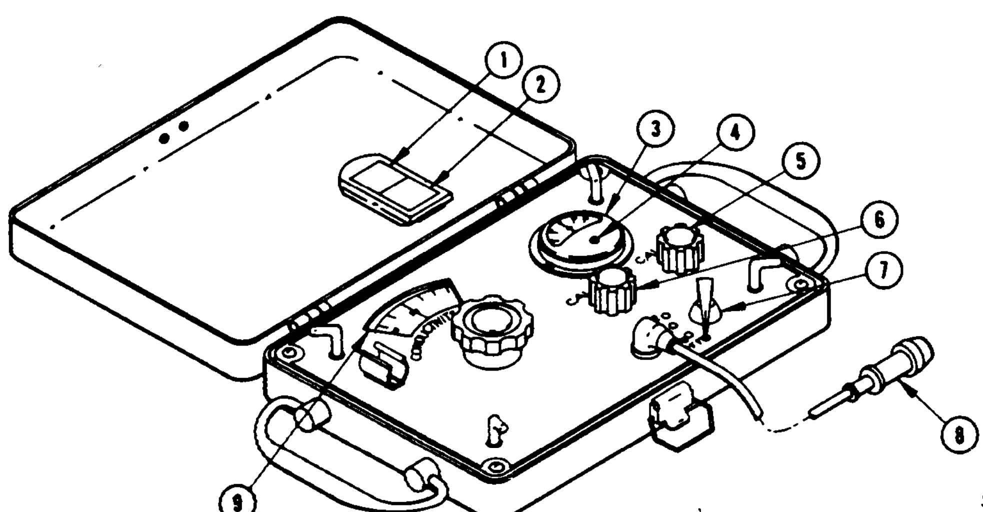
21. TYPES OF EQUIPMENT.

a. ***Eddy current inspection equipment*** consists essentially of a probe and an electronic instrument. The probe contains a coil, used for inducing the electric current into the part being inspected. The electronic instrument contains circuitry which measures the variations in the electric current flow and records these changes on a meter or cathode ray tube or a combination of both.

b. ***Several types of equipment*** are available for making the eddy current inspection. Figure 10 shows a portable, transistorized, battery operated instrument for measuring conductivity. Figure 11 shows a typical instrument used for inspection on the bench for analyzing material for structural changes. Types of probes recommended for these inspections are:

(1) Inside probe coils, which are inserted into cavities such as interior of hollow tubes or drilled holes.

(2) Outside probe coils which are placed on the surface of test object. (See Figure 12 for example of probes.)



1 HIGH CONDUCTIVITY STANDARD
2 LOW CONDUCTIVITY STANDARD
3 METER
4 METER ADJUSTMENT SCREW
5 "CAL-HIGH" KNOB
6 "CAL-LOW" KNOB
7 SWITCH
8 PROBE
9 CONDUCTIVITY DIAL

FIGURE 10.—Magnatest conductivity tester.

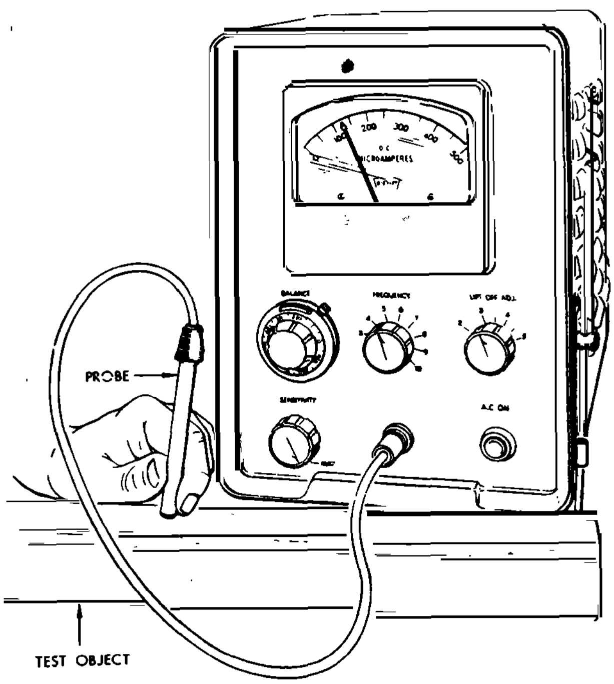


FIGURE 11.—Magnatest tester.

c. ***Care should be taken to insure that*** the eddy current equipment selected has been designed to accomplish the work. There have been cases where the incorrect equipment was used. Some test equipment is designed to be used on magnetic materials, others for use on nonmagnetic materials and some models are designed for use on both type materials. The manufacturer's specifications should always be consulted to assure that the eddy current equipment has the capability to accomplish the particular inspection application.

22. INSPECTION PROCEDURE.

a. ***Inspection of a part.***

(1) The surface of the area being inspected must be thoroughly cleaned so the eddy current probe can make good contact.

(2) Dirt, carbon, or grease deposits must be cleaned with solvents. If part being inspected is high-heat-treated steel, use only approved solvents.

b. ***Calibration of an eddy current meter.*** The following steps outline a detailed process required for calibration of an eddy current meter:

(1) Connect probe to instrument.

(2) Turn instrument on, leaving sensitivity minimum.

(3) Allow 20–30 minutes for warm up.

(4) Set frequency control to No. 1 and rotate LIFT-OFF control clockwise to stop.

(5) Rotate BALANCE control so that meter reads between 100 and 200 microamps.

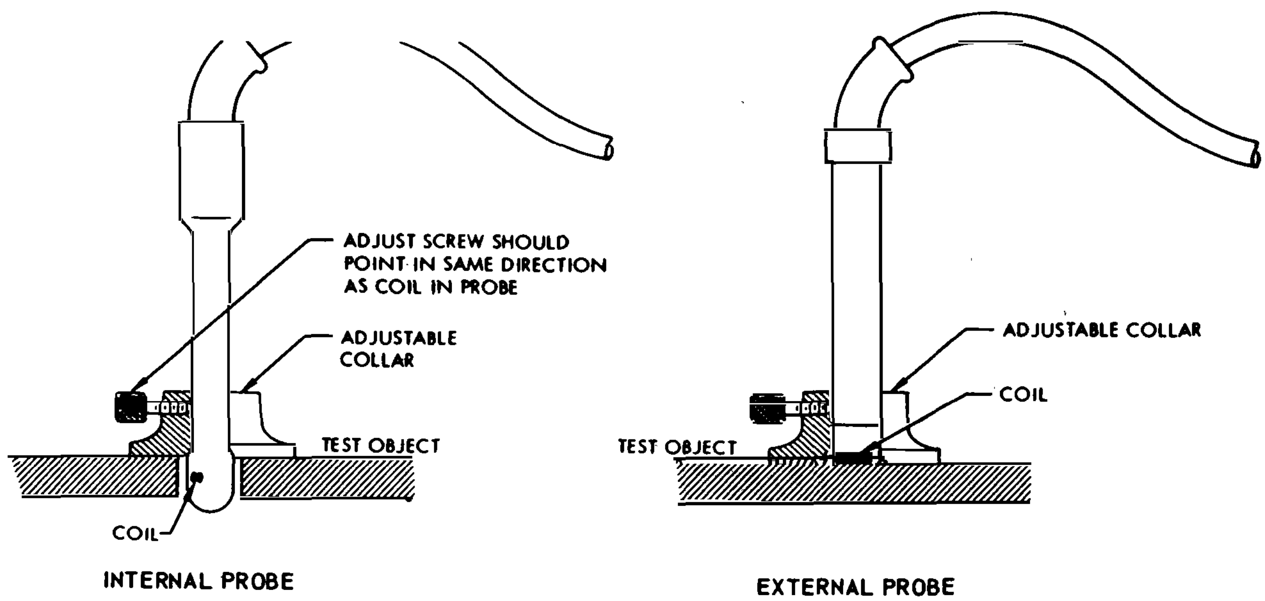


FIGURE 12.—Types of probes.

(6) Adjust the collar of the probe so that the sensing coil extends approximately halfway through the part.

(7) Place probe into bolthole and rotate LIFT-OFF control counter-clockwise and note meter deflection reversal. If meter reverses, continue to step (10). For surface probes place coil on flat surface and continue with procedure.

(8) If the meter deflection does not reverse, return LIFT-OFF control to full clockwise position and increase FREQUENCY CONTROL one step (to No. 2). Adjust the balance control if necessary to keep the meter needle on scale.

(9) Repeat step (8) until the direction of meter deflection reverses. (For surface probe see step (16)).

(10) Alternately place the probe in, and remove the probe from the hole to be tested; noting the direction and amount of meter deflection. After each removal, rotate the LIFT-OFF control until the meter reads approximately the same when the probe is completely removed as it does whe the probe is completely inside the hole. (Minor adjustments of BALANCE control may be necessary to bring the meter needle on scale.)

(11) Increase the sensitivity and repeat step (10). Do this until the SENSITIVITY control is completely clockwise, using the BALANCE control to keep the meter needle on scale.

> NOTE.—The LIFT-OFF control is the fine adjustment of the operating frequency, while the FREQUENCY control is the coarse adjustment. During this step the LIFT-OFF control may be rotated completely counterclockwise without achieving the desired results. If this happens, rotate the FREQUENCY control to the next lowest number; rotate the LIFT-OFF control all the way clockwise and finish step (11).

(12) With the probe in the hole, press sideways on the probe in such a way as to force the sensing coil away from the wall of the hole. Note the amount of deflection.

(13) Rotate the LIFT-OFF control clockwise and repeat step (1). The deflection will be less. Repeat this until the meter reads the same when it is against the hole wall as it does when it is removed from the wall one or two thousandths of an inch. (See note for step (11)). At this point, balancing for lift-off is complete. Hole elongation and surface roughness will have a very minor effect on the meter, however, sensitivity to cracks is higher than with any other method of adjusting for lift-off.

(14) Once the probe has been properly balanced, the hole is inspected by rotating the probe so that the pick-up coil passes over all of the surfaces. If a crack exists the instrument will show a sharp deflection as the coil passes over it. This sharp deflection should not be confused with the slow minor changes which will occur because of minor changes in the conductivity of the base material.

(15) Minor adjustment of the BALANCE control may be required to bring the meter needle on scale as the coil approaches the surface or edge of the hole.

(16) For calibration of a surface probe, place a single sheet of paper (.002 to .003 inches thick) between the probe and the sample, noting the amount and direction of meter deflection. Rotate the LIFT-OFF control until the meter reads approximately the same when the probe is on the paper as it does when the probe is on the sample.

(17) For final adjustments see step (11).

23. AREA INSPECTION.

a. ***After completion of the meter calibration*** as outlined in paragraph 21 above, proceed as follows:

(1) Using the surface probe, work back and forth over suspected area, or using the internal probe, rotate inside the hole and work up and down the wall.

(2) When a damaged area is encountered, such as a crack, inclusion, corrosion, etc., the meter needle will suddenly deflect. (Due to a sudden change in material conductivity.)

(3) By working the probe around the area and observing meter needle deflection, it will be possible to obtain an accurate location of the damaged area, which can be marked. Inexperienced personnel should not attempt to interpret the results of the nondestructive tests. Misinterpretation can result in serviceable parts being rejected and defective parts being accepted.

b. *Preparation of airplane.* When conducting eddy current inspections near fuel tank areas, the airplane may have to be defueled. Otherwise, no other preparation of airplane is required when conducting eddy current inspection on the aiplane.

c. *Preparation of part.* The part being inspected must be thoroughly clean. Deposits of dirt, grease, carbon, rust, and scale must be removed. If part being inspected is high-heat steel, use only solvents listed.

24. REPRESENTATIVE EDDY CURRENT INSPECTIONS.

a. *Landing gear wheel tire bead seat area.* Inspections have located cracks which may have propagated from small corrosion pits in the bead seat.

b. *Fastener holes.* Fastener holes throughout the primary structure of the airplane.

c. *Turbine engine compressor disc.* These parts may be inspected for cracks which may propagate through the disc hub web from a circumferential step radius. By use of special techniques, the inspection may be accomplished on certain engines with only partial engine disassembly.

d. *Fuselage skin.* Upper crown skin crack stopper spot welds.

e. *Main landing gear.* Main landing gear beam trunnion bearing hole and uplock bell crank arm.

f. *Horizontal stabilizer.* Upper rear spar chord.

25. EDDY CURRENT GUIDELINES.

The eddy current technique may be selected for the inspection process with the following as guidelines:

a. *The area to be inspected* is of a limited size, such as a fastener hole, and only a small probe can be used.

b. *There is a random flaw orientation* that would make the use of ultrasonic inspection time consuming.

c. *The flaw-seeking portion of the probe* should be some distance from the inspector's hand.

26. RESERVED.

Chapter 6. ULTRASONIC INSPECTION

27. GENERAL. Ultrasonic inspection utilizes a high-frequency sound wave as a means of detecting discontinuities in parts. This is accomplished by beaming the high-frequency wave through the part, and viewing the response pattern on an oscilloscope (cathode ray) tube. By examining the variations of a given response pattern, discontinuities, flaws, or boundary conditions are detected. Ultrasonic inspection on aircraft is largely confined to fastener joints or susceptible areas around fastener holes. The high-frequency sound waves are of short wave length and relatively low-energy levels to prevent damage to the structure. The use of ultrasonic equipment under normal conditions does not require special safety precautions for personnel.

28. ULTRASONIC EQUIPMENT. There are two basic methods of ultrasonic inspection, and they determine the equipment required. The first method is immersion inspection, and the second is contact inspection. Immersion equipment is heavy and stationary. Contact equipment is smaller and portable. Inspection requirements in this chapter are confined to field type inspections, requiring only the contact inspection type equipment.

29. COMPONENTS. Basic components of an ultrasonic flaw detector consist of:

a. ***A power supply*** to produce the various required voltages.

b. ***The rate generator or timer,*** whose function it is to start and synchronize all other functions.

c. ***The pulser,*** which generates a high-voltage, short-duration spike to "shock" the crystal into resonant vibration.

d. ***The transducer (crystal)*** which transmits a high-frequency sound wave into the test piece, receives the reflected echo, and converts it into an electrical impulse.

e. ***The amplifier or receiver,*** to amplify and properly prepare the echo signal for display.

f. ***The sweep generator,*** which starts to trace a line horizontally across the cathode-ray tube screen at the same time the pulse "shocks" the transducer into action.

g. ***The marker generator,*** which produces time marks, such as square waves to be presented simultaneously with the horizontal sweep to aid in depth measurement.

h. ***The oscilloscope (cathode-ray) tube*** which presents a picture of the echo signals.

30. APPLICATIONS. Ultrasonic is a fast, reliable nondestructive testing method which employs electronically produced, high-frequency sound waves that will penetrate metals, liquids, and many other materials at speeds of several thousand feet per second. Because ultrasonic techniques are basically mechanical phenomena, they are particularly adaptable to the determination of structural integrity of engineering materials. Their principle applications consist of:

a. Flaw detection.

b. Thickness measurement.

c. Determination of elastic moduli.

d. Evaluation of the influence of processing variables on the specimen.

31. FEATURES. The desirable features of ultrasonic tests include:

a. ***Versatility,*** access to only one surface of the specimen is needed and the test equipment may be taken to the work.

b. ***Fast response,*** permitting rapid and automated inspection.

c. ***Accuracy in the measurement*** of flaw position and estimation of flaw size.

d. ***Great penetrating power,*** allowing examination of extremely thick sections.

e. ***High sensitivity*** permitting detection of minute defects.

32. EXAMPLES OF CAPABILITIES. The following are a few applications, which indicate the capabilities of ultrasonic testing as it is practiced today:

a. ***Ultrasonic techniques are used to detect*** laps, seams, laminations, inclusions, rolling cracks, and other defects in steel plates ¼″ to about 12″ thick. Discontinuities as small as 0.5% of the plate thickness are detectable as are laminations down to less than 0.00002″ thick.

b. ***Ultrasonics are used to locate*** porosity, cupping, internal ruptures, and nonmetallic inclusions in bar stock and ingots of various sizes up to 48″ in diameter.

c. ***Ultrasonic tests locate*** cracks, blow holes, insufficient penetration, lack of fusion, and other discontinuities in welds. Ultrasonics are used to evaluate bond quality in brazed joints and honeycomb assemblies.

d. ***Ultrasonics are used*** to inspect forgings such as turbine shafts and rotors.

33. LIMITATIONS.

a. ***There are many factors which limit the application*** of ultrasonic testing. Among the most important are sensitivity, resolution, and noise discrimination. Sensitivity is the ability of the instrument to detect the small amount of energy reflected from a discontinuity. Resolution is the ability of the instrumentation to detect flaws lying close to the test surface or to separate and distinguish the indications from several defects occurring close together in the specimen. Noise discrimination is the capacity of the instrumentation for differentiating between the signals from defects and the unwanted noise of either electrical or acoustical nature.

b. ***These variables in turn are affected*** by others, such as frequency and pulse energy. For example, when frequency is increased, the sensitivity increases. With the increase in sensitivity, smaller inhomogenetics within the material will become detectable; this will increase the noise level thus hindering signal discrimination. With an increase in pulse energy, material noise will increase and resolution will decrease.

c. ***In addition, the geometry and condition of the test material may limit*** the application of ultrasonic testing. For example, size, contour, complexity, defect orientation, and undesirable internal structure such as grain size, porosity, inclusion content, and fine dispersed precipitants.

d. ***Problems concerning*** the couplants, surface roughness, and scanning also limit applications for ultrasonic testing.

34. REQUIREMENTS. Due to the many conditions which can and do restrict the application of ultrasonics, a successful inspection cannot be expected unless there is:

a. ***Ultrasonic testing equipment*** suitable for the specific application.

b. ***Capable operators.***

c. ***A clear definition*** of the test problem.

d. ***Adequate reference standards.***

e. ***Practical test specifications.***

f. ***Realistic acceptance criteria.***

g. ***Detailed test records.***

h. ***Frequent inspection of the equipment.***

35. AIRCRAFT PREPARATION. This inspection technique does not require part disassembly or removal. However access to the desired area must be accomplished. Consequently, some fairing or access panel removal may be required, and limited adjacent equipment disassembly. The following considerations of the area are necessary for ultrasonic inspection.

a. ***The surface condition*** of the part must be determined. A rough surface with numerous pits and bumps is difficult to inspect due to the unsteady pattern of the response.

b. ***Limited scale or corrosion removal*** may be required on steel forgings to provide a smooth surface.

c. ***Paint and dirt*** should be removed. Heavy paint will absorb most of the sound energy and must be removed before inspection is possible.

36. ULTRASONIC INSPECTION REQUIREMENTS. This inspection must be performed only by qualified personnel who are acquainted with the equipment and procedures. To obtain best results, the following suggestions should be observed:

a. Locally fabricate a standard test block to given dimensions of the indicated material as shown in Figure 13.

b. Locally fabricate a mount (or shoes) for the transducer head to dimensions as shown in Figure 14 using lucite.

c. Select couplant grease or oil as suggested by the individual inspection requirement.

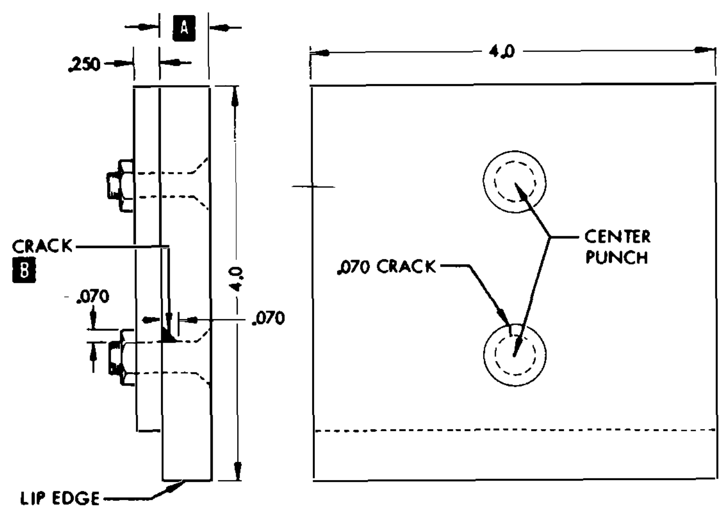
d. The response cannot distinguish between a defect or a fabrication hole. Consequently, all adjoining fabrication holes must be identified and located prior to inspection for defects.

37. STANDARD TEST BLOCK. Ultrasonic equipment is calibrated using a standard test block of the same material and gage as the part to be tested. Recommended test blocks for inspections can be locally fabricated. Test blocks must be made of a suitable material as determined by

NOTE

A THIS DIMENSION WILL VARY ACCORDING TO INSPECTION AREA. THIS SECTION REQUIRES STANDARDS OF .160, .330 AND .350. VARIATIONS CAN BE MADE AS REQUIRED.

B CUT THIS CRACK WITH JEWELERS SAW.

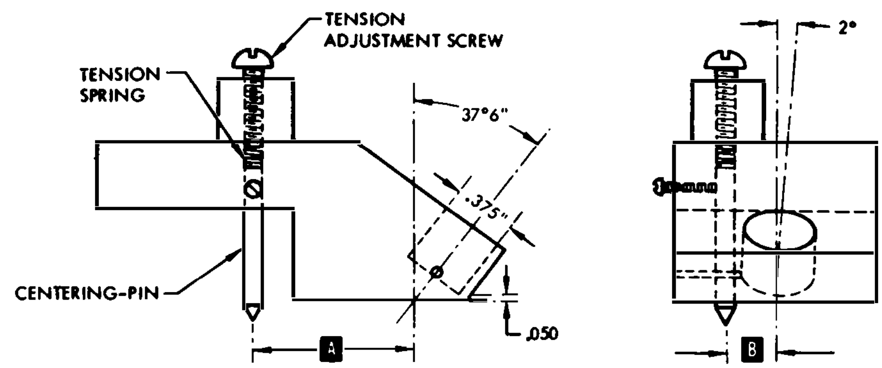


TEST BLOCK MATERIAL

MATERIAL	ALLOY	TEMPER	REMARKS
Aluminum	2014 or 7075	F T6	For all aluminum base alloys
Magnesium	AZ80A	F	For all magnesium base alloys
Titanium	T1 6AL-4V	Annealed	For all titanium base alloys
Steel Wrought	AISI 4130 or AISI 4340	Annealed Annealed	For all SAE-AISI 1000, 2000, 3000 and 4000 series of steel alloys
Nickel Base Alloys	Rene' 41 per BMS 7-96	Solution Heat Treated	For nickel base, Cr., Mo., Co. Alloys
Cast Steel	Cast Steel per QQ-S-681 Class 4B1	Normalized	All cast steel parts
Use the above compositions for standard test blocks for the general alloy groups listed.			

FIGURE 13.—Standard test block.

inspection requirement. Figure 13 lists materials and test block fabrication which are recommended for equipment calibrations of inspections in this section. When required, specialized test blocks and fabrication instructions will be found with inspection instructions.



TRANSDUCER MOUNT CONSTRUCTION

INSPECTION MATERIAL THICKNESS	DIMENSION A	DIMENSION B
.160	.480	.210
.350	.350	.200

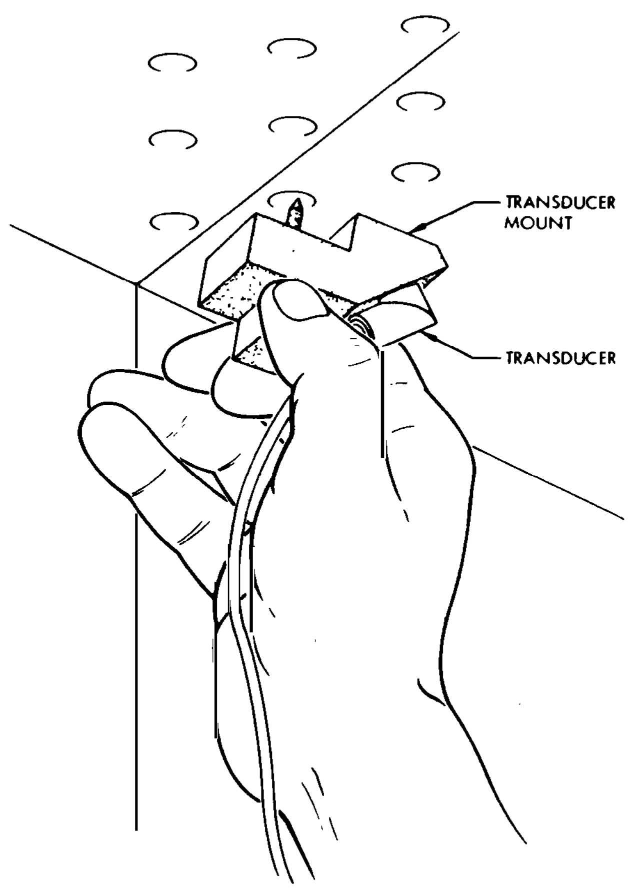


FIGURE 14.—Transducer mount–fastener hole inspection.

38. TRANSDUCER MOUNT. A transducer mount is recommended to permit proper relationship between sonic beam and part being inspected. The transducer mount (or shoe) can be locally constructed of lucite. Figure 14 gives the design for a shoe usable with most fastener hole inspections. However, when specialized mounts (or shoes) are needed, fabrication instructions will be a part of the inspection technique.

39. EQUIPMENT CALIBRATION. The ultrasonic test equipment is calibrated by placing the fixture centering pin on the center of the steel fastener head (previously center-punched) and slowly rotating the transducer around the comparison standard fastener until a response is obtained from the saw cut. The sensitivity of the equipment is adjusted until the response indication on the cathode-ray tube is approximately 50 percent of saturation.

40. REPRESENTATIVE INSPECTIONS.

a. Corrosion in integral wing fuel tanks.

(1) Micro-organisms in petroleum distillate products, used in turbine-powered aircraft, results in failure of integral fuel tank coatings and corrosion of the wing skins.

(2) Corrective measures are being initiated by the petroleum industry and others to eliminate this microbiological activity in jet fuels. However, problems with internal corrosion pitting and surface attacks in aircraft fuel tanks continue to be experienced.

(3) Standard ultrasonic inspection techniques are used for determining and recording the condition of the interior surfaces of wet-wings.

(4) Longitudinal waves should be used since shear and plate waves will not accurately establish the definition or extent of corrosion pits.

b. To scan the underneath surface of an aircraft wing, the following equipment is utilized by the Air Force and some airlines.

(1) A wheel-search unit. To assure a satisfactory coupling, the surface to be scanned is moistened.

(2) An oscilloscope with a fast pulse repetition rate. This is necessary to conduct a rapid scan of 500 square inches or more in 15 minutes.

(3) A C-scan facsimile recorder.

(4) An automatic and manually controlled scanning bridge and carriage.

(5) A positioning mechanism, scanner support structure, and lift platform. This equipment places the wheel-search unit in a position to scan the lower surface of the wing and provides the apparatus necessary to relate the motion of the search unit to the facsimile recorder. This equipment also permits a rapid engagement of the scanner with the aircraft and requires no jacking or other handling of the aircraft, nor is it necessary to drain the fuel tanks.

(6) Intergranular corrosion appears on the C-scan recording as a solid area projecting outward from fastener holes or other locations where there is a transverse cut exposing the edge of the plate. Large or small areas of pit-type corrosion may appear anywhere on the recording with high-density areas giving a mottled appearance to the recording. Thus, the extent and the kind of corrosion can be determined from the recording.

c. Main Landing Gear Torsion Link Lugs. A surface-wave probe is used on the lug surfaces and on the thickened boss section for fatigue cracks occurring in random directions. It is necessary to direct the ultrasonic sound beam towards the crack at an angle of 90° in order to obtain the optimum reflection. This means that careful scanning in all directions and in all positions around the bosses and lugs is necessary to ensure complete coverage of the suspected area. (See Figure 15.)

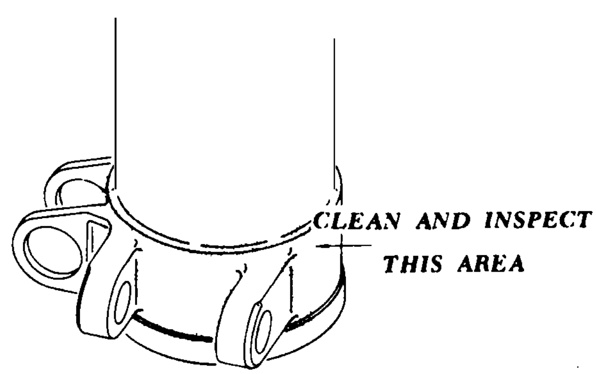
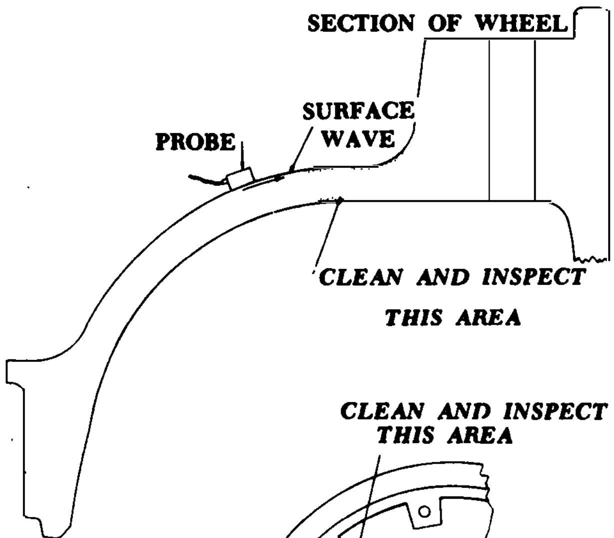


FIGURE 15.—Main landing gear torsion link lugs.

d. Main and Nose Landing Gear Wheels. A surface-wave probe is used to scan around the wheel web for cracks occurring adjacent to the bosses of the tie-bolt holes. The surface wave is able to detect cracks which are not always indicated by other methods of examination. For cracks occurring in the zone of the tire areas, a second probe, having an angle of 30° refraction, is sometimes employed for testing the bead seat radius where the test is carried out without disassembly of the wheel. The angle is necessary to direct the beam away from any reflecting surfaces, such as changes in contour, into the zone where defects occur. (See Figure 16.)



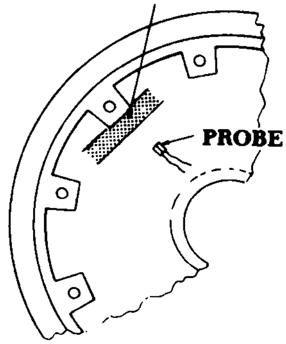


FIGURE 16.—Main and nose landing gear wheels.

e. Main Landing Gear Torsion Link. The probe is applied to the member on its surface with the beam directed toward suspected zones. Usually most of the surface of the torsion link is scanned for fatigue cracks in any position where highly stressed areas are experienced. (See Figure 17.)

f. Pratt and Whitney JT3D engine. Spacer between the first and second stage fan hub is inspected in an assembled engine. A surface wave transducer is used to inspect for cracks at a center rib which is located circumferentially around the inside surface of the spacer.

g. L–188 wing panels or "planks." These are chemically milled and have overlap splices and integral stiffeners span-wise. The overlap splice between each of these "planks" is inspected for span-wise cracks on the entire upper and lower wing surface. When a flaw is indicated by shear wave technique, longitudinal wave technique is used to help define extent of the crack.

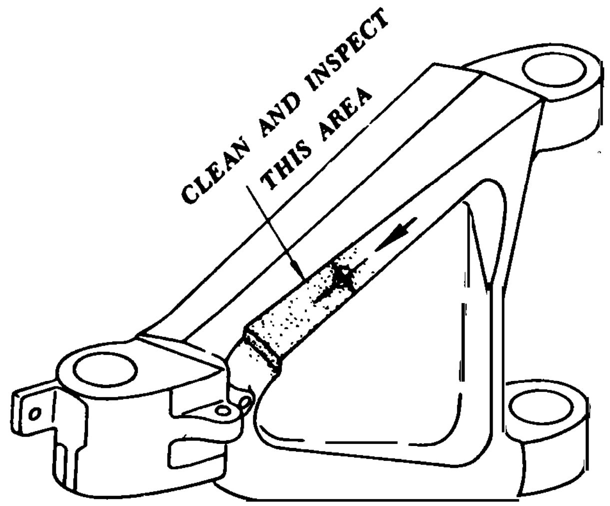


FIGURE 17.—Main landing gear torsion link.

h. L–188 aircraft cabin windows. The outer panels are machine polished to remove scratches and surface blemishes. Following this rework, the thickness of the panel is measured using the ultrasonic resonance technique.

i. Main landing gear down lock torque tube. An inspection is made to determine the soundness of furnace brazed areas that secure the end fittings to this tube. A longitudinal wave is used and areas of poor braze bond are readily detectable by the signal displayed on the ultrasonic screen.

41. FIBERSCOPES (FIBER OPTICS). Fiberscopes can be used for inspecting areas in an engine or aircraft structure which are hidden or not readily accessible without a major disassembly. However, there must be an opening provided, such as igniter holes, ports or access doors, which will permit entry of the fiberscope. For example, the inside of a combustion chamber of a turbojet engine can be inspected by inserting the fiberscope through the igniter hole. Some large engines have special ports which permit the inspection of certain internal areas with the scope. Fiberscopes transmit light for illumination and not an image. Light is transmitted to the desired location for inspection from a remote light source. The distal end of the scope can be moved in an up or down position as desired by the operator. Inspection of the object is made through an eye viewer attached to the scope. A camera can be attached to the viewer and a photograph made of the object.

42.–45. RESERVED.

Chapter 7. VISUAL INSPECTION

46. SCOPE OF METHOD. Visual inspection is the oldest of the nondestiuctive methods of testing. It is a quick and economical method of detecting various types of cracks before they progress to failure. Its reliability depends upon the ability and experience of the inspector. He must know how to search for structural failures and how to recognize areas where such failures are likely to occur. Defects that would otherwise escape the naked eye can often be detected with the aid of optical devices because:

a. ***They magnify defects*** that could not be seen by the unaided eye.

b. ***They permit visual inspection*** of areas that are not accessible to the unaided eye.

47. VISUAL INSPECTION AIDS. The equipment necessary for conducting a visual inspection usually consists of a strong flashlight, a mirror with a ball joint, and a 2.5x – 4x magnifying glass. A 10x magnifying glass is recommended for positive identification of suspected cracks. Visual inspection of some areas can be made only with the use of a borescope.

a. ***Corrosion treatment.*** Before attempting a close, visual inspection of any selected part or structural area, it should be checked for signs of corrosion. Any corrosion found, should be tested to discover its extent and severity. Heavy or severe corrosion requires immediate corrective action. If mild corrosion is present, it should be carefully, but completely, removed before continuing with preparations for the visual inspection.

b. ***Structural failure determination.*** The first step in a visual inspection should be an examination of the area for deformed or missing fasteners. These should be identified for subsequent replacement. A close examination for cracks in the surfaces of structural members should then be made with the aid of a flashlight. The majority of cracks start at, and progress from, points of concentrated stress such as sharp corner cutouts and fastener holes. Cracks may also occur in sheet metal bend radii and similar places that were subjected to severe forming operations during manufacture.

c. ***Cleaning of structural parts.*** All parts of areas from which mild corrosion has been removed should be thoroughly cleaned using an approved solvent. (Metal conditioner should not be applied at this time as it may interfere with subsequent dye penetrant inspection.)

d. ***All other areas to be inspected*** should also be cleaned of any deposits that might hinder the discovery of existing surface flaws. The protective finish need not be removed. The cleaning should be performed using any approved solvent. For cleaning high-heat-treat steel parts, or areas in which a high-heat steel part is installed, use only the approved solvents.

e. ***Crack detection technique.*** When looking for surface cracks, the inspector should point his

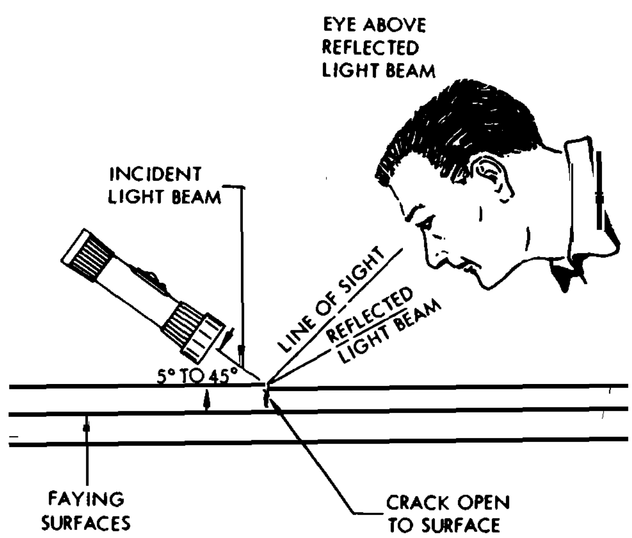


FIGURE 18.—Inspection for cracks.

flashlight towards himself and hold it at an angle of 5° – 45° to the surface. (See Figure 18.) The extent of the crack may be traced by directing the beam at right angles to the crack. Never direct the light beam at such an angle that the reflected beam shines directly into the eyes. The proper procedure is to keep the eyes above the reflected beam.

f. *Verification of cracks*. A 10x magnifying glass may be used to confirm the existence or extent of a suspected crack. If this is not adequate, another type of nondestructive inspection should be performed on the area. The dye penetrant method is most commonly used for this purpose.

48. BORESCOPES. A borescope is a precision optical instrument with a built-in light source. Borescopes are specialized forms of telescopes and are available in numerous models from 10-inch diameter and a few inches long to diameters less than 0.75 inch and several feet long. Short-length borescopes with large diameters yield the brightest images. Due to light losses, the brilliance of the image diminishes as the length of the borescope increases. Most borescopes enable the observer to view an area of approximately 1-inch diameter with the objective lens of the instrument 1 inch away. (See Figure 19 for construction details.) The size of the visual field usually varies with the diameter for a given magnification system. The entire lens system of the instrument is corrected for maximum definition. This helps to eliminate eyestrain and fatigue caused by continuous, detailed inspection of large areas.

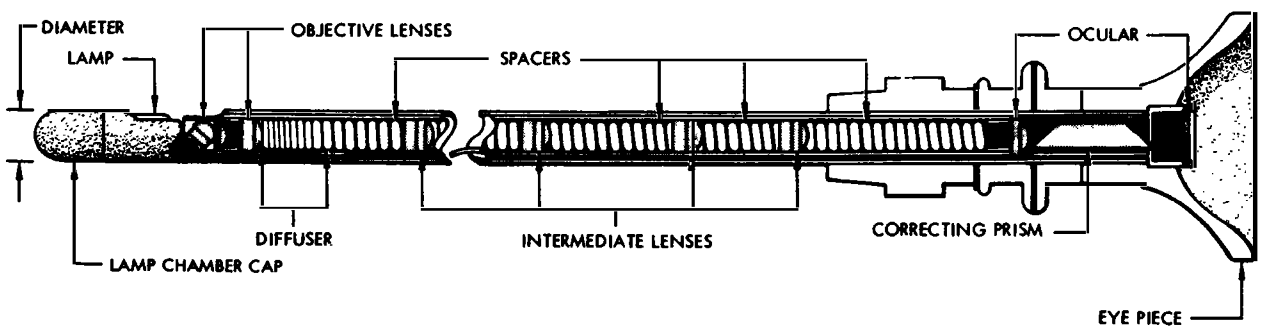


FIGURE 19.—Typical borescope construction.

a. *Borescope design*. The design varies according to the application for which the instrument is intended. The basic types are described below and illustrated in Figure 20.

(1) Direct-vision borescope—provides a view directly forward.

(2) Right-angle borescope—provides a view at right angles to the axis of the instrument with the light usually located just ahead of the objective lens.

(3) Retrospective borescope—provides an oblique, rearward view with the light located to the rear of the objective lens. This type of borescope provides the only known method of accurately inspecting the internal surface of a bore which has an internal shoulder.

(4) Foroblique borescope—provides an oblique, forward view with the light located at the forward end of the instrument. The view extends to an angle of about 55° from the axis. A unique feature of this type of borescope is that, by rotating it, the working area of the visual field is greatly enlarged.

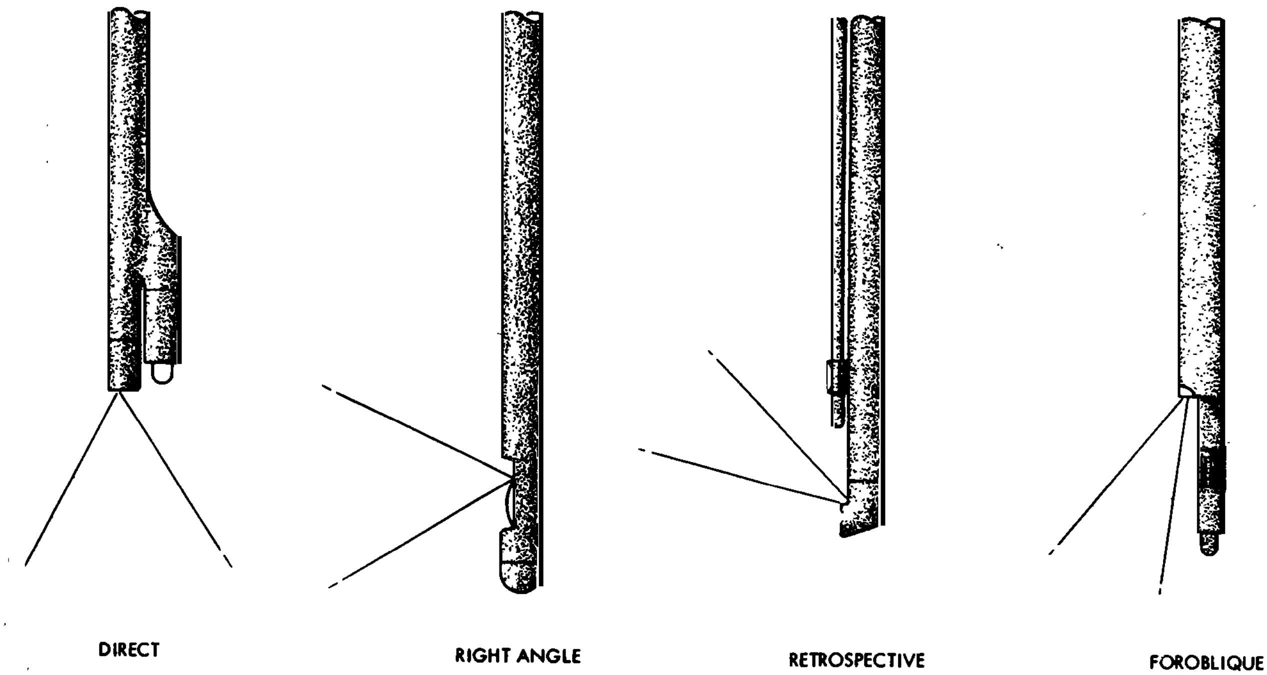


FIGURE 20.—Types of borescopes.

49–50. RESERVED.

Chapter 8. NEW APPLICATIONS FOR NONDESTRUCTIVE TESTING

51. FORECASTINGS. Many new applications, such as the continuous monitoring of critical aircraft structures for fatigue cracking by the use of pattern-placed transducers, are envisioned for nondestructive testing. Means will have to be developed for the analysis of forthcoming structural materials such as the fiber-reinforced materials. Ideally, the development of testing techniques will occur simultaneously with the material development program; however, this is not always the case. Most of us are familiar with medical applications of radiography and with the fact that medical X-ray technology was well developed before significant industrial applications were available. The medical field is now making use of ultrasonic technology which was initially developed for industry.

52. INDUSTRY USAGE. The manufacturing, repair, and damage assessment of structures and other hardware in the space and lunar environment will require the development of a whole new family of nondestructive test instruments and procedures. Virtually every aircraft component and assembly which is subjected to nondestructive testing is undergoing evaluation to determine how faster and more thorough quality inspection techniques can be applied as they are conceived and developed. This is a continuous process which requires the close cooperation of FAA and industry. (See Appendix 1.) It should be obvious that improvements will be equally beneficial to the pipeline contractor or tank car manufacturer as to the manufacturer of aircraft fuel tanks.

53. PRIORITIES. Efforts to improve discontinuity location and identification should have the highest priority. The development of faster testing systems is also urgently required. Improvement in applications, specification improvement, improved display systems, and miniaturization are also of significant importance and deserve major development efforts.

54. FUTURE OF NONDESTRUCTIVE TESTING. There is an unlimited future for nondestructive testing. Only a sampling of new and predicted developments has been covered in this handbook. It is obvious that to derive the maximum benefit from nondestructive testing, not only technology, but also communications between management, the physicist, the materials engineer, the design engineer, and field maintenance nondestructive testing personnel must be improved.

Appendix 1. NONDESTRUCTIVE TESTING METHODS

1. VISUAL INSPECTION.

2. PENETRANT METHODS.

a. Visible dye penetrant.

b. Flourescent dye penetrants.

3. MAGNETIC PARTICLE METHODS.

a. Direct current, Wet.

b. Direct current, Dry.

c. Alternating current, Wet.

d. Alternating current, Dry.

4. EDDY CURRENT.

5. ULTRASONIC METHODS.

a. Pulse echo (immersion or contact).

b. Through-transmission (immersion or contact).

c. Resonance.

d. Natural frequency.

6. RADIOGRAPHIC.

a. X-radiation.

(1) Film radiography.

(2) Fluoroscopy.

(3) Xeroradiography.

(4) TV imaging.

(5) Color radiographs.

b. Gamma Radiation (isotopes).

7. OTHER METHODS. The development of the new nondestructive testing equipment is proceeding rapidly. However, progress in adapting this equipment and laboratory techniques to reliably solve field aircraft maintenance inspection problems is somewhat lacking. This is probably due partly to the application of the new equipment. Among new areas of development for aircraft application are the following:

a. ***Infrared.*** Utilization of infrared energy as a nondestructive technique has recently received attention. Infrared has been used in chemical analysis but the use of these techniques to verify the integrity of components is new. These techniques capitalize on the fact that heat is either generated by or can be induced into anything. One interesting use of this application is the evaluation of the condition of electrical or electronic components. By knowing the heat generated by a sound efficient contact one can predict the life expectancy of any similar contact simply by measuring the heat generated from the contact being evaluated.

b. ***Liquid crystals.*** The relationship between the liquid crystal state and more familiar crystalline solid state for organic substances is shown in Figue 21 without endeavoring to define the liquid crystal state. It is estimated that one out of every 200 organic compounds is subject to liquid crystalline behavior. Liquid crystals have designated classes and one is called "Cholersteric ester." It possesses unique optical properties which can be applied in the field of nondestructive testing. Over clearly defined temperature ranges, liquid crystals appear to have the flow characteristics of a liquid while retaining the order of a crystalline solid. Each liquid crystal responds in its own way to temperature changes with a reflection of color (red, green, etc.) depending on the temperature of the environment.

Nondestructive inspection utilizes liquid crystals which are in a slurry form or embedded in tape. This tape or slurry is applied to the surface of the part being inspected. The temperature change in the part will cause the liquid crystal to change color. Some applications include checks for delaminations in honeycomb materials and location of hot points or overheating in electronic devices.

c. ***Radiography color enhancement technique.*** Radiography embodying black and white film for flaw indication, is one of the oldest NDT techniques in the aviation industrial application.

However, NDT technicians have experienced difficulty in film interpretation due to the limitations associated with the readout of black and white film. This may be due, in part, to improper radiographic procedures which resulted in the flaw indication not being recorded on the film.

Further, flaw indications may be recorded on the film but will not be retrievable because of the lack of an adequate film contrast. The human eye has certain restrictions when attempting to distinguish between various shades of gray which variance might be an indication of a flaw.

In recent years research efforts have been combined to expand the detection capability of radiography with color film. Two basic systems for the color enhancement have been developed. One is the photographic system and the other is an electronic system. The photographic method is a laboratory technique and offers a greater resolution or sensitivity than the electronic system. The electronic system is commercially available, provides real time (immediate) for film processing and is an automatic system.

Both systems offer greater resolution in film interpretation than the standard back lighting process (illuminator or "zoom" lens) for black and white film. Color enhancement eliminates the various shades of gray on the film and provides for a faster, earier and more accurate interpretation of the film.

Some information will not be recorded on the film unless the X-ray tube head, for black and white exposures, is positioned normal to the plane of the flaw. However, the electronic and/or photographic color enhancement process widens the angle of incident and the flaw will be indicated on the film although the tube head, within certain limits, is not positioned normal to the plane of the flaw.

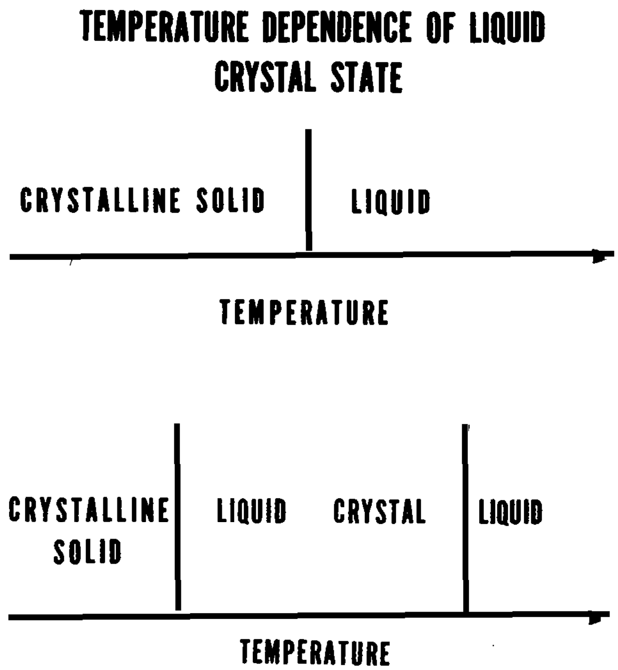


FIGURE 21.—Temperature dependence of liquid crystal state.

Appendix 2. STANDARD ABBREVIATIONS.

STANDARD ABBREVIATIONS. The standard abbreviations used are as follows:

LE—Leading Edge
TE—Trailing Edge
WS—Wing Station
BS—Body Station
NS—Nacelle Station
BWL—Body Water Line
NWL—Nacelle Water Line
WBL—Wing Buttock Line
TYP—Typical
HT—Heat Treat
MAX—Maximum
MIN—Minimum
LH—Left Hand (Left side of airplane)
RH—Right Hand (Right side of airplane)
S—Stiffener
FSD—Film Source Distance
FFD—Film Focal Distance
⌖ —Location of X-ray Source
℄—Center Line
CRT—Cathode Ray tube

Appendix 3. TERMINOLOGY AND DEFINITIONS.

TERMINOLOGY AND DEFINITIONS. Nondestructive inspection is the examination of the structure and components of the aircraft for defects on the surface or inside the material, or hidden by other structures without damaging the part. The terminology and definitions that are peculiar to the different types of nondestructive inspections are described below.

1. **Defect** is a discontinuity which interferes with the usefulness of the part, a fault in any material or part detrimental to its serviceability.

2. **Black light** is a term applied to the invisible radiant energy having wave lengths shorter than violet light but longer than X-rays. The black light filter transmission normally peaks between 3,200 and 4,000 Angstrom units in wavelength. It is used to make visible, in the dark, materials containing fluorescence.

3. **Fluorescence** describes the effects produced by certain chemical products which exhibit the property of emitting visible light during the activation by black light.

4. **Developers** are materials, wet or dry, which will draw or absorb penetrant from a surface crack or defect to the extent of visibility under natural, artificial, or black light, as applicable. Developers also control the background of the high-contrast penetrant color system.

5. **Emulsifier** is an agent which will, when added or applied to an oil-like penetrant material, make the penetrant removable from surfaces by water rinsing.

6. **Water washable**—A water-washable penetrant is an oil-like material containing an emulsifying agent which makes it washable by water rinsing.

7. **Post emulsifiable**—A post-emulsifiable penetrant is an oil-like material which, after application to a surface, can be made water washable by the application of an emulsifier.

8. **Penetrant remover** is a solvent-type liquid used to clean penetrants from the surface of a material.

9. **Penetrant sensitivity** is the ability of the penetrant, processing technique, and developer to detect surface-connected discontinuities and provide an indication visible to the unaided eye.

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