SAE Aerospace
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AEROSPACE INFORMATION REPORT

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Superseding AIR4777

Nondestructive Inspection (NDI) Methods Used During Production and Operation of Aircraft Wheels and Brakes

RATIONALE

AIR4777A has been reaffirmed to comply with the SAE five-year review policy.

1. SCOPE:

This SAE Aerospace Information Report (AIR) identifies current nondestructive inspection (NDI) methods used to insure product integrity and maximize "in service" life of the major structural components of aircraft wheel and brake assemblies.

2. APPLICABLE DOCUMENTS:

The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other documents shall be the issue in effect on the date of the purchase order.

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AMS 2300	Premium Aircraft-Quality Steel Cleanliness Magnetic Particle Inspection Procedure
AMS 2301	Steel Aircraft Quality, Cleanliness Magnetic Particle Inspection Procedure
AMS 2442	Magnetic Particle Acceptance Criteria for Parts
AMS 2630	Ultrasonic Inspection Product Over 0.5 inch (12.5 mm) Thick
AMS 2644	Inspection Material, Penetrant
AMS 3044	Magnetic Particles, Wet Method, Oil Vehicle
AMS 3045	Magnetic Particles, Wet Method, Dry Powder
ARP891	Determination of Aluminum Alloy Tempers Through Electrical Conductivity Measurement
AS3071	Acceptance Criteria - Magnetic Particle, Fluorescent Penetrant and Contrast Dye Penetrant Inspection

2.2 ASTM Publications:

Available from ASTM, 100 Barr Harbor, West Conshohocken, PA 19428-2959.

ASTM B 594	Standard Practice for Ultrasonic Inspection of Aluminum-Alloy Wrought Products for Aerospace Applications
ASTM E 10	Brinell Hardness of Metallic Materials
ASTM E 18	Rockwell Hardness and Superficial Hardness of Metallic Materials
ASTM E 384	Microhardness of Materials
ASTM E 709	Standard Guide for Magnetic Particle Examination
ASTM E 1417	Liquid Penetrant Examination
ASTM E 1444	Standard Practice for Magnetic Particle Examination

2.3 U.S. Government Publications:

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-F-38762	Fluorescent Penetrant Inspection Units
MIL-HDBK-728/2	Eddy Current Testing
MIL-HDBK-728/3	Liquid Penetrant Testing
MIL-HDBK-728/4	Magnetic Particle Testing
MIL-HDBK-728/6	Ultrasonic Testing
MIL-HDBK-6870	Inspection Program Requirements, Nondestructive for Aircraft and Missile Materials and Parts
MIL-STD-1537	Electrical Conductivity Test for Verification of Heat Treatment of Aluminum Alloys, Eddy Current Method
MIL-STD-1875	Ultrasonic Inspection, Requirements for
MIL-STD-2154	Inspection, Ultrasonic, Wrought Metals, Process for

3. CURRENT NDI METHODS:

Today there are five NDI techniques that are commonly used to detect flaws during manufacturing and "in service" maintenance and overhaul of aircraft wheel and brake structural components. Following is a brief description of each of these methods. A list of associated industry specifications for each inspection method is provided in Table 1.

TABLE 1 - Nondestructive Inspection Industry Specifications

Specification	Title
General	
MIL-HDBK-6870	Inspection Program Requirements, Nondestructive for Aircraft and Missile Materials and Parts
Liquid Penetrant	
MIL-HDBK-728/3	Liquid Penetrant Testing
ASTM D 1417	Standard Practice for Liquid Penetrant Examination
AMS 2644	Inspection Material, Penetrant
MIL-F-38762	Fluorescent Penetrant Inspection Units
AMS 2646C-82	Contrast Dye Penetrant Inspection
AS3071A-77	Acceptance Criteria - Magnetic Particle, Fluorescent Penetrant and Contrast Dye Penetrant Inspection
Magnetic Particle	
MIL-HDBK-728/4	Magnetic Particle Testing
AMS 2641A	Vehicle, Magnetic Particle Inspection Petroleum Based
AMS 2300 Rev G-91	Premium Aircraft-Quality Steel Cleanliness Magnetic Particle Inspection Procedure
AMS 2301 Rev G-84	Steel Aircraft Quality, Cleanliness Magnetic Particle Inspection Procedure
AMS 3041 Rev A-84	Magnetic Particles, Wet Method, Oil Vehicle
AMS 3042 Rev A-84	Magnetic Particles, Wet Method, Dry Powder
AMS 2442-93	Magnetic Particle Acceptance Criteria for Parts
ASTM E 709-91	Standard Guide for Magnetic Particle Examination
ASTM E 1444-93	Standard Practice for Magnetic Particle Examination
Eddy Current	
MIL-HDBK-728/2	Eddy Current Testing
MIL-STD-1537	Electrical Conductivity Test for Verification of Heat Treatment of Aluminum Alloys, Eddy Current Method
ARP891A-76	Determination of Aluminum Alloy Tempers Through Electrical Conductivity Measurement
Ultrasonic	
MIL-HDBK-728/6	Ultrasonic Testing
MIL-STD-1875	Ultrasonic Inspection, Requirements for
MIL-STD-2154	Inspection, Ultrasonic, Wrought Metals, Process for
AMS 2630A-80	Ultrasonic Inspection Product Over 0.5 inch (12.5 mm) Thick
ASTM B 594-90	Standard Practice for Ultrasonic Inspection of Aluminum-Alloy Wrought Products for Aerospace Applications
Indentation	
ASTM E 10	Brinell Hardness of Metallic Materials
ASTM E 18	Rockwell Hardness and Superficial Hardness of Metallic Materials
ASTM E 384	Microhardness of Materials

3.1 Liquid Penetrant Inspection:

Liquid penetrant inspection is a nondestructive method of revealing discontinuities that are open to the surfaces of solid and essentially nonporous materials. Indication of a wide spectrum of flaw sizes can be found regardless of the configuration of the workpiece and regardless of the flaw orientation. Liquid penetrants are drawn into various types of minute surface openings by capillary action. This process is well suited to the detection of many surface breaking flaws such as cracks, laps, porosity, shrinkage areas, laminations, and similar discontinuities. It is extensively used for the inspection of wrought and cast products of both ferrous and nonferrous metals.

In practice, the liquid penetrant process is relatively simple to use and control. The equipment used in liquid penetrant inspection can vary from an arrangement of simple tanks containing penetrant, emulsifier, and developer to sophisticated computer-controlled automated processing and inspection systems. Optimum end results require that the surfaces of parts subjected to liquid penetrant examination be adequately cleaned and free of contaminants that may prevent the penetrant from being drawn into surface breaking flaws.

NOTE: Due to the service environment of aircraft wheels and brakes, extensive cleaning is required to ensure reliable liquid penetrant inspection. Cleaning procedures which outline the most effective methods and products available are contained in the wheel and brake component maintenance manuals. Particular caution should be exercised against over washing during the penetrant removal process and the very undesirable potential of smearing metal over cracks during paint removal or repair operations.

The major limitation of liquid penetrant inspection is that it can detect only imperfections that are open to the surface. Other methods must be used for detecting subsurface flaws. Factors that can limit the use of liquid penetrants are significant surface roughness or porosity. Such surfaces produce excessive background signals which interfere with inspection.

3.2 Magnetic Particle Inspection:

Magnetic particle inspection is a method of locating surface and subsurface discontinuities in ferromagnetic materials. It depends on the fact that when the material or part under test is magnetized, magnetic discontinuities that lie in a direction generally transverse to the direction of the magnetic field will cause a leakage field to be formed at and above the surface of the part. The presence of this leakage field and, therefore, the presence of the discontinuity, is detected by the use of finely divided ferromagnetic particles applied over the surface, with some of the particles being gathered and held by the leakage field. This magnetically held collection of particles forms an outline of the discontinuity and generally indicates its location, size, shape, and depth.

3.2 (Continued):

The magnetic particle method is a sensitive means of locating small and shallow surface cracks in ferromagnetic materials. Discontinuities that do not actually break through the surface are also indicated in many cases by this method, although certain limitations must be recognized and understood.

If a discontinuity is fine, sharp, and close to the surface, such as a long stringer of nonmetallic inclusions, a clear indication can be produced. If the discontinuity lies deeper, the indication will be less distinct. The deeper the discontinuity lies below the surface, the larger it must be to yield a readable indication.

Magnetic particle indications are produced directly on the surface of the part and constitute magnetic pictures of actual discontinuities. Skilled operators can sometimes make a reasonable estimate of crack depth with suitable powders and proper technique. Occasional monitoring of field intensity in the part is needed to ensure adequate field strength.

There is little or no limitation on the size or shape of the part being inspected. The surfaces of parts subjected to magnetic particle inspection must be adequately cleaned in order that the particles are sufficiently mobile to accumulate at magnetic field leakage sites and not form false indications.

There are certain limitations to magnetic particle inspection. For example:

a. Thin coatings of paint and other nonmagnetic coverings, such as plating, may adversely affect the sensitivity of magnetic particle inspection.

b. The method can be used only on ferromagnetic materials.

c. For best results, the magnetic field must be in a direction that will intercept the principal plane of the discontinuity; this sometimes requires two or more sequential inspections with different magnetizations.

d. Demagnetization following inspection is often necessary.

e. Postcleaning to remove remnants of the magnetic particles clinging to the surface may sometimes be required after testing and demagnetization.

f. Exceedingly large currents are sometimes needed for very large parts.

g. Care is necessary to avoid local heating and burning of finished parts or surfaces at the points of electrical contact.

h. Although magnetic particle indications are easily seen, experience and skill are sometimes needed to judge their significance.

3.3 Eddy Current Inspection:

Eddy current inspection is based on the principles of electromagnetic induction and is used to identify or differentiate among a wide variety of physical, structural, and metallurgical conditions in electrically conductive ferromagnetic and nonferromagnetic metals and metal parts. Eddy current inspection can be used to:

a. Measure or identify such conditions and properties as electrical conductivity, magnetic permeability, grain size, heat treatment condition, hardness, and physical dimensions.

b. Detect seams, laps, cracks, voids, and inclusions.

c. Sort dissimilar metals and detect differences in their composition, microstructure, and other properties.

d. Measure the thickness of a nonconductive coating on a conductive metal, or the thickness of a nonmagnetic metal coating on a magnetic metal.

Because eddy currents are created using an electromagnetic induction technique, the inspection method does not require direct electrical contact with the part being inspected. The eddy current method is adaptable to high-speed inspection and, because it is absolutely nondestructive, can be used to inspect an entire production output if desired. The method is based on indirect measurement, and the correlation between the instrument readings and the structural characteristics and serviceability of the parts being inspected must be carefully and repeatedly established.

Eddy current inspection is extremely versatile, which is both an advantage and a disadvantage. The advantage is that the method can be applied to many inspection problems provided the physical requirements of the material are compatible with the inspection method. In many applications, however, the sensitivity of the method to the many properties and characteristics inherent within a material can be a disadvantage; some variables in a material that are not important in terms of material or part serviceability may cause instrument signals that mask critical variables or are mistakenly interpreted to be caused by critical variables. Each eddy current inspection must seek to control all the variables except those which the inspection is intended to evaluate.

In eddy current inspection, the eddy currents create their own electromagnetic field, which can be sensed either through the effects of the field on the primary exciting coil or by means of an independent sensor. In nonferromagnetic materials, the secondary electromagnetic field is derived exclusively from eddy currents. However, with ferromagnetic materials, additional magnetic effects occur that are usually of sufficient magnitude to overshadow the field effects caused by the induced eddy currents. Although undesirable, these additional magnetic effects result from the magnetic permeability of the material being inspected and can normally be eliminated by magnetizing the material to saturation in a static (direct current) magnetic field.

3.4 Ultrasonic Inspection:

Ultrasonic inspection is a nondestructive method in which beams of high frequency sound waves are introduced into materials for the detection of surface and subsurface flaws in the material. The sound waves travel through the material with some attendant loss of energy (attenuation) and are reflected at interfaces. The reflected sound is converted to an electrical signal which is displayed and analyzed to determine such characteristics as material thickness and the presence and location of flaws or material discontinuities.

The amplitude of deflection depends largely on the physical state of the materials forming the interface and to a lesser extent on the specific physical properties of the material. For example, sound waves are almost completely reflected at metal/gas interfaces. Partial reflection occurs at metal/liquid or metal/solid interfaces, with the specific percentage of reflected energy depending mainly on the ratio of certain properties of the materials on opposing sides of the interface.

Cracks, laminations, shrinkage cavities, bursts, flakes, pores, disbonds, and other discontinuities that produce reflective interfaces can usually be easily detected.

The principal advantages of ultrasonic inspection as compared to other methods for nondestructive inspection of metal parts are:

a. Superior penetrating power, which allows the detection of flaws deep in the part.

b. High sensitivity, permitting the detection of extremely small flaws.

c. Greater accuracy than other nondestructive methods in determining the position of internal flaws, estimating their size and characterizing their orientation, shape, and nature.

d. Only one surface needs to be accessible.

e. Operation is electronic, which provides almost instantaneous indication of flaws. This makes the method suitable for immediate interpretation, automation, rapid scanning, in-line production monitoring, and process control. With most systems a permanent record of inspection results can be made for future reference.

f. The method is nonhazardous to operations or to nearby personnel and has no effect on equipment and materials in the vicinity.

g. Portability.

3.4 (Continued):

The disadvantages of ultrasonic inspection include the following:

a. Manual operation requires careful attention by experienced technicians.

b. Extensive technical knowledge is required for the development of inspection procedures.

c. Parts that are rough, irregular in shape, very small or thin, or not homogenous are difficult to inspect.

d. Discontinuities that are present in a shallow layer immediately beneath the surface may not be detectable.

e. Reference standards are needed, both for calibrating the equipment and for characterizing flaws.

3.5 Indentation Hardness:

Hardness is resistance to plastic indentation. This may involve a simple scratch test or indentation by loading a ball, diamond, or other penetrator with a weight and measuring the length, width, or depth of the indentation. The harder the metal, the smaller the indentation for a given load. The higher the load, the larger the size of indentation for a given metal. Of course, the indenter material must be harder than the material tested to prevent deformation of the indenter material. That is why indenters are frequently made of diamond, tungsten carbide, or hardened steel. The most common hardness tests used on wheels and brakes are:

a. Rockwell: In which a diamond cone or hardened steel sphere is used.

b. Brinell: In which a 10 mm steel or tungsten carbide sphere is used.

The hardness numbers are usually read directly from a table of values calculated for one parameter, such as the length, width, or depth of the indentation.

Hardness is roughly proportional to strength. Hardness may, therefore, be used as rapid comparative strength test, and frequently, specifications specify minimum acceptable hardness values.

4. NDI USES IN THE MANUFACTURING AND OPERATIONAL LIFE PHASES:

Figures 1 and 2 illustrate the wheel and brake components that are subjected to in-service nondestructive inspection. Tables 2 and 3 contain a summary of typical structural materials, NDI methods used, and the region of the component that is inspected.