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MILITARY STANDARD

INSPECTION, MAGNETIC PARTICLE

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/AREA NDTI/

DEPARTMENT OF DEFENSE
Washington, D.C. 20325

Inspection, Magnetic Particle

1. This Military Standard is approved for use by all Departments and Agencies of the Department of Defense.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Director, US Army Materials and Mechanics Research Center, ATTN: AMXMR-SMS, Watertown, MA 02172-0001 by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

FOREWARD

This standard is a procedural document describing wet and dry techniques for magnetic particle inspection.

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1. SCOPE

1.1 Scope. This standard establishes minimum requirements for magnetic particle inspection used for detection of discontinuities at or immediately below the surface of ferromagnetic material.

2. REFERENCE DOCUMENTS

2.1 Government documents.

2.1.1 Specifications, standards, and handbooks. Unless otherwise specified, the following specifications, standards, and handbooks of the issue listed in that issue of the Department of Defense Index of Specifications and Standards (DoDISS) specified in the solicitation form a part of this specification to the extent specified herein.

SPECIFICATIONS

Military

MIL-M-47230 - Magnetic Particle Inspection Soundness Requirements for materials, parts and weldments
MIL-I-83387 - Inspection Process, Magnetic Rubber
DOD-F-87935 - Fluid , Magnetic Particle Inspection, Suspension (Metric)

STANDARDS

Federal

FED-STD-595 - Colors

Military

MIL-STD-410 - Nondestructive Testing Personnel Qualification and Certification
MIL-STD-2175 - Castings, Classification and Inspection of

(Copies of specifications, standards, drawings and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications. The following document(s) form a part of this specification to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted shall be those listed in the issue of the DoDISS specified in the solicitation. The issues of documents which have not been adopted shall be those in effect on the date of the cited DoDISS.

2.2.1 American Society for Testing and Materials.

ASTM A275 Magnetic Particle Examination of Steel Forgings

ASTM A456 Specification for Magnetic Particle Examination of Large Crankshaft Forgings

ASTM D93 Flash Point By Pensky-Martens Closed Tester

ASTM D96 Water and Sediment in Crude Oils

ASTM D445	Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity)
ASTM E125	Reference Photographs for Magnetic Particle Indications on Ferrous Castings.
ASTM E269	Standard Definitions of Terms Relating to Magnetic Particle Examination

(Applications for copies should be addressed to American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.)

2.2.2 Society of Automotive Engineers: Aerospace Materials Specifications.

AMS 2300	Premium Aircraft-Quality Steel Cleanliness Magnetic Particle Inspection Procedure
AMS 2301	Aircraft Quality Steel Cleanliness Magnetic Particle Inspection Procedure
AMS 2303	Aircraft Quality Steel Cleanliness Martensitic Corrosion Resistant Steels Magnetic Particle Inspection Procedure
AMS 3040	Magnetic Particle Inspection Material Dry Method
AMS 3041	Magnetic Particles, Wet Method, Oil Vehicle
AMS 3042	Magnetic Particles Wet Method, Dry Powder
AMS 3043	Magnetic Particles Wet Method, Oil Vehicle, Aerosol Canned
AMS 3045	Magnetic Particles, Fluorescent Wet Method, Oil Vehicle
AMS 3046	Magnetic Particles, Fluorescent Wet Method, Oil Vehicle, Aerosol Packaged
AMS 3161	Inspection Vehicle, High Flash, Odorless

(Copies of publications may be obtained from the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, Pennsylvania 15096.)

3. DEFINITIONS

3.1 Alternating current (AC). An electrical current that reverses its direction of flow at regular intervals.

3.2 Black light. Electromagnetic radiation in the near ultraviolet range of wavelength 320 to 400 nanometer (1 nm = 10^{-9} meters) with those wavelengths near 365 nm predominating.

3.3 Classification. The initial review of a visible magnetic particle accumulation to decide if it is held on the test piece by magnetic means or by non-magnetic means (i.e. if it is a relevant, non-relevant or false indication).

3.4 Coil shot. Production of longitudinal magnetization accomplished by passing current through a coil encircling the part being inspected.

3.5 Conditioned water. Water with an additive or additives which impart specific properties such as proper wetting, particle dispersion, or corrosion resistance.

3.6 Continuous method. The continuous method of examination consists of applying or otherwise making available on the surface of the piece, an ample amount of magnetic particles to form satisfactory indications while the current is being applied.

3.7 Defect. An unintended discontinuity with size, shape, orientation or location which makes it detrimental to the useful service of the part.

3.8 Flux leakage. A local distortion of the normal magnetic flux pattern of a magnetized part caused by a discontinuity in the part.

3.9 Full wave direct current (FWDC). A rectified three-phase alternating current.

3.10 Gauss. This is the unit of flux density or induction in the cgs electromagnetic unit system. (1 gauss = 10^{-4} tesla) (In air 1 gauss is equivalent to 1 oersted which equals 79.58 amps per meter).

3.11 Half wave direct current (HWDC). A rectified single phase alternating current that produces a pulsating unidirectional field.

3.12 Head Shot. Producing circular magnetization by passing current directly through the part being inspected while being held in contact with the head stocks in a horizontal wet machine.

3.13 Indication. An accumulation of magnetic particles on the test piece that forms during the inspection process.

3.14 Indication, False. An indication of magnetic particles on the part held by gravity or surface roughness or which arises from improper processing.

3.15 Indication, nonrelevant. An indication caused by flux leakage that has no relation to a discontinuity that is considered to be a defect. (For example, magnetic writing or a change in section due to part design).

3.16 Magnetic flux. A conceptualization of the magnetic field intensity based on the line pattern produced when iron filings are sprinkled on paper laid over a permanent magnet. The magnetic field lies in the direction of the flux lines and has an intensity proportional to the line density.

3.17 Magnetization. The process by which the elementary magnetic domains of a material are aligned predominantly in one direction.

3.18 Permeability. The ratio of flux density produced to magnetizing field. (High permeability materials are easier to magnetize than low permeability materials.)

3.19 Procuring activity. The agency for which the system/equipment is built or service provided.

3.20 Prods. Hand held electrodes through which a magnetizing current is applied resulting in a distorted circular field.

3.21 Residual method. The application of magnetic particles after the magnetizing force has been discontinued.

3.22 Suspension. A two-phase system consisting of finely divided magnetic particles dispersed in a liquid vehicle.

3.23 Swinging field. A magnetic field which periodically alters its direction during a single magnetic particle test.

3.24 Water break test. A quality control test for conditioned water to determine that the surface tension of the water has been reduced sufficiently by a wetting agent to satisfactorily cover the surface of the items to be inspected.

3.25 Wet method. The inspection technique in which the magnetic particles employed are suspended in a liquid vehicle.

3.26 Other definitions. Definitions not given herein shall be as specified in ASTM E269.

4. GENERAL REQUIREMENTS

4.1 Principles of magnetic particle inspection.

4.1.1 Intended use of magnetic particle inspection. When specified, the magnetic particle inspection method shall be used to detect cracks, laps, seams, inclusions, and other discontinuities at or near the surface of ferromagnetic materials. Magnetic particle inspection may be applied to raw material, billets, finished and semifinished materials, welds, and in-service parts. Magnetic particle inspection is not applicable to nonferromagnetic metals and alloys such as austenitic stainless steels.

4.1.2 Basic principle. The method is based on the principle that the magnetic flux in a magnetized material is distorted locally by the presence of discontinuities. This distortion of the internal field pattern, termed "flux leakage", is capable of attracting and holding an inspection medium of finely divided magnetic particles. The resulting accumulation of particles will be visible under the proper lighting conditions. Sensitivity is greatest for discontinuities which break the surface and diminishes rapidly with increasing depth below the surface.

4.1.3 Magnetization and particle application. Magnetic particle inspection consists of magnetizing the area to be inspected, application of suitably prepared magnetic particles while the area is magnetized, and subsequent classification, interpretation, and evaluation of any resulting particle accumulations. Maximum detectability occurs when the discontinuity has a depth five times its opening, a length at least equal to its depth, and positioned perpendicular to the magnetic flux. Due to the importance of the magnetic field orientation on sensitivity, magnetization is necessary in two perpendicular directions, except when specifically exempted by the procuring activity.

4.1.4 Classification, interpretation, and evaluation. Magnetic particle patterns produced during the inspection process must be classified, interpreted as to their cause, and then evaluated in terms of part integrity according to requirements which define the type, size, location, orientation, and area concentration of discontinuities which are unacceptable in a specific part.

4.2 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the contractor is responsible for the performance of all the inspections to the requirements specified herein. The contractor shall specify more stringent requirements than the minimum specified in this standard when necessary to assure that a component will meet its functional and reliability requirements. Except as otherwise specified, the contractor may utilize his own facilities or any other facilities suitable for the performance of the inspection requirements specified herein. The Government reserves the right to perform any of the inspections set forth in this standard where such inspections are deemed necessary to assure that supplies and services conform to prescribed requirements.

4.3 Qualification of inspection personnel. All personnel performing magnetic particle inspection shall be qualified and certified in accordance with MIL-STD-410. Personnel making accept/reject decisions in accordance with the process described by this standard shall be qualified to at least a level II per MIL-STD-410. Personnel performing the processing steps described in this standard shall be qualified to at least a level I per MIL-STD-410.

4.4 Acceptance requirements. The acceptance requirements applicable to the part or group of parts shall be incorporated as part of a written procedure either specifically or by reference to other applicable documents such as MIL-M-47230 containing the necessary information. Applicable drawings or other documents shall specify the acceptable size and concentration of discontinuities in high and low stress areas of fabricated parts. These acceptance requirements shall be as approved or as specified by the procuring activity

4.5 Written procedure. Magnetic particle inspection shall be performed in accordance with a written procedure applicable to the parts or group of parts under test. The procedure shall be in accordance with the requirements and guidelines of this standard. The procedure shall be capable of detecting the smallest rejectable discontinuities specified in the acceptance requirements. On approval of the procuring activity, or its authorized representative, the written procedure may be a general one which clearly applies to the specific parts being tested. All written procedures shall be approved by an individual qualified and certified to MIL-STD-410, Level III for magnetic particle inspection, and shall be subject to the approval of the procuring activity.

4.5.1 Elements of the written procedure. The written procedure shall include at least the following elements, either directly or by reference to the applicable documents:

a. Identification of the parts to which the procedure applies. This shall include the material and alloy of which the parts are fabricated.
b. Areas of the part to be examined.
c. Directions of magnetization to be used, the order in which they are applied, and any demagnetization procedures to be used between shots.
d. Method of establishing the magnetization (prods, yoke, cable wrap, etc).
e. The type of magnetizing current (AC, HWDC, FWDC, etc.) and the equipment to be used.
f. The current level, or the number of ampere-turns, to be used and the duration of its application.
g. Part preparation required before testing.
h. Type of magnetic particle material (dry or wet, visible or fluorescent, etc.) to be used and the method and equipment to be used for its application.
i. Type of records and method of marking of parts after inspection.
j. Acceptance requirements, to be used for evaluating indications and disposition of parts after evaluation.
k. Post-inspection demagnetization and cleaning requirements.
l. The procedure identification number and the date it was written.
m. Sequence of magnetic particle inspection as related to manufacturing process operations.

4.6 Record of inspection. The results of all magnetic particle inspections shall be recorded. All recorded results shall be identified, filed, and made available to the procuring activity upon request. Records shall provide for traceability to the specific part or lot inspected, and shall identify the inspection contractor or facility and the procedures used in the inspection.

4.7 Magnetizing and demagnetizing equipment. Performance of a satisfactory magnetic particle inspection requires magnetization of the part to a specified level in a specified direction. Magnetization can be accomplished either by passing an electric current directly through the material (direct method), by inducing a current to flow in the part under test (induced current method), or by placing the material within the magnetic flux of an external source such as a coil (indirect method). The types of equipment available include yokes, portable units, mobile units, stationary units, and special application units (e.g. a unit to produce a swinging field). The types of currents used for magnetization are full-wave rectified three phase current (FWDC), half-wave rectified single phase current (HWDC), and alternating current (AC). The equipment used shall adequately fulfill the magnetizing and demagnetizing requirements, as outlined herein, without damage to the part under test and shall include the necessary features required for safe operation.

4.8 Inspection sequence. Magnetic particle inspection shall be performed after the completion of operations that could cause surface or near-surface defects. These operations include, but are not limited to, forging, heat treating, plating, cold forming, welding, grinding, straightening, machining, and proof loading. Magnetic particle inspection, unless otherwise specified, shall not be performed with coatings in place that could prevent the detection of surface defects in a ferromagnetic substrate. Such coatings include paint or chrome plate greater than 0.08 mm (0.003 inch) in thickness or ferromagnetic coatings such as electroplated nickel greater than 0.03 mm (0.001 inch) in thickness.

4.9 Lighting intensities.

4.9.1 Visible light intensities. Visible light shall be used when testing with nonfluorescent particles. The intensity of the visible light at the surface of the parts undergoing inspection shall be maintained at a minimum of 2000 lux (200 foot-candles). Unless otherwise specified, fluorescent magnetic particle inspection shall be performed in a darkened area with a maximum visible light level of 20 lux (2 foot-candles).

4.9.2 Black light intensities. Unless otherwise specified, the black light intensity at the examination surface shall be 1000 $\mu W/cm^2$ or greater when measured with a suitable black-light meter. Portable or hand held black lights shall produce an intensity greater than 1000 $\mu W/cm^2$ when measured at 380 mm (15 inches) from the black light source.

4.10 Materials.

4.10.1 Magnetic particle materials. The particles used in magnetic particle inspection shall be finely divided ferromagnetic materials which have been treated to impart visibility against the background of the surfaces under inspection. They may be either colored for use with visible light or coated with a fluorescent dye for use with black light. The particles may be designed for use as a free flowing dry powder (dry method), for suspension at a given concentration in a suitable liquid (wet method), for suspension in a polymerizeable material (magnetic rubber method), or for suspension in a slurry (magnetic painting). The particles shall be designed to have a high magnetic permeability and a low retentivity. Careful control of particle size and shape is required to obtain consistent results. The particles shall be non-toxic, free from rust, grease, paint, dirt or other deleterious material which might interfere with their proper functioning.

4.10.1.1 Dry particle requirements. Dry particles shall meet the requirements of AMS 3040. In applying AMS 3040 the particles shall show indications as listed in Table I on the test ring specimen of Figure 1 using the following procedure:

> Place a conductor with a diameter between 25 and 31 mm (1 and 1.25 inches) through the center of the ring and circularly magnetize the ring by passing the current specified in Table I through the central conductor. Using a suitable squeeze bulb or other applicator, apply the particles to the ring surface while the current is flowing. Examine the ring for indications under the appropriate lighting conditions.

4.10.1.2 Wet particle requirements. Wet particles shall meet the requirements of AMS 3041, AMS 3042, AMS 3043, AMS 3045, or AMS 3046, as applicable. In applying these specifications, the particles shall show indications as listed in Table I on the test ring specimen of Figure 1 using the following procedure:

> Place a conductor through the center of the ring and circularly magnetize the ring by passing the current specified in Table I through the central conductor employing the continuous method. Examine the ring for indications under the appropriate lighting conditions.

4.10.2 Suspension vehicles. The suspension vehicle for the wet method shall be a light petroleum distillate conforming to AMS 3161 or DOD-F-87935. When approved by the procuring agency, suitably conditioned water may be used. The viscosity of the suspension shall not exceed 5.0 mm^2s^{-1} (5.0 centistokes) at the temperature of use when tested in accordance with ASTM method D 445. The flash point of the suspension should be a minimum of 93°C (200°F) when tested in accordance with ASTM method D93 (see Paragraph 6.4 on safety). The background fluorescence of the suspension vehicle shall be less than the limit specified in DOD-F-87935.

4.10.3 Particle concentration. The concentration of particles in the test bath shall be as specified in the written procedure but in no case outside the range of 0.1 to 0.5 ml in a 100 ml bath sample for fluorescent particles and 1.2 to 2.4 ml for nonfluorescent particles. Fluorescent particles and nonfluorescent particles shall not be used together.

4.10.4 Conditioned water vehicle. When water is used as a suspension vehicle for magnetic particles, it shall be suitably conditioned to provide for proper wetting, particle dispersion, and corrosion protection (an example would be tap water with approximately 12.8 percent wetting agent, 0.3 percent antifoaming agent, and 3.9 percent rust inhibitor). Proper wetting shall be determined by a water break test (see Paragraph 5.8.4.2). In general, more wetting agent is required to wet smooth surfaces than rough surfaces. Whenever possible, non-ionic wetting agent should be used. However, in all cases, the amount of wetting agent added should be limited so as not to raise the alkalinity of the suspension above a pH of 10.0. Use of conditioned water vehicle on cadmium plated steels with tensile strength of 180 ksi or above is prohibited.

5. DETAIL REQUIREMENTS

5.1 Preparation of parts for test.

5.1.1 Pre-inspection demagnetization. The part shall be demagnetized before inspection if prior operations have produced a residual magnetic field which will interfere with the inspection.

5.1.2 Surface cleanliness and finish. The surface of the part to be inspected shall be essentially smooth, clean, dry, and free of oil, scale, machining marks, or other contaminants or conditions which might interfere with the efficiency of the inspection.

5.1.3 Coatings. Thin non-ferromagnetic coatings, which do not exceed 0.08 mm (0.003 inch) in thickness and ferromagnetic coatings not exceeding 0.03 mm (0.001 inch) in thickness which do not interfere with the inspection may be left on in-service components during inspection unless otherwise specified. When such coatings are non-conductive, they must be removed where electrical contact is to be made. Unless otherwise specified, production parts shall be magnetic particle inspected prior to application of coating.

5.1.4 Plugging and masking. Unless otherwise specified by the procuring agency, small openings and oil holes leading to obscure passages or cavities shall be plugged with a suitable non-abrasive material which is readily removed and, in the case of engine parts, is soluble in oil. Effective masking shall be used to protect those components, such as certain non-metallics, which may be damaged by contact with the suspension.

5.2 Magnetization methods.

5.2.1 Permanent magnets. Permanent magnets are not to be used for magnetic particle inspection unless specifically authorized by the procuring activity.

5.2.2 Types of magnetizing current. The types of magnetizing current used for magnetic particle inpection are full-wave rectified three phase current (FWDC), half-wave rectified single phase current (HWDC), and alternating current (AC). AC is to be used only for the detection of defects open to the surface. FWDC has the deepest possible penetration and must be used when inspecting for defects below the surface when using the wet magnetic particle method. HWDC is advantageous for the dry powder method because this type of current gives increased mobility and sensitivity to the particles due to its pulsating unidirectional field.

5.2.3 Magnetic field directions. Discontinuities are difficult to detect by the magnetic particle method when they make an angle less than 45° to the direction of magnetization. To assure detection of discontinuities in any direction each part must be magnetized in a least two directions at right angles to each other. Depending on part geometry this may consist of circular magnetization in two or more directions, of both circular and longitudinal magnetization, or of longitudinal magnetization in two or more directions. Exceptions necessitated by part geometry, size or other factors require specific approval of the procuring activity. When specifically approved by the procuring activity, multidirectional (swinging field) magnetization may be used to fulfill the requirement for magnetization in two directions.

5.2.4 Multidirectional magnetization. With suitable circuitry a multidirectional (swinging) field in a part may be established (for example, by selectively switching the magnetizing current between contact pairs positioned approximately 90 degrees apart). In using this method, the particle application must be timed so that the magnetization reaches its full value in all directions during the time particles are being applied to the surface under test. Multidirectional magnetization is roughly equivalent to AC or HWDC magnetization in two or more directions. Multidirectional magnetization shall not be used unless specifically approved by the procuring activity.

5.2.5 Direct magnetization. Direct magnetization is accomplished by passing current directly through the part under test. Electrical contact is made to the part using prods, clamps, magnetic leeches, or by other means. Precaution shall be taken to assure that the electrical current is not flowing while contacts are being applied or removed and that excessive heating does not occur in the contact area. Prods shall not be used for inspection of aerospace vehicle parts or on finished surfaces.

5.2.6 Indirect magnetization. Indirect part magnetization uses preformed coils, cable wraps, yokes, or a central conductor to produce a magnetic field of suitable strength and direction to magnetize the part under test.

5.2.7 Induced current magnetization. Induced current magnetization is accomplished by inductively coupling a part to an electrical coil to create a suitable current flow in the part as illustrated in Figure 2. This method shall be used only with specific approval of the procuring activity.

5.3 Magnetic field strength. The applied magnetic field shall have sufficient strength to produce satisfactory indications but must not be strong enough to cause masking of relevant indications by nonrelevant accumulations of magnetic particles. Factors which determine the required field strength include the size, shape, and material permeability of the part, the technique of magnetization, the method of particle application and the type and location of defects sought. When using prods, or when testing cylindrically shaped samples using coils, cable wraps, central conductors, or direct magnetization, current levels shall be as specified in Paragraph 5.3.1. For other configurations, proper magnetization levels may be verified by testing parts having known defects of the type size and location specified in the acceptance requirements or with a gaussmeter capable of determining the peak values of the tangential field using a Hall-effect probe or equivalent. Tangential applied field strengths in the range of 2.4 to 4.8 kAm^{-1} (30 to 60 gauss) are adequate magnetization levels for magnetic particle inspection. Assure that field strengths in this range are present in all areas to be inspected on the part.

5.3.1 Magnetization current levels. When a current or field range is given, the largest value listed shall be used unless such value causes interference due to nonrelevant indications or overheating of the part. When interference occurs, the current level may be lowered until the interference disappears, but in no case outside the lower limit given.

5.3.1.1 Prod current levels. When using prods on material 19 mm (3/4 inch) in thickness or less, 3.5 to 4.5 amperes per mm of prod spacing (90 to 115 A/in) shall be used. For material greater than 19 mm (3/4 inch) in thickness, 4.0 to 5.0 amperes per mm of prod spacing (100 to 125 A/in) shall be used. Prod spacing shall not be less than 50 mm (2 inches) or greater than 200 mm (8 inches). The effective width of the magnetizing field when using prods is 1/4 of the prod spacing on each side of a line drawn through the prod centers.

5.3.1.2 Direct circular magnetization. When magnetizing by passing current directly through the part (i.e. using "head shots") the current shall be from 12 A per mm of part diameter to 32 A per mm of part diameter (300 to 800 A/in). The diameter of the part shall be taken as the largest distance between any two points on the outside circumference of the part. Normally currents will be 32 A per mm (500 A/in) or lower with the higher currents (up to 800 A/in) being used to inspect for inclusions or to inspect alloys such as 15-5 PH steel.

5.3.1.3 Central conductor circular magnetization. Circular magnetization may be provided by passing current through a conductor which passes through the inside of the part. In this case alternating current is to be used only when the sole purpose of the test is to inspect for surface discontinuities on the inside surface of the part. If only the inside of the part is to be inspected, the diameter shall be the largest distance between two points, 180 degrees apart on the inside circumference. Otherwise, the diameter is determined as in para 5.3.1.2.

5.3.1.3.1 Centrally located conductor. When the axis of the central conductor is located near the central axis of the part the same current levels as given in paragraph 5.3.1.2 ("Direct circular magnetization") shall apply.

5.3.1.3.2 Offset central conductor. When the conductor passing through the inside of the part is placed against an inside wall of the part, the current levels as given in paragraph 5.3.1.2 ("Direct circular magnetization") shall apply except that the diameter shall be considered the sum of the diameter of the central conductor and twice the wall thickness. The distance along the part circumference (interior or exterior) which is effectively magnetized shall be taken as four times the diameter of the central conductor as illustrated in Figure 3. The entire circumference shall be inspected by rotating the part on the conductor, allowing for approximately a 10 percent magnetic field overlap.

5.3.1.4 Longitudinal magnetization. Longitudinal magnetization is accomplished by passing current through a coil encircling the part, or section of the part, to be tested (i.e. by using a "coil shot"). This produces a magnetic field parallel to the axis of the coil. For low fill factor coils the effective field extends a distance on either side of the coil center approximately equal to the radius of the coil(see Figure 4). For cable wrap or high fill factor coils, the effective distance of magnetization is 230 mm (9 inches) on either side of the coil center (see Figure 5). For parts longer than these effective distances, the entire length shall be inspected by repositioning the part within the coil, allowing for approximately 10 percent effective magnetic field overlap.

5.3.1.4.1 Longitudinal magnetization with low fill factor coils. When the cross sectional area of the coil is 10 or more times the cross sectional area of the part being inspected, then the product of the number of coil turns, N, and the current in amperes through the coil, I, shall be:

a. For parts positioned to the side of the coil;

$$NI = \frac{K}{L/D} \quad (\pm 10\ \%)$$

where K = 45,000 ampere turns
L = length of the part
D = diameter of the part (measured in the same units as the length)

b. For parts positioned in the center of the coil;

$$NI = \frac{KR}{(6L/D) - 5} \quad (\pm 10\ \%)$$

where R = radius of the coil in mm (or in inches)
K = 1690 ampere turns per mm (43,000 ampere turns per inch if R is measured in inches)
L = the length of the part
D = the diameter of the part (measured in the same units as the length)

If the part has hollow portions replace D with D_{eff} as given in Paragraph 5.3.1.4.3. These formulas hold only if L/D is greater than 3 and less than 15. If L/D is less than 3, pole pieces (pieces of ferromagnetic material with the same diameter as the part being tested) shall be placed on each end of the part to effectively increase L/D to 3 or greater. If L/D is greater than 15, the value 15 shall be substituted for L/D.

5.3.1.4.2 Longitudinal magnetization with cable wrap or high fill factor coils. When the cross sectional area of the coil is less than twice the cross sectional area (including hollow portions) of the part under test, then the product of the number of coil turns, N, and the current in amperes through the coil, I, shall be:

$$NI = \frac{K}{(L/D)+2} \quad (\pm 10\ \%)$$

where K = 35,000 ampere turns
L = the length of the part
D = the diameter of the part (measured in the same units as the length)

If the part has hollow portions replace D with D_{eff} as given in Paragraph 5.3.1.4.3. This formula holds only if L/D is greater than 3 and less than 15. If L/D is less than 3, pole pieces (pieces of ferromagnetic material with the same diameter as the part being tested) shall be placed on each end of the part to effectively increase L/D to greater than 3. If L/D is greater than 15, the value 15 shall be substituted for L/D.

5.3.1.4.3 Calculating the L/D ratio for a hollow or cylindrical part. When calculating the L/D ratio for a hollow or cylindrical part, D shall be replaced with an effective diameter, D_{eff}, calculated using:

$$Deff = 2\,[(A_t - A_h)\,/\pi]^{1/2}$$

where A_t = the total cross sectional area of the part
A_h = the cross sectional area of the hollow portions of the part

For cylindrical part this is equivalent to:

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

where OD = the outside diameter of the cylinder.
ID = the inside diameter of the cylinder.

5.4 Particle application.

5.4.1 Continuous method. In the dry continuous method, magnetic particles are applied to the part while the magnetizing force is present. In the wet continuous method the magnetizing circuit shall be closed just before the suspension is diverted from the part. Application of the magnetic particles (see 5.4.4 and 5.4.5) and the magnetization method shall be as prescribed in the paragraphs referenced herein.

5.4.2 Residual magnetization method. In the residual magnetization method the magnetic particles are applied to the test part immediately after the magnetizing force has been discontinued. The residual method is not as sensitive as the continuous method but it can be useful, for example, to detect in-service induced fatigue cracks on the surface of material with a high retentivity. The residual method shall be used only when specifically approved by the procuring activity or as an interpretation aid unless otherwise specified.

5.4.3 Prolonged magnetization. When using polymers, slurries, or paints, prolonged or repeated periods of magnetization are necessary because of lower magnetic particle mobility in the high-viscosity vehicles.

5.4.4 Dry magnetic particle application. When using dry particles the flow of magnetizing current shall be initiated prior to the application of the magnetic particles to the surface under test and terminated after powder application has been completed and any excess blown off. The duration of the magnetizing current shall be at least 1/2 second and short enough to prevent any damage to the part due to overheating or other causes. Dry powder shall be applied in a manner such that a light, uniform dust-like coating settles on the surface of the test part while the part is being magnetized. Specially designed powder blowers or shakers using compressed air or hand power shall be used. The applicators shall introduce the particles into the air in a manner such that they reach the part surface in a uniform cloud with a minimum of

force. After the powder is applied, and before the magnetizing force is removed, excess powder shall be removed by means of a dry air current with sufficient force to remove the excess particles, but not strong enough to disturb particles held by a leakage field that is indicative of discontinuities. In order to recognize the broad, fuzzy, lightly held powder patterns formed by near surface discontinuities, the formation of indications must be carefully observed during powder application and during removal of the excess powder. Sufficient time for formation and examination of indications shall be allowed during the testing process. The dry particle method shall not be used to inspect aerospace components without specific approval of the procuring activity.

5.4.5 Wet magnetic particle application. Fluorescent or nonfluorescent particles suspended in a liquid vehicle at the required concentration shall be applied either by gently spraying or flowing the suspension over the area to be inspected. Proper sequencing and timing of part magnetization and application of particle suspension are required to obtain proper formation and retention of indications. This generally requires that the stream of suspension be diverted from the part simultaneously with, or slightly before, energizing the magnetic circuit. The magnetizing current shall be applied for a duration of at least 1/2 second for each application with a minimum of two shots being used. Care shall be exercised to prevent any damage to the part due to overheating or other causes. Weakly held indications on highly finished parts are readily washed away and hence care must be exercised to prevent high-velocity flow over critical surfaces.

5.4.6 Magnetic slurry/paint application. Magnetic paints or slurries are applied to the part with a brush, squeeze bottle or aerosol can before or during the magnetization operation. This method is for special applications, such as overhead or underwater examination. This method shall be used only when specifically approved by the procuring activity.

5.4.7 Magnetic polymer application. Polymerizable material containing magnetic particles shall be held in contact with the test part during the period of its cure. Before curing takes place and while the magnetic particles are still mobile, the part shall be magnetized to the specifed level. This requires prolonged or repeated periods of magnetization. This method is for special applications, such as bolt holes, which cannot be readily tested by the wet or dry method and shall be used only when specifically approved by the procuring agency. MIL-I-83387 establishes the inspection process for magnetic rubber.

5.5 Interpretation of indications.

5.5.1 Types of indications. Indications are accumulations of magnetic particles on the test piece that form during the inspection process. These indications can be divided into false indications, nonrelevant indications, and relevant indications.

5.5.1.1 False indications. Indications which are not the result of magnetic forces are termed false indications. Examples are particles held mechanically or by gravity in shallow depressions or particles wedged into rust or scale on the surface.

5.5.1.2 Nonrelevant indications. Indications which adhere to flux leakage areas created by intentional design factors such as keyways, drilled holes, or abrupt cross-sectional changes, or which are due to accidental causes such as magnetic writing, are termed nonrelevant.

5.5.1.3 Relevant indications. Indications produced by any other flux leakage fields are termed relevant. All relevant indications shall be evaluated according to the applicable acceptance requirements specified in the written procedure. Relevant indications which have been evaluated and determined to be unacceptable discontinuities shall be described in detail on the appropriate rejection form and submitted for dispostion in accordance with contract requirements.

5.6 Recording of indications. When required by the written procedure, the location of all indications shall be marked on the part and permanent records of the location, direction and frequency of indications may be made by one or more of the following methods:

5.6.1 Written description. By recording the location, length, direction, and number of indications by a sketch or in a tabular form.

5.6.2 Transparent tape. For dry particle indications, by applying transparent adhesive-backed tape to which the indications will adhere and placing it on an approved form along with information giving its location on the part.

5.6.3 Strippable film. By covering the indication with a spray-on strippable film that fixes the indications in place and placing the resultant reproduction on an approved form along with information giving its location on the part.

5.6.4 Photography. By photographing the indications themselves, the tape, or the strippable film reproduction and placing the photograph on a tabular form along with information giving its location on the part.

5.7 Post-inspection demagnetization and cleaning. Unless directed otherwise by the procuring activity, all parts shall be demagnetized, cleaned, and corrosion protected after inspection.

5.7.1 Demagnetization. When using AC demagnetization the part shall be subjected to a field with a peak value greater than, and in nearly the same direction as, the field used during inspection. This AC field is then gradually decreased to zero. When using an AC demagnetizing coil, hold the part about 30 cm (1 ft) in front of the coil and then move it slowly and steadily through the coil and at least 100 cm (3 ft) beyond the end of the coil. Repeat this process as necessary. Rotate and tumble parts of complex configuration while passing through the field of the coil. When using DC demagnetization, the initial field shall be higher than, and in nearly the same direction as, the field reached during inspection. The field shall then be reversed, decreased in magnitude, and the process repeated (cycled) until an acceptably low value of residual field is reached. Whenever possible parts which have been circularly magnetized shall be magnetized in the longitudinal direction before being demagnetized. After demagnetization, a magnetic field probe or strength meter shall not detect fields greater than 240 Am^{-1} (3 gauss) anywhere on the part.

5.7.2 Post-inspection cleaning. Cleaning shall be by use of a suitable solvent, air blower, or by other means. All traces of the magnetic particles and magnetic particle test materials which might interfere with subsequent use of the part shall be removed (chlorinated solvents shall not be used on parts containing crevices). Care shall be taken to thoroughly remove all plugs in holes and cavities and all masking. Parts shall be protected from any possible corrosion or damage during the cleaning process and shall be treated to prevent the occurrence of corrosion before continued processing.

5.8 Quality control.

5.8.1 Inspection system verification. The overall sensitivity and performance of the magnetic particle inspection system including the equipment, materials and the lighting environment being used, shall be verified initially and at regular intervals thereafter. The required verification intervals are stated in Table II. Records of the verification results shall be maintained. Personnel assigned to perform and audit the verification shall be identified.

5.8.2 Use of test part with discontinuities. A reliable method for evaluating an inspection procedure is to use representative test parts containing defects of the type, location, and size specified in the acceptance requirements. If correct magnetic particle indications can be produced and identified in these representative parts, then the overall system and inspection procedure is verified. Parts used for verification will be thoroughly cleaned following the inspection and checked under black or white light, as appropriate to the inspection process, to ensure residual indications do not remain.

5.8.3 Fabricated test parts with artificial discontinuities. When actual production parts with known defects of the type, location and size needed for verification, are not available or are impractical, then ,upon the approval of the procuring activity, fabricated test parts with artificial discontinuities suitable for verification of the test procedure, the pie-field indicator of Figure 6, or the AISI Ketos tool steel ring as shown in Figure 1 may be substituted. Parts used for verification will be thoroughly cleaned following the inspection and checked under black or white light, as appropriate to the inspection process, to ensure residual indications do not remain.

5.8.4 Suspension vehicle tests.

5.8.4.1 Concentration tests. Particle concentration and contamination shall be determined upon start up, at regular intervals thereafter, and whenever the bath is changed or adjusted. The required testing intervals are stated in Table II.

5.8.4.1.1 Determination of wet particle concentration. Agitate the particle suspension a minimum of 30 minutes to insure a uniform distribution of particles throughout the bath. Place a 100 ml sample of the agitated suspension in a pear-shaped centrifuge tube (shaped and graduated as specified in ASTM D96). Demagnetize the sample and allow the tube to stand undisturbed for at least 30 minutes. Read the volume of settled particles. If the concentration is out of the tolerance stated in the written procedure (or that given in Paragraph 4.10.3) add particles or suspension vehicle, as required, and redetermine the particle concentration. If the settled particles appear to be loose agglomerates rather than a solid layer, take a second sample. If the second sample also appears agglomerated, replace the entire suspension.

5.8.4.1.2 Determination of wet particle contamination. Perform the tests specified in paragraph 5.8.4.1. In addition, examine the liquid above the precipitate with black light. The liquid shall be essentially nonfluorescent. Examine the precipitate. If two distinct layers can be seen, read the volume of each layer. The top layer volume (contamination) shall not exceed 30 percent of the bottom layer volume (magnetic particles) nor shall it fluoresce. If either condition is unsatisfactory, the entire suspension shall be replaced.

5.8.4.2 Water break test. In this test a part with a surface finish the same as the parts to be tested is flooded with the conditioned water and the appearance of the surface is noted after flooding is stopped. If a continuous even film forms over the entire part, sufficient wetting agent is present. If the film of suspension breaks, exposing bare surface, insufficient wetting agent is present or the part has not been adequately cleaned.

5.8.5 Equipment calibration. Magnetic particle testing equipment shall be checked for performance and accuracy at time of purchase and at intervals thereafter as given in Table II, whenever malfunction is suspected or when specified by the procuring agency, and whenever electrical maintenance which might affect equipment accuracy is performed.

5.8.5.1 Ammeter accuracy. To check the equipment ammeter, a calibrated ammeter shall be connected in series with the output circuit. Comparative readings shall be taken at three output levels encompassing the useable range of the equipment. The equipment meter reading shall not deviate by more than ±10 percent of full scale from the current value shown by the calibrated ammeter (when measuring HWDC, the current values shown by the calibrated DC ammeter reading shall be doubled). The ammeter should be checked according to the time frame indicated in Table II.

5.8.5.2 Timer control check. On equipment using a timer to control current duration, the timer should be checked to within ±0.1 second using a suitable electronic timer.

5.8.5.3 Magnetic field quick break check. On equipment which utilizes a quick-break feature, proper functioning of this circuit shall be verified. The test may be performed using a suitable oscilloscope or other applicable method as specified by the equipment manufacturer.

5.8.5.4 Dead weight check. Yokes and permanent magnets (when allowed) shall be dead weight tested. Alternating current yokes shall have a lifting force of at least 45 N (10 pounds) with a 50 to 100 mm (2 to 4 inch) spacing between legs. Direct current yokes and permanent magnets shall have a lifting force of at least 135 N (30 pounds) with a 50 to 100 mm (2 to 4 inch) spacing between legs or 225 N (50 pounds) with a 100 to 150 mm (4 to 6 inch) spacing.

5.9 Marking of inspected parts. Unless otherwise specified by the procuring agency, parts which have been accepted using magnetic particle inspection shall be marked in accordance with the applicable drawing, purchase order, contract or as specified herein. Marking shall be applied in such a manner and location as to be harmless to the part. The identification shall not be obliterated or smeared by subsequent handling and, when practicable, placed in a location which will be visible after assembly. When subsequent processing would remove the identification, the applicable marking shall be affixed to the record accompanying the finished parts or assembly.

5.9.1 Impression stamping or vibro engraving. Impression stamping or vibro engraving shall be used when permitted or required by the applicable written procedure, detail specification or drawing, or when the nature of the part is such as to provide for impression stamping of part numbers or other inspector's markings. Impression stamping shall be located only in the area provided adjacent to the part number or inspector's stamp.

5.9.2 Etching. When impression stamping or vibro engraving is prohibited, parts shall be etched using an etching fluid or other means and a method of application acceptable to the contractor. The etching process and location shall not adversely affect the functioning of the part.

5.9.3 Dyeing. When stamping, vibro engraving or etching is not permissible, identification shall be accomplished by dyeing.

5.9.4 Other identification. Other means of identification such as tagging, shall be used for parts which have a construction or function precluding the use of stamping, vibro engraving or etching, as in the case of completely ground or polished balls, rollers, pins, or bushings.

5.9.5 Identifying symbols and color markings.

5.9.5.1 100-percent inspection. When items are inspected and accepted by 100-percent inspection, each item shall be marked as follows:

5.9.5.1.1 Dyeing. When dyeing is applicable, a dye of acceptable adherence which is predominately blue (per FED-STD-595) shall be employed.

5.9.5.1.2 Stamping, vibro engraving or etching. When impression stamping, vibro engraving or etching is used to mark 100-percent inspected parts, the letter "M" with a circle around it shall be employed.

5.9.5.2 Lot inspection. When items are accepted by means of a sampling procedure, each item of an accepted lot shall be marked as follows:

5.9.5.2.1 Dyeing. When dyeing is applicable, a dye of acceptable adherence which is predominately orange per FED-STD-595 shall be employed.

5.9.5.2.2 Stamping, vibro engraving or etching. When impression stamping, vibro engraving or etching is used to mark lot-inspected parts, the letter "M" with an ellipse around it shall be employed.

6. NOTES

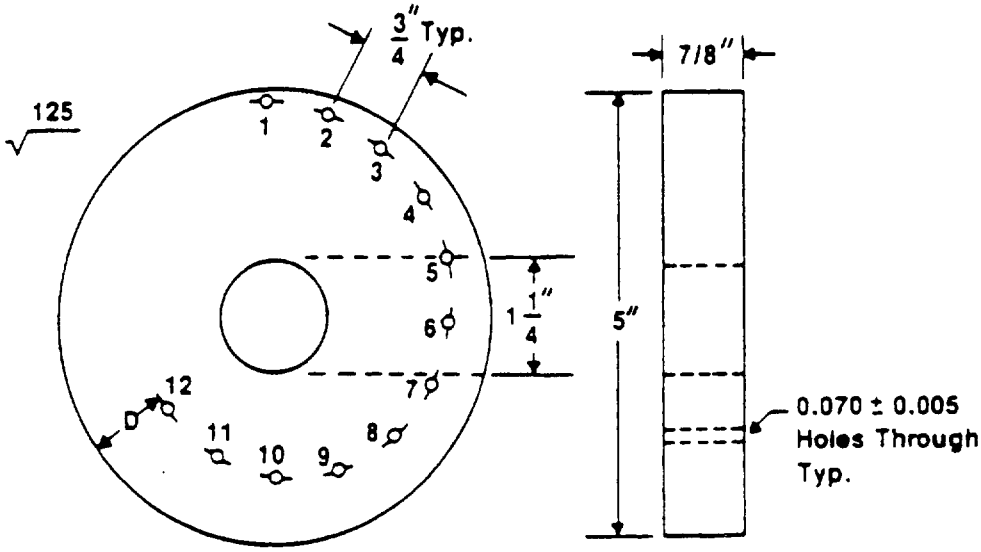
6.1 Eye glasses. When using fluorescent materials, inspectors shall not wear eye glasses equipped with light sensitive lenses (i.e. lenses that darken when exposed to ultraviolet light or sunlight).

6.2 Aircraft quality steel cleanliness. The inspection of aircraft-quality steel for cleanliness using magnetic particle inspection shall be as specified in AMS 2300, AMS 2301, or AMS 2303 as appropriate to the type of steel being inspected. However, inspection of parts fabricated from this material shall be in accordance with the requirements of this document.

6.3 Acceptance requirements. Methods for establishing acceptance requirements for large crankshaft forgings are discussed in ASTM A456. Methods for establishing requirements for steel forgings are discussed in ASTM A275. Methods for classifying metal castings are given in MIL-STD-2175. MIL-M-47230 provides a classification scheme for ferromagnetic forgings, castings, extrusions and weldments.

6.4 Safety. Dry cleaning solvents are not to be used for suspending particles. Proper precautions must be taken to prevent the ignition of hydrocarbon suspension baths by overheating, electrical arcing, etc. Precautions shall be taken to prevent inhaling of dry particle materials. The use of suitable face masks is recommended. It is the recommended that the intensity of black light incident on unprotected skin or eyes not exceed 1000 $\mu W/cm^2$.

6.5 Dark adaptation. Personnel must wait at least one minute after entering a darkened area for their eyes to adjust to the low level lighting before performing fluorescent magnetic particle inspection.



Notes: All Tolerances are ± 0.03" Except Where Shown
Hole Numbers 8-12 are Optional

Hole	1	2	3	4	5	6	7	8	9	10	11	12
D, Inches ±0.005	.07	.14	.21	.28	.35	.42	.49	.56	.63	.70	.77	.84

Figure 1. AISI KETOS tool steel ring for use in magnetic particle system verification and testing of magnetic particles. All dimensions are in inches. Material shall be AISI 01 tool steel from annealed round stock. Hardness shall be 90-95 Rockwell B.

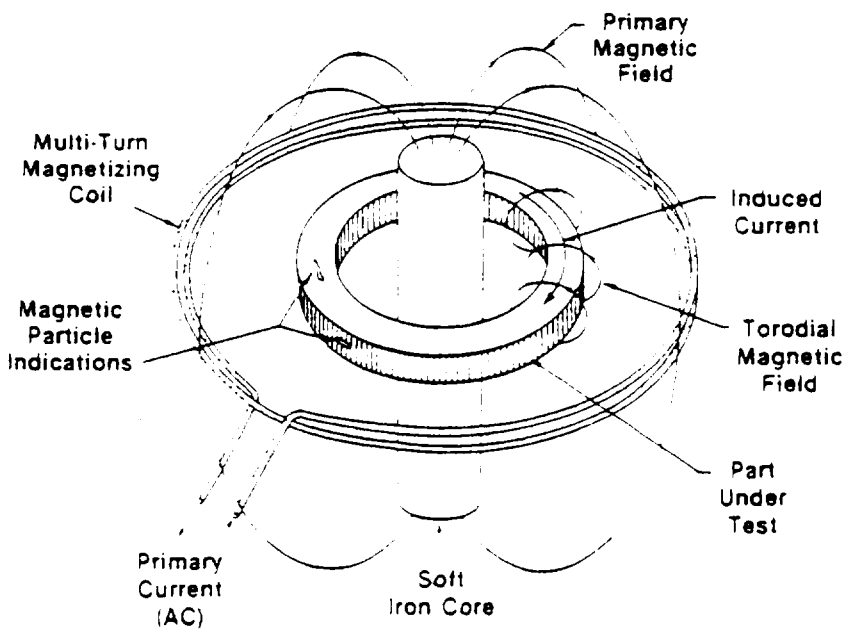


Figure 2. Example of induced current magnetization. The primary current sets up an oscillating magnetic field. This primary magnetic field induces a current in the ring shaped part under test.

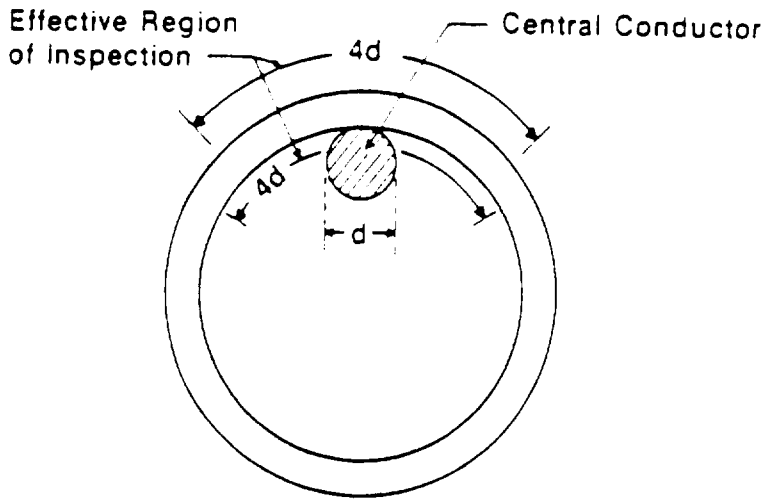


Figure 3. The effective region of inspection when using an offset central conductor is equal to four times the diameter of the conductor as indicated.

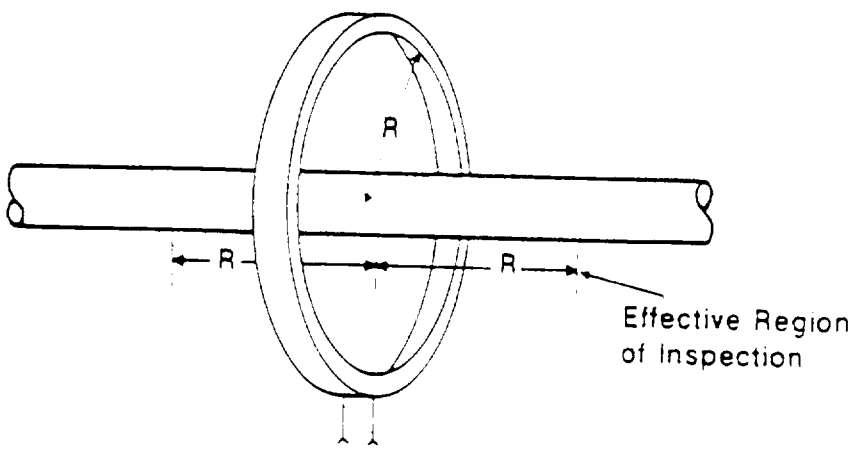


Figure 4. Effective region of inspection for a low fill-factor coil.

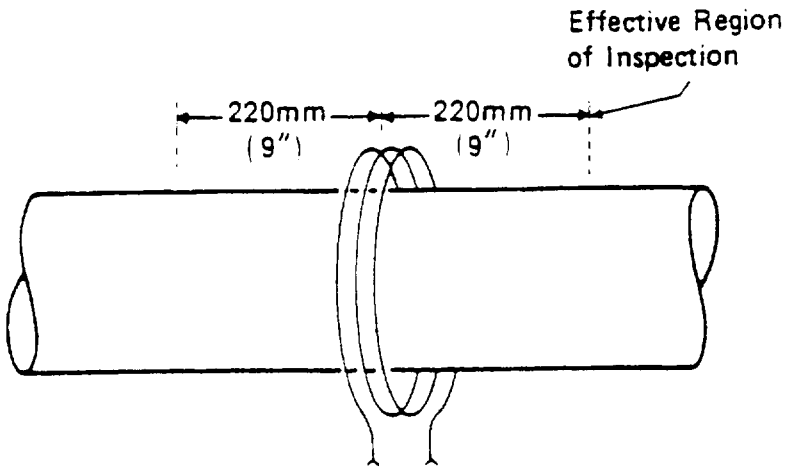


Figure 5. Effective region of inspection for a high fill-factor coil.

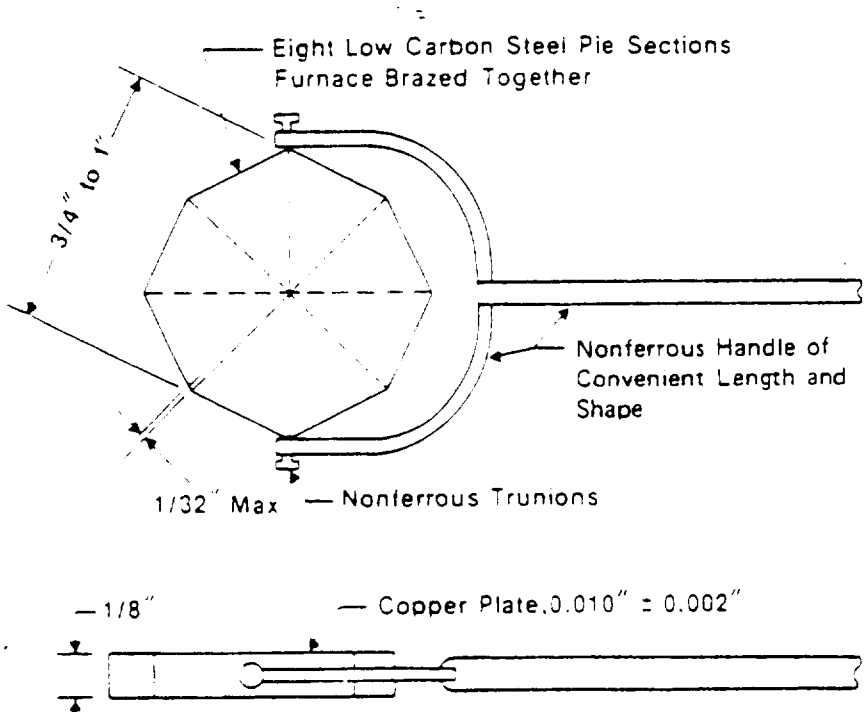


Figure 6. Pie-field indicator for use in magnetic particle inspection system verification. All dimensions are in inches. Eight low carbon steel pie-shaped sections are furnace brazed together and copper plated.

TABLE I

Required indications when using the ring specimen of Figure 1.

Particles Used	Central Conductor FWDC Amperage	Minimum Number of Holes Indicated
Wet suspension, fluorescent or nonfluorescent	1400	3
	2500	5
	3400	6
Dry powder	1400	4
	2500	6
	3400	7

TABLE II

Required verification intervals.

ITEM	MAXIMUM TIME BETWEEN VERIFICATIONS
Lighting:	
Black light intensity	1 day
White light intensity	1 week
Background white light intensity	1 week
System performance using test piece or ring specimen of Figure 1	1 day
Wet particle concentration	8 hours, or every shift change
Water break test	1 month
Wet particle contamination	1 week
Equipment calibration/check:	
Ammeter accuracy	6 months
Timer control	6 months
Quick break	2 months
Dead weight check	2 months

Note: The maximum time between verifications may be extended when substantiated by actual technical stability/reliability data.

Custodians:

Army -- MR
Navy -- AS
Air Force -- 20

Review activities:

Army -- AR, AV, EA, MI
Navy -- SH
Air Force -- 99, 70, 80, 82, 24, 84

User activities:

Army -- AT, AL, ME, TE, AR
Navy -- OS
Air Force -- 71

Preparing Activity:

Army - MR

Project No. NDTI-0054

(WP # ID-0381A/DISK-0305A. FOR AMMRC USE ONLY)

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	☐ MANUFACTURER
	☐ OTHER *(Specify)*: _____

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a. Paragraph Number and Wording:

b. Recommended Wording:

c. Reason/Rationale for Recommendation:

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