SAE The Engineering Society For Advancing Mobility Land Sea Air and Space® INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

SURFACE VEHICLE INFORMATION REPORT

SAE J425 | REV. MAR91

Issued 1960-06
Revised 1991-03

Superseding J425 MAR81

(R) ELECTROMAGNETIC TESTING BY EDDY CURRENT METHODS

Foreword—This Document has not changed other than to put it into the new SAE Technical Standards Board Format.

1. *Scope*

Scope—The purpose of this SAE Information Report is to provide general information relative to the nature and use of eddy current techniques for nondestructive testing. The document is not intended to provide detailed technical information but to serve as an introduction to the principles and capabilities of eddy current testing, and as a guide to more extensive references listed in Section 2.

2. *References*

2.1 Related Publications—The following publications are provided for information purposes only and are not a required part of this document.

2.1.1 ASM PUBLICATION—ATTN: MSC/Book Order, ASM International, PO Box 473, Novelty, OH 44072-9901.

Metals Handbook, Eighth Edition, Vol. 11, 1976, pp. 75–93.
Metals Handbook, Ninth Edition, Vol. 17, Nondestructive Evaluation and Quality Control, 1989.

2.1.2 ASTM PUBLICATION—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959

ASTM Annual Standards, Part 11, Standards E 215, E 243, E 268, E 309, E 376, E 426, E 566, E 570, E 571, E 690.

2.1.3 OTHER PUBLICATIONS

Nondestructive Testing Handbook, Second Edition, Vol. 4, Electromagnetic Testing, 1986, American Society for Nondestructive Testing, Columbus, OH 43228
Programmed Instruction Handbooks, PI-4-5, Eddy Current Testing, 1971. Classroom Training Handbook, CT-6-5, Eddy Current Testing, 1971. The above prepared by General Dynamics and available from American Society for Nondestructive Testing.
Hugo L. Libby, Introduction to Electromagnetic Nondestructive Test Methods, New York: John Wiley and Sons, Inc., 1985
Tool and Manufacturing Engineer's Handbook, Vol. 4, Quality Control and Assembly, 1987, Society of Manufacturing Engineers, Dearborn, MI 48121

QUESTIONS REGARDING THIS DOCUMENT: (412) 772-8512 FAX: (412) 776-0243
TO PLACE A DOCUMENT ORDER; (412) 776-4970 FAX: (412) 776-0790
SAE WEB ADDRESS http://www.sae.org

3. ***General***—Eddy current testing is a method of electromagnetic testing which uses induced electrical currents to indicate or measure certain characteristics of electrically conducting bodies (ferrous and nonferrous). Applications are in one of three general categories: metal sorting, surface discontinuity detection, or thickness measurement. Under appropriate conditions and with proper instrumentation, eddy current testing has been used to:

a. Detect discontinuities such as seams, laps, slivers, scabs, pits, cracks, voids, inclusions, and cold shuts.
b. Sort for chemical composition on a qualitative basis.
c. Sort for physical properties such as hardness, case depth, and heat damage.
d. Measure conductivity and related properties.
e. Measure dimensions such as the thickness of metallic coatings, plating, cladding, wall thickness or outside diameter of tubing, corrosion depth, and wear.
f. Measure the thickness of nonmetals, when a metallic backing sheet can be employed.

4. ***Principle***—Eddy currents are induced in a test piece by a time varying magnetic field generated by an alternating current flowing in a coil. The coil configuration may assume a wide variety of shapes, sizes, and arrangements. The coil may surround the test piece or may be placed on or near the surface.

Eddy currents are influenced by many characteristics of the metal: conductivity, magnetic permeability, geometry, mass, and homogeneity. This fact makes it possible to evaluate many different characteristics of the test piece with appropriate test procedures.

In electromagnetic testing, energy is dissipated in the test piece by two separate processes: magnetic hysteresis and eddy current flow. In magnetic materials, both effects are present. In nonmagnetic and magnetically saturated materials, the hysteresis effect is absent or suppressed; and the prevalent losses are due to eddy currents.

Saturation is a term used generally to describe the condition of a ferromagnetic material at its maximum value of magnetization. To provide saturation, a direct current magnetic field or a permanent magnet of sufficient strength is applied to bring the material to a point where the ratio force approaches unity. In this condition, the material behaves as if it were nonmagnetic. Theoretically, magnetic saturation should not be necessary for nonferromagnetic material, but some nonmagnetic materials contain small amounts of ferromagnetic material which can generate electrical noise during testing. This noise can usually be eliminated by the use of a saturating field.

5. ***Procedure***—The effect of the characteristics of the test piece on the eddy currents may be studied in a number of different ways. A characteristic to be studied is related to a change in the amplitude, distribution, or phase of the eddy currents, or some combination of these three. These changes are reflected as changes in the exciting coil or in auxiliary coils located to be sensitive to the eddy currents. These changes may be measured as voltage differences, current differences, phase differences, or changes in the impedance of the coil or coils.

The coils and the instrumentation can be arranged to measure a given characteristic directly, or they may be used as a comparator. In the latter case, the measurement is the difference between the characteristics of the test piece and a similar piece of known or acceptable characteristics. Such measurements can also be made to determine differences between various segments of the same test piece.

Even with the best instrumentation, it is sometimes difficult to separate effects of the characteristics to be measured from effects of other characteristics. The success of an eddy current test depends on:

a. Proper coil design and arrangement
b. Selection of the proper test frequency
c. Selection of the proper analysis circuit
d. Use of proper magnetic field strength
e. Optimization and maintenance of electromagnetic coupling between the coil and test piece
f. Selection of the most suitable stage in the manufacturing process for the inspection procedure

Eddy current effects are most pronounced near the surface, with sensitivity for detecting irregularities of composition or structure falling off as depth below the surface increases. Depth of eddy current penetration of an object decreases as test frequency increases. Ferromagnetic metals, such as steel, are generally tested with low frequencies in the range of 1 to 10 000 Hz (10 kHz). Nonmagnetic metals with higher conductivity, such as aluminum, are generally tested with frequencies around 100 kHz, while those with lower conductivity, such as titanium, are generally tested with frequencies in the range of 1 to 10 MHz. There are numerous exceptions to these generalities.

6. Test Coil Methods

6.1 Single Coil—In this method, a single coil is used. It may have one or more windings for excitation and detection. A winding is excited from an alternating current source within the test instrument. The amplitude and phase of the voltage across a winding is a function of the effect of the test piece on the coil.

6.2 Differential Coil—An arrangement where two separate detector coils are used to compare two different test pieces, or two different portions of the same test piece. A voltage appears at the output terminal of the coils when the effective permeability, conductivity, mass, geometry, or homogeneity of the metal in the two coils differ.

7. Method Of Analysis

7.1 Lumped Impedance—In the lumped impedance analysis, a single coil is employed. A characteristic of the test piece is correlated to the amplitude and phase of the coil voltage.

7.2 Impedance Plane Analysis

7.2.1 MAGNETIC PARAMETER AMPLITUDE—The single coil or the differential coil method may be employed in this analysis. The variation in amplitude and phase of the detector coil voltage is measured and plotted in an impedance plane. The coil parameters are correlated to a test piece characteristic. Some variation in chemistry and size can be tolerated in this system providing the proper test frequency is employed.

7.2.2 PHASE ANGLE ANALYSIS—A two-coil method is more suited to this type of analysis. The phase angle between the voltage at the driving coil and that at the detector coil is measured and related to a test piece characteristic.

8. Equipment—Eddy current test instrumentation with a wide range of test frequencies and associated coils and probes of various sizes are commercially available to meet the needs of many applications. One of the advantages of electromagnetic equipment is that it lends itself to automatic operations for regularly shaped parts. Electromagnetic equipment can be large, elaborate, and expensive when multiple stations and materials handling sections are included, such as are used on sheets and plates. Manual systems which are small, simple, and inexpensive are common in other instances, and are used with large or irregularly shaped objects.

The electronic apparatus energizes an encircling coil or probe with alternating currents of suitable frequency and amplitude and detects the electromagnetic response of the coil. Equipment may include a detector phase discriminator, filter circuits, modulation circuits, magnetic saturation devices, recorders, and signaling devices as required by the application.

The encircling or probe coil assembly is capable of inducing current in the part and sensing changes in the electric and magnetic characteristics of the part.

A mechanical device capable of passing a part (such as a tube) through the encircling coil or past the probe may be used. It generally operates at uniform speed with minimum vibration of the coil, probe, or part, and maintains the article to be inspected in proper register or concentricity with the probe or encircling coil. A mechanism capable of uniformly rotating or moving the part or the probe may be required.

An end effect suppression device, a means capable of suppressing the signals produced at the ends of tubes or bars, may be used.

Reference standards are generally required to relate eddy current measurements to test part characteristics, and to adjust the sensitivity of the electronic apparatus.

8.1 Typical Examples of Equipment Variations for Different Applications

8.1.1 Equipment using impedance plane analysis and operable over a range of test frequencies from 1 Hz to 10 kHz has been used to sort carbon steel mixtures involving different compositions and/or different heat treat conditions. A unique advantage of this instrument is that it is possible to quickly determine the optimum frequency for performing a given test. Similar equipment has been calibrated to indicate conductivity, hardness, case depth, and dimensions.

8.1.2 Equipment using a single coil to scan the surface has been used to detect and indicate the depth of seams, cracks, laps, slivers, and similar surface and near-surface imperfections in bars, rounds, billets, and tubular products. The sensitivity of this equipment depends on the surface conditions of the product under test. On a hot-rolled surface with thin, tightly adherent scale, seams as shallow as 0.25 mm (0.010 in) are reliably evaluated. Product with heavy or broken scale should be cleaned by grit blasting prior to testing. Under more favorable (smoother, less scale) surface conditions seams as shallow as 0.13 mm (0.005 in) have been evaluated. On polished (ground) surfaces, seams and cracks as shallow as 0.025 mm (0.001 in) have been detected.

8.1.3 Equipment using differential test coils has been used to detect imperfections in carbon steel tubular and bar products. Testing frequencies ranging from 400 Hz to over 20 kHz have been used. At the lowest testing frequencies, and with the use of magnetic saturation, defects have been reliably detected (OD, ID, or subsurface) in the wall of tubular products with wall thicknesses as great as 15.9 mm (0.62 in). When testing at frequencies as low as 400 Hz, the testing speed is limited to about 30.5 m/min (100 ft/min). When higher testing frequencies are used, the testing speed can be correspondingly increased. Higher testing frequencies can be used for testing product with thinner walls and higher resistivity.

8.1.4 Vector sensitive instruments operate on the impedance plane principle. The frequency range of these instruments is from 100 Hz to 6 MHz. This type of operation considers both the amplitude and phase of the eddy currents. This allows one to optimize the instrument response for a selected material variable, while minimizing response to another variable, such as probe spacing.