Eddy Current Testing by Electromagnetic Methods —SAE J425b

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EDDY CURRENT TESTING BY ELECTROMAGNETIC METHODS—SAE J425b

SAE Information Report

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1. Purpose—The purpose of this report is to provide general information relative to the nature and use of eddy current techniques for nondestructive testing. The report 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 the Bibliography.

2. 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 non-ferrous). 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, but not limited to, 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.

3. 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, 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: (a) magnetic hysteresis and (b) eddy current flow. In magnetic materials, both effects are present. In non-magnetic 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 values of magnetization. To provide saturation, a direct current magnetic field or a permanent magnet of sufficient magnitude 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 non-magnetic. Theoretically, magnetic saturation should not be necessary for non-ferromagnetic material, but some non-magnetic 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.

4. 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.

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, and

(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 Hz to 10,000 Hz (10 kHz). Non-magnetic 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 MHz to 10 MHz. There are numerous exceptions to these generalities.

5. Test Coil Methods

5.1 Single Coil—In this method, a single coil is used. It may have one, two, or three 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.

5.2 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.

6. Method of Analysis

6.1 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 coil voltage.

6.2 Impedance Plane Analysis

6.2.1 MAGNETIC PARAMETER AMPLITUDE—The single coil, the two-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.

6.2.2 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.

7. Equipment—One of the advantages of electromagnetic equipment is that it lends itself to automatic operation for regularly shaped parts. Electromagnetic equipment can be large, elaborate, and expensive when multiple stations and materials handling sections are included, such as used on sheets and plates. Manual systems which are small, simple, and inexpensive are also common in other instances such as used with large or irregularly shaped objects.

The electronic apparatus is capable of energizing an encircling coil or probe with alternating currents of suitable frequency and amplitude and is capable of sensing the electromagnetic response of the sensors. 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 adjust the sensitivity of the electronic apparatus.

Typical Examples of Equipment Variations for Different Applications:

7.1 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.

7.2 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 imperfections in bars, rounds, billets and tubular products. The sensitivity of this equipment depends on the surface condition of the product under test. On a hot-rolled surface with thin, tightly adherent scale, seams as shallow as 0.010 in. (.25 mm) 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 such as shallow as 0.005 in (0.13 mm) have been evaluated. On polished (ground) surfaces, seams and cracks as shallow as 0.001 in (0.025 mm) have been detected.