Designation: E1629 – 07

Standard Practice for
Determining the Impedance of Absolute Eddy-Current Probes[1]

1. Scope

1.1 This practice covers a procedure for determining the impedance of absolute eddy-current probes (bridge-type, air or ferrite core, wire wound, shielded, or unshielded) used for finding material defects in electrically conducting material. This practice is intended to establish a uniform test methodology to measure the impedance of eddy-current probes prior to receipt of these probes by the purchaser or the specifier.

1.2 *Limitations*—This practice does not address the characterization or measurement of the impedance of differential, a-c coupled, or transmit/receive types of probes. This practice does not address the use of magnetic materials in testing probes. This practice shall not be used as a basis for selection of the best probe for a particular application or as a means by which to calibrate a probe for a specific examination.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 The following document forms a part of this practice to the extent specified herein:

2.2 *ASTM Standards:*
E1316 Terminology for Nondestructive Examinations[2]

3. Terminology

3.1 *Definitions*—The terminology relating to eddy-current examination that appears in Terminology E1316 shall apply to the terms used in this practice.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *eddy-current test block— for the purposes of the method described in this practice*, a rectangular block made of an aluminum alloy (see 6.1.2) to which an active eddy-current probe is applied.

3.3 *Mathematical Symbols*:

3.3.1 *j*—a symbol used in electrical engineering to represent $\sqrt{-1}$. It is associated with the restriction to the flow of electrical current caused by capacitors and coils.

3.3.2 *N*— any number.

3.3.3 | –N|—the magnitude of *N*, regardless whether *N* is positive, negative, or a vector quantity.

3.3.4 $\sqrt{N}$— the square root of *N*.

3.3.5 $(-N)^2$—*N* squared, that is, $N \times N$.

3.3.6 Δ*N*— delta *N*, the change or difference in *N*.

3.4 *Abbreviations:*

3.4.1 *tan*—used for the tangent function. The $\tan^{-1}$, arc tangent or inverse tangent function, returns a value that is a measure of an angle and can be in either degrees or radians. When using a calculator to determine the $\tan^{-1}$, care should be taken to determine whether the answer is in degrees or radians since the numerical values that represent the same angle are different.

3.4.2 *cos*—used for the cosine function.

3.4.3 *sin*—used for the sine function.

4. Significance and Use

4.1 Eddy-current probes may be used for the nondestructive examination of parts or structures made of electrically conducting materials. Many of these examinations are intended to discover material defects, such as cracks, that may cause the part or structure to be unsafe or unfit for service. Eddy-current probes that fail to meet the performance level requirements of this practice shall not be used for the examination of material or hardware unless the probe is qualified by some other system

or an agreement has been reached by the probe manufacturer and the purchaser, or both.

5. General Practice

5.1 *Use of Test Blocks*—The test blocks described in this practice shall not be used for purposes other than measuring the impedance of eddy-current probes as specified in this practice. They shall not be used for standardizing an examination or for determining sensitivity to flaws.

5.2 *Responsibility*—Initial determination of the impedance values of eddy-current probes shall be performed by the probe manufacturer in accordance with this practice. The results shall be delivered with the probe and maintained by the organization using the probe. While the retesting of probes may be performed using this practice, only the results obtained before the probe is in use should be compared to the initial impedance values. The impedance results should not be compared to the initial values after a probe has been used.

6. Specific Practice

6.1 *Test Method*—Impedance measurements shall be made on an aluminum alloy test block with a machined slot that conforms to the requirements of this practice. The operating frequency (as specified by the probe manufacturer) may vary for each probe examined, depending on the specific probe geometry, required skin depth, matching impedance, desired signal strength, and application. A commercial impedance measuring instrument that conforms to 6.1.1 shall be used to make the measurements. The measurements will be recorded on the worksheet (Appendix X1) to calculate the probe impedance. The calculated values shall be compared to the acceptable criteria (6.3) to determine probe acceptability.

6.1.1 *Test Equipment*—The test instrument shall be either a commercial impedance measuring instrument or an LCR meter with an oscillator capable of driving a current in the probe at the probe's operating frequency. The output shall display the probe impedance in either polar coordinates, providing a magnitude and a phase angle, or rectangular coordinates, providing resistive and reactive components of the impedance, or both formats, that is, in polar and rectangular coordinates.

This instrument shall be certified as having been calibrated in accordance with the manufacturer's specifications, with the calibration sticker indicating the calibration date and the required interval or next calibration date.

6.1.2 *Test Blocks*—The test block shall be fabricated from 7075-T6 aluminum alloy 1.9-cm (0.75-in.) thick, with slotted holes for testing bolt hole probes and a slotted flat section for testing surface probes. All test surfaces shall be polished to an average finish ≤ 15 µm (591 µin.). The conductivity of the aluminum alloy should be between 30 and 35 % IACS.

6.1.2.1 The slotted flat section shall have side measurements of at least six times the coil diameter or 5.1 by 5.1 cm (2 by 2 in.), whichever is larger. The slot shall be machined across the block's surface and shall measure at least 5.0 cm (2-in.) long. The slot cross section shall measure 0.1 ± 0.01 mm (0.004 ± 0.0004 in.) wide and 0.5 ± 0.025 mm (0.02 ± 0.001 in.) deep.

6.1.2.2 The test holes shall be made for all of the nominal sizes of bolt hole probes to be examined. The edges of the holes shall be spaced 1.9-cm (0.75-in.) apart from each other and from the block edges. The slot shall run the entire length of the hole and will be 0.1 ± 0.01-mm (0.004 ± 0.0004-in.) wide and 0.5 ± 0.025-mm (0.02 ± 0.001-in.) deep.

6.1.2.3 Fig. 1 shows a representative test block with the holes used for testing two different sizes of bolt hole probes. The length of the block ($x + 5.1$ cm) depends on the number and size of the test holes required by the user, as well as the amount of clearance required between each hole and the block's edges.

6.2 *Measurement Procedure:*

6.2.1 *Measurements*—Impedance values can be expressed in different ways. Impedances are most commonly given in either rectangular or polar coordinates. In polar form, the impedance is expressed as a magnitude, |Z|, with a corresponding phase angle, θ, and often appears as $|Z| \angle \theta$. In rectangular form the impedance is expressed as a combination of a resistive component, R, and a reactive or imaginary (denoted by j) component, X. This form often appears as $R \pm jX$. Fig. 2 shows two points measured in both forms and the resulting impedance change (ΔZ) calculation. This is typical of the way in which impedance changes are measured on actual eddy-current
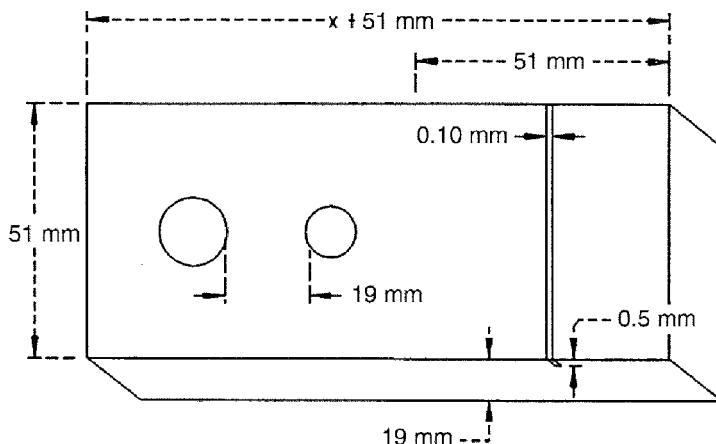

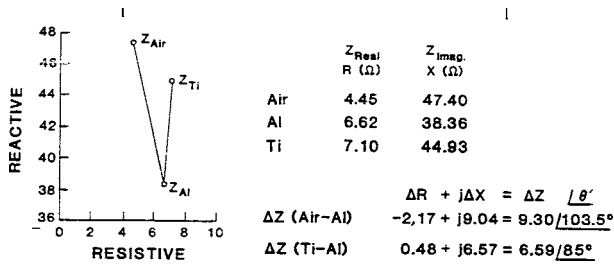
FIG. 1 Representative Test Block

FIG. 2 Rectangular and Polar Coordinates and Resulting ΔZ

	Z_{Real} R (Ω)	$Z_{Imag.}$ X (Ω)
Air	4.45	47.40
Al	6.62	38.36
Ti	7.10	44.93

$\Delta R + j\Delta X = \Delta Z \; \underline{/\theta'}$

ΔZ (Air–Al) $-2.17 + j9.04 = 9.30 \underline{/103.5°}$

ΔZ (Ti–Al) $0.48 + j6.57 = 6.59 \underline{/85°}$

probes using the test method specified in this practice. The impedance of a probe is measured first off the slot and then on the slot in this method, and the difference between these two measurements is calculated. An error may occur in the calculations if appropriate coordinate conversions are not made (addition and subtraction are performed in the case of rectangular coordinates and multiplication and division in the case of polar coordinates).

6.2.1.1 All performance tests shall be conducted within the temperature range from 15 to 27°C (60 to 80°F). The probe test frequency shall depend on the rated operating frequency of the particular probe under test (see X1.4.3.3).

6.2.2 *Probe Impedance in Air*—Attach the probe to the impedance measuring instrument, and position the probe at least 50.8 mm (2 in.) away from any electrically conducting material or hardware, or both. Measure the impedance and record the impedance values on the worksheet. Compare the measurement to the values listed in 6.3.1.

6.2.3 *Average Off-Slot Probe Impedance*— Place the probe on the surface of or in the hole in the test block, as appropriate. For a surface probe, place the probe on four different positions on the face of the block. The center of each position shall be at least four coil diameters from any edge, slot, or hole. For a bolt hole probe, rotate the probe face in the hole to four different positions that are away from the slot and the top and bottom of the hole. Measure the impedance and record the four impedance values on the worksheet in either polar or rectangular coordinates. If necessary, convert the polar values to R_{off} and X_{off} (resistive and reactive components). Calculate the magnitude of each of the measurements and record them on the worksheet. Determine the variation (scatter) in the magnitudes of the measurements as defined in X1.3.1.3 and compare it to the requirements given in 6.3.2. When acceptable values are

obtained, average the four values to calculate $R_{off\ avg}$ and $X_{off\ avg}$. Record the averages on the worksheet.

6.2.4 *Maximum On-Slot Impedance*—Position the probe face on the slot to obtain a maximum impedance reading. Perform this procedure four times, and record the four resulting impedances in rectangular coordinates, R_{on} and X_{on}, on the worksheet. Average the four values to calculate $R_{on\ avg}$ and $X_{on\ avg}$. Record the averages on the worksheet.

6.2.5 *Probe Performance Criterion*—The probe impedance change caused by the slot, ΔZ, is the magnitude of $R_{on\ avg} - R_{off\ avg}$ and $X_{on\ avg} - X_{off\ avg}$. The fractional change is the absolute value of ΔZ divided by $|Z_{off\ avg}|$. Appendix X1 contains the formulas for calculating the values of $|\Delta Z|$ and $|Z_{off\ avg}|$. Record the calculated values on the worksheet and compare them to the requirements of 6.3.3 to determine acceptance.

6.3 *Acceptance Criteria*—Acceptance of a probe being characterized by this practice requires that it meet all of the following criteria:

6.3.1 *Probe Impedance in Air*—Unless otherwise specified, the magnitude of the probe impedance in air shall be between 20 and 1000 Ω, and the phase shall be between 70 and 90 deg. An impedance value below 20 Ω indicates the possibility of a short circuit in the probe coil, and a value above 1000 Ω indicates a possible open circuit.

6.3.1.1 The magnitude of the impedance in air shall be within 10 % of the value specified for that type of probe by the probe manufacturer and be within the input impedance range specified for the measuring instrument.

6.3.2 *Measurement Scatter*—A variation greater than 4 % among the off-slot impedance measurements indicates that the values are too scattered. The measurements must be repeated using greater care in holding the surface probe more securely or fitting the bolt hole probe more snugly in the hole. Repeated high variation indicates that an analysis of the system should be performed using different examiners or known acceptable probes. The probe is unacceptable if the measurement scatter cannot be reduced to the acceptable value.

6.3.3 *Probe Impedance Ratio*—These ratios will be determined by agreement between the eddy-current probe manufacturer and the probe purchaser.

7. Keywords

7.1 absolute eddy-current probes; eddy-current probes; impedance; nondestructive testing