Designation: A 712 – 97

Standard Test Method for Electrical Resistivity of Soft Magnetic Alloys[1]

This standard is issued under the fixed designation A 712; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the measurement of electrical resistivity of strip or bar specimens of soft magnetic alloys.

1.2 *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.*

1.3 The values are stated only in SI units and are to be regarded as standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 34 Practice for Sampling and Procurement Testing of Magnetic Materials[2]

3. Summary of Test Method

3.1 The electrical resistance of a 0.25-m long (minimum) test specimen is measured with a Kelvin-type resistance bridge or a digital multimeter or the potentiometer-ammeter method. The resistivity is then calculated from the resistance measurement and the dimensions of the specimen and is known as the electrical resistivity of the material. This value is equal to the resistance between opposite faces of a cube of unit dimensions.

4. Apparatus

4.1 Kelvin-type resistance bridge or a digital multimeter or a d-c potentiometer and d-c ammeter providing resistance measurements to an accuracy within 0.5 % of the accepted true value.

5. Sampling

5.1 Samples shall be representative of the material in the physical condition as shipped or agreed upon by the manufacturer and the purchaser.

6. Test Specimen

6.1 The test specimen shall be a straight strip or bar or wire of substantially uniform cross-sectional area.

6.2 It shall have a minimum length of 0.25 m. Strip specimens preferably should have a uniform width of 0.03 m minimum, unless not available.

6.2.1 If width of the strip material to be sampled prevents obtaining a sample of 0.03-m minimum width, the specimen width to be used shall be the maximum obtainable and shall be agreed upon between the manufacturer and the purchaser.

6.2.2 Bars and wires having circular, rectangular, or other sections shall be used in the sectional dimensions as produced, unless they are so large as to require cutting a representative sample of suitable dimensions.

6.3 It shall be free of obvious surface defects.

6.4 The surface shall be cleaned by wiping with a cloth. Oil and grease, if present on the surface, shall be removed with a suitable solvent. Normal surface oxide or core plating need not be removed except in areas in which it is necessary to make satisfactory electrical contact.

7. Procedure

7.1 Measure the electrical resistance of the test specimen using a Kelvin-type resistance bridge or a digital multimeter or potentiometer-ammeter system having separate current and potential leads.

7.2 The distance between each potential lead contact and the corresponding current lead contact shall be at least twice the width of the test specimen with the two potential contacts lying between the current contacts. The distance between the potential contacts shall be not less than 0.12 m.

7.3 The dimension of each potential contact in the direction of the length of the specimen shall be not more than 0.5 % of the distance between potential contacts.

7.4 The contacts to the specimen shall be located centrally with respect to the specimen's width dimension, and the current contacts shall cover more than 80 % of the width. A reliable contact shall be made with the specimen by both the current and potential leads.

7.5 Specimen temperature during test should be about 25°C.

7.6 To eliminate errors as a result of contact potential, take two readings, one direct and one with the current reversed, in close succession.

7.7 The electrical current in the test specimen must be limited to avoid overheating but must be adequate to provide sufficient sensitivity to show an out-of-balance condition when

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[2] *Annual Book of ASTM Standards*, Vol 03.04.

the resistance reading is changed 0.5 % of the value recorded. If the current is too low, sensitivity is low also, and a balance can be shown for a broad range of resistance.

8. Calculation

8.1 *Strip Specimens*:

8.1.1 Determine the average cross-sectional area of the test specimen from the weight, length, and density as follows:

$$A = m/l\delta \quad (1)$$

where:

A = cross-sectional area of test specimen, m^2;
m = mass of test specimen, kg;
l = length of test specimen, m; and
δ = density of test specimen, kg/m^3, determined in accordance with Practice A 34.

8.1.2 Eq 1 assumes a negligible mass of any coating material.

8.2 *Bar and Wire Specimens*—The cross-sectional area of the test specimen shall be based on direct measurements with a micrometer or caliper.

8.3 Calculate resistivity from the measured value of electrical resistance and the cross-sectional area as follows:

$$\rho = RA/l_2 \quad (2)$$

where:

ρ = electrical resistivity of the material, $\Omega \cdot m$;
R = resistance of electrical path, Ω;
A = cross-sectional area of electrical path, m^2; and
l_2 = length of electrical path between potential contacts on the test specimen, m.

8.4 The resistivity units in ohm-metres shown in Eq 2 can be converted to microhm-centimetres by multiplying the ohm-metre figure by 10^8 microhm-centimetres per ohm-metre. For example, if the resistivity is $0.25 \times 10^{-6}\ \Omega \cdot m$; $0.25 \times 10^{-6} \times 10^8\ \mu\Omega \cdot cm/\Omega \cdot m$ is equal to $25\ \mu\Omega \cdot cm$.

NOTE 1—The resistivities of commercial soft magnetic alloys are shown in Annex A1.

9. Precision and Bias

9.1 Although no rigorous interlaboratory comparisons of Test Method A 712 have been performed, it is estimated that the reproducibility standard deviation is no greater than 2 % of the mean.

9.2 The bias of Test Method A 712 is believed to be zero.

10. Keywords

10.1 electrical resistivity; magnetic alloy; potentiometer-ammeter; resistance bridge

ANNEX

(Mandatory Information)

A1. RESISTIVITIES

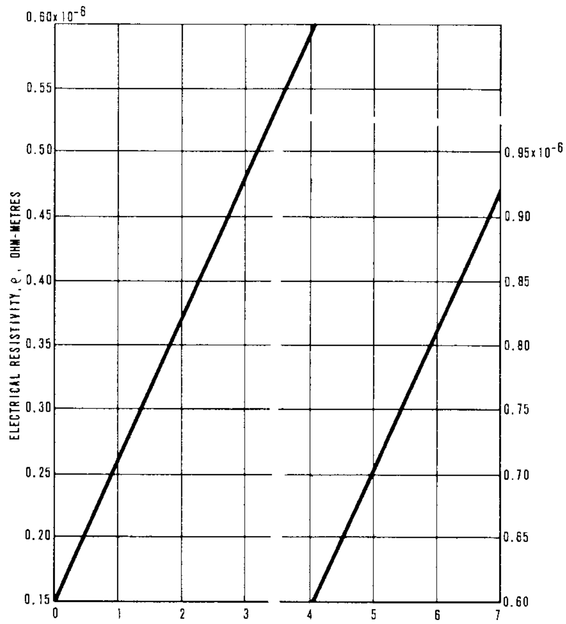
A1.1 This test method assumes the establishment of a uniform current density along the test specimen throughout the region between the potential contacts. The current contacts should be in the form of transverse clamps covering at least 80 % and preferably the entire width of the specimen. The potential contacts can be either knife edge or point contacts.

A1.1.1 If a potentiometer is used, a suitable d-c source and ammeter are required to establish and measure the total current in the specimen, which should be limited to avoid excessive heating. The required R is then the ratio of the measured potential drop to the measured current. When the potentiometer is balanced, no current flows in the potential leads so that any contact resistance at the potential points is of no consequence.

A1.1.2 The Kelvin bridge is calibrated to read directly the resistance between the potential points without knowledge of the current in the specimen. Contact resistance at the potential points and the resistance of the four leads to the specimen are not a part of the required R and are usually negligible portions of the corresponding components of the bridge system.

A1.1.3 Digital multimeters used for measuring resistance in the range required for this test method will be equipped for four-wire ohm measurements. In the four-wire method, a controlled source current is applied to the resistance to be measured via the current leads, and the voltage drop is sensed across the potential (or sense) leads. Since the input resistance of the digital multimeter is very large (typically greater than 10 MΩ), the contact resistance between the sense leads and the specimen and the resistance of the leads do not affect the measurement.

A1.2 Typical resistivities of iron-silicon-aluminum alloy steel sheets are shown in Fig. A1.1 and other soft magnetic alloys in Table A1.1. Commercial electrical steels are low-carbon, silicon-iron, or silicon-aluminum-iron alloys containing up to 3.5 % silicon and only a small amount of aluminum.



NOTE 1—The linear equation for the graph in this figure is as follows:

$$\rho = 0.1325 \times 10^{-6} + 0.113 \text{ (percent silicon + percent aluminum)} \times 10^{-6}\ \Omega \cdot \text{m}$$

where ρ = electrical resistivity in ohm-metres at approximately 25°C. The equation is based on the average line drawn through many test points obtained on commercial grades of electrical steels of various compositions. Individual tests may show departures from the average line, which is shown in equation and graphical form for general use and guidance. The intercept constant 0.1325 applies only to steels having alloying elements over about 0.15 %. As the percentage of alloying elements decreases to low values, the intercept constant decreases, approaching the value of about 0.107.

FIG. A1.1 Electrical Resistivities Versus Composition of Commercial Grades of Electrical Steels

TABLE A1.1 Electrical Resistivity of Soft Magnetic Alloys of Nickel, Chromium, and Iron

General Composition	Typical Electrical Resistivity, Ω· m	General Name
36 % Nickel, balance iron	0.82×10^{-6}	Invar
45 % Nickel, balance iron	0.53	45 Permalloy
48 % Nickel, balance iron	0.48	High Perm, 49; 4750
52 % Nickel, balance iron	0.43	52 Alloy
65 % Nickel, balance iron	0.22	65 Permalloy
77 % Nickel, 5 % copper, 2.6 % chromium, balance iron	0.60	Mumetal
78.5 % Nickel, balance iron	0.16	78 Permalloy
80 % Nickel, 4 % molybdenum, balance iron	0.58	4–79 Permalloy; Hy Mu 80
80 % Nickel, 5 % molybdenum, balance iron	0.60	5–79 Permalloy; Hy Mu 800 Supermalloy
17 % Chromium, balance iron	0.61	Stainless Type 430