Foreword

(Formal Clauses to be added later)

Need of the standard:

The traditional method to measure electrical conductivity is based on Kelvin Bridge which is quite complicated and time consuming. It is envisaged that with the help of this standard, the measurement of electrical conductivity of nonmagnetic conductive materials like copper, aluminium, titanium, zirconium & their alloys, and austenitic stainless steel would become much easier and faster.

For the guidance purpose of the user of this standard, the minimum specimen/sample thickness required, based on the combination of test frequency and electrical conductivity of the materials, for testing of electrical conductivity by eddy current method ~~at different electrical and different test frequencies~~ is given in ANNEX A

Considerable assistance has been derived from ASTM E1004-17 ‘Standard Test Method for Determining Electrical Conductivity Using the Electromagnetic (Eddy Current) Method’ for the formulation of this standard.

For BIS use only

Draft Indian Standard

On

Non-destructive testing — Eddy Current Testing—Determination of Electrical Conductivity of Non-magnetic Metals

~~Standard Test Method for Determining Electrical Conductivity of Non-Magnetic Conductive Materials Using the Electromagnetic (Eddy Current) Testing~~

1. Scope

1.1 This test method covers a procedure for determining the electrical conductivity of nonmagnetic **metals** like copper, **aluminium, titanium, zirconium & their alloys, and austenitic stainless steel** using the electromagnetic (eddy current) method. The procedure is primarily for use with commercially available direct reading electrical conductivity instruments.

1.2 This test method is applicable to **non-magnetic conductive materials** that have a flat surface and ~~includes metals~~ with or without a thin nonconductive coating.

1.3 Electrical conductivity, when evaluated with eddy current instruments, is usually expressed as

1) Percentage of the electrical conductivity of the International Annealed Copper Standard (% IACS)

2) Siemens/meter (S/m).

The conductivity of the Annealed Copper Standard is defined to be 0.58 × 10^8 S/m (100 % IACS) at 20°C.

2 REFERENCES

The following standards contain provisions which through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subjected to revision, and parties to agreements based on this standard are encouraged to investigate the possibility ofapplying the most recent editions of the standards indicated below:

IS No.	*Title*
IS 12965 : 1990	Glossary of terms used in electromagnetic (Eddy Current) testing
IS 13805: 2004	General standard for qualification and certification of non - Destructive testing personnel - Specification (First Revision)

3.Terminology

For the purpose of this standard the definition given in IS 12965 and following shall apply:

3.1 Temperature coefficient—the fractional or percentage change in electrical conductivity per degree Celsius change in temperature.

4. QUALIFICATION AND CERTIFICATION OF TESTING PERSONNEL

The testing personnel shall be qualified and certified as Eddy Current Testing Level I for conducting the test and at least Level II for writing the instructions, **analysing the results** and issuing the report as per IS 13805 or any other nationally/internationally accepted standard.

5. PRINCIPLE OF THE TEST

Eddy current testing is based on the electromagnetic induction. The **test** coil carries alternating current supplied by eddy current equipment. The coil is associated with primary alternating magnetic field .This coil is having its own Impedance. When this coil comes near a conducting material, a circular alternating current is induced in the conductor by the primary flux associated with the coil. This circular alternating current is called eddy current. The direction of the eddy current is opposite to the direction of primary current and the plane of the eddy current is parallel to the coil winding. Eddy current is associated with the secondary magnetic field which opposes the primary magnetic field associated with the test coil. Hence, net magnetic field associated with the test coil changes and thereby the impedance of the test coil changes. This change in the impedance of the test coil represents the condition of the test material. The generation of the eddy current depends on the electrical conductivity and magnetic permeability of the test material and the test frequency and the lift-off. By selecting the appropriate test parameters a particular variable can be determined by eddy current testing. The results of eddy current conductivity examination are based on the comparison of an unknown sample with two reference standard **samples, one sample is of lowest conductivity and one sample of highest conductivity in the range of measurement of electrical conductivity**.

6. Significance and Use

6.1 Absolute probe coil methods, when used in conjunction with reference standards of known value and eddy current equipment, provide a means for determining the electrical conductivity of nonmagnetic **conductive** materials.

6.2 Electrical conductivity of a sample, when used in conjunction with another method listed and compared to reference charts, can be used as a means of determining: (I) type of metal or alloy, (2) type of heat treatment (for aluminum this evaluation should be used in conjunction with a hardness examination), (3) aging of the alloy, (4) effects of corrosion, (5) heat damage, (6) temper, and (7) hardness.

7. Limitations

7.1 The ability to accomplish the examinations is dependent on the electrical conductivity change caused by the variable of interest. If the electrical conductivity is a strong function of the variable of interest, these examinations can be very accurate.

7.2 If electrical conductivity measurements are used to interpret a property that is related to the electrical conductivity, the correlation curve relating the property to the electrical conductivity should be established for such use.

8. Variables Influencing Accuracy

8.1 Consider the influence of the following variables to ensure an accurate evaluation of electrical conductivity.

8.1.1 **Temperature**— The instrument, probe, reference standards, and parts being examined shall be stabilized at ambient temperature prior to conductivity evaluation. When possible, examinations should be performed at room temperature (typically 20 °C).

8.1.2 **Probe Coil to Metal Coupling—**Variations in the separation between the probe coil and the surface of the sample (lift-off) can cause large changes in the instrument output signal. The sensitivity of the instrument vary widely due to lift-off.~~Instruments vary widely in sensitivity due to lift-off~~ The equipment should ~~some~~ have adjustments for minimizing the effect of lift-off. Standardize the instrument with values at least as large as the known lift-off. Surface curvature may also affect the coupling. If any surface curvature is present on the test job then the calibration shall be done with the reference sample of similar curvature. (Consult the manufacturer's manual for limitations on lift-off and surface curvature).

8.1.3 **Uniformity of Sample**—Variations in material properties are common and can be quite large. Discontinuities or inhomogeneities in the metal near the position of the probe coil will change the value of the measured conductivity.

NOTE 1—Similar materials from various manufacturing methods (extrusion, forging, casting, rolling, machined vs. unmachined) may exhibit significant conductivity variation between processes. Eddy current conductivity meters can be affected by detecting differences in material grain structure, alloy uniformity, and internal stresses so care must be taken as this can influence accuracy.

8.1.4 **Surface Conditions**—Surface treatments and roughness can affect the measured electrical conductivity value of a material. Preferable surface roughness (Ra) should be 1.6 microns maximum. Conductive coatings such as cladding will have a pronounced effect on electrical conductivity readings as compared to the base material values. Procedures for determining the electrical conductivity of clad materials are not addressed in this test method. The sample surface should be clean and free from grease, dirt and any metallic particle embedment at the test location.

8.1.5 **Instrument Stability**—Instrument drift, noise, and nonlinearities can cause inaccuracies in the measurement. The instrument may have the facility for the compensation of these variables.

8.1.6 **Nonunique Conductivity Values**—It should be noted that two different alloys can have the same conductivity. Thus, in some cases, a measurement of conductivity may not uniquely characterize an alloy.

8.1.7 **Sample Thickness**—Eddy current density decreases exponentially with depth (that is, distance from the metal surface). The depth at which the density is approximately 37 % (1/e) of its value at the surface is called the standard depth of penetration δ. Calculate the standard depth of penetration for nonmagnetic conductive materials using one of the following formulas

$$\delta = \sqrt{\frac{1}{\pi\mu\sigma f}}$$

Where,

π= 3.14, μ= μ_ox μ_r, μ_o =$4\pi \times 10^{-7}$ H/m , $\mu_r = 1$ (non -ferromagnetic material)

$Standard\ depth\ of\ penetration\ (\delta)\ is\ in\ metre$

$Frequency\ (f)\ in\ in\ Hz$

$Conductivity\ (\sigma)\ \ is\ in\ {}^{S}/_{m}$

$When\ \sigma\ is\ in\ \%IACS, then\ \rho(micro\text{–}ohm\text{–}cm)\ =\ 172.41/\sigma(\%IACS)$

$So, \delta = \sqrt{\frac{\rho}{\pi\mu f}}$

$Resistivity\ (\rho)\ is\ in\ ohm{-}metre$ π= 3.14, μ= μ_ox μ_r, μ_o =$4\pi \times 10^{-7}$ H/m , $\mu_r = 1$ (non -ferromagnetic material)

$Standard\ depth\ of\ penetration\ (\delta)\ is\ in\ metre$

$Frequency\ (f)\ in\ in\ Hz$

Normally, thickness of sample should be three times the standard depth of penetration

Note - When testing thin materials, stacking of the test parts may be acceptable. Similar material, preferably from the same batch or sheet, may be used to back the material being examined, thereby increasing the effective thickness. Stacked materials must be bare, without cladding, and fit so that they are in intimate contact at the area to be measured. The total thickness of the stacked material must be at least 3 standard depths of penetration (3δ). The electrical conductivity measured using the above technique for stacked material may not represent the actual value.

8.1.8 Instrument frequency- Depth of penetration of Eddy current is inversely proportional to the frequency. The graph shown in Figure 1 represents the minimum material thickness required for electrical conductivity of a particular material and test frequencies. ~~Its value is represented in Table 1~~.

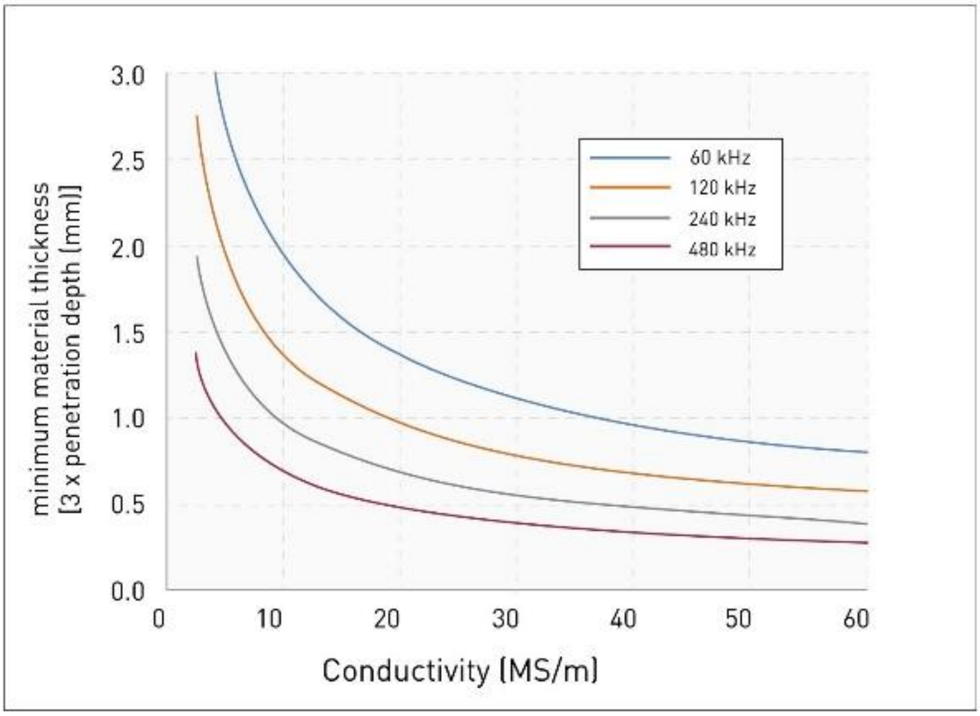

Fig1. Minimum thickness of the test object ***as a function of frequency and electrical conductivity***

A simple test to determine whether a test object meets the requirements for minimum thickness at the desired measuring frequency can be performed using the copper standard included with the instrument.

9. Apparatus

9.1 **Electronic Apparatus**— The electronic apparatus shall be capable of energizing the probe coil with alternating currents of suitable frequencies and power levels and shall be capable of sensing changes in the measured impedance of the coil. Equipment may include any suitable signal-processing device (phase discriminator, filter circuits, and so forth). The output may be displayed in either analogue or digital readouts. Readout is normally in percent IACS although it may be scaled for readings in other units. Additional apparatus, such as computers, plotters, or printers, or combination thereof, may be used in the recording of data. It shall be capable of measuring electrical conductivity as low as 1% IACS and as high as 100% IACS at resolution of 0.1% IACS.

9.2 **Probe**—Probe coil designs combine empirical and mathematical design methods to choose appropriate combinations of characteristics. The usual probe diameter ranges from 8 mm to 14 mm. The probe coil is of absolute type. For most electrical conductivity instruments, the cable connecting the coil to the instrument is an integral part of the measuring circuit and the cable length should not be modified without consulting the instrument manufacturer or manual.

9.2.1 Mechanical handling apparatus for feeding the samples or moving the probe coil, or both, may be used to automate a specific measurement. It is recommended to use appropriate fixtures to steady and stabilize the product or the probe coil to prevent variations in lift-off and subsequent variations in test results.

9.3 **Reference Standards**—Reference standards shall be made from homogeneous and non-magnetic conductive materials of electrical conductivity ranges from 1% IACS (Low Electrical Conductivity) to 100% IACS (High Electrical Conductivity). ~~same as the test material for which this reference standard is to be used. The chemical composition, heat treatment and fabrication history of the reference standard should be same as the test piece.~~ They must have a thickness equal or greater than 3 times of standard depth of penetration at the selected test frequency and a width and length equal to or greater than 2 times the probe edge effect. The edge effect will be calculated as coil diameter plus 4 times of standard depth of penetration.

9.3.1 Electrical conductivity reference standards are precise electrical standards and should be treated as such. Scratching of the surface of the standard may introduce measurement error. Avoid dropping or other rough handling of the standard. Keep the surface of the standard as clean as possible. Clean with a nonreactive liquid and a soft cloth or tissue. Store reference standards in a place where the temperature is relatively constant. Avoid thermal shocking of the reference standards or placing them where large temperature variations are present.

9.4 Selection of Test Frequency

The test frequency determines the standard depth of penetration as well as sensitivity of the test system. During Electrical Conductivity Measurements the test frequency shall be selected in such a way that the sufficient depth of the penetration could be achieved and the effect of surface roughness should not interfere the test results. Generally, the test frequency is used in the range of 5kHz to 500kHz depending upon the electrical conductivity and thickness of the material.

10. Calibration Procedure

10.1 Connect the required probe coil to the instrument.

10.2 Switch on the instrument and allow it to warm up for at least the length of time recommended by the manufacturer.

10.3 The instrument, probe, and reference standards should be standardized at room temperature (typically 20 °C).

10.4 Make all necessary setups, setting of test parameters (such as frequency etc.) and control adjustments in accordance with the manufacturer’s recommendation.

10.5 Put the probe on low conductivity sample and feed the value of the corresponding electrical conductivity in the instrument. Similarly, put the probe on high electrical conductivity sample and feed the value of the corresponding electrical conductivity in the instrument. In analogue systems, the fine tuning of the electrical conductivity setting can be obtained by adjusting the knob corresponding to higher and lower conductivity setting. In digital system, this action can be accomplished by touch/push buttons.

11. Test Procedure

After Calibration of the equipment, put the probe on unknown conductivity sample and find the value of the electrical conductivity from the equipment.

12. Verification of the standardization of the Equipment

Check the standardization at the start of the run and at least once every hour of continuous operation and at the end of a run. If there is a metal temperature change greater than 20°C, or whenever improper functioning of the system is suspected, the values of the standard reading is outside the limits, or any change of the hardware of the test set-up is done, the operator should repeat tests starting from the last passed check standardization.

13. Reporting of the Result

13.1 The written report of an electrical conductivity measurement should contain any information about the examination setup that will be necessary to duplicate the examination at the same or some other location, plus such other items as may be agreed upon between the producer and purchaser. Specific items to be recorded should be agreed upon and determined by the using parties. When specified, the manufacturer shall submit to the purchaser a test report including at least the following information:

1) Apparatus Description;
   a) Equipment type
   b) Model number
   c) Serial number
   d) Recorder type (if used);
2) Coil;
   a) Size
   b) Type.
3) Other interconnecting apparatus;
4) Reference standards;
5) Measurement frequency;
6) Description of Materials;
   a) Geometry
   b) Chemistry
   c) Heat treatment
7) Standardization method.
8) Temperature
   a) Temperature of the reference standards.
   b) Sample temperature.
   c) Ambient temperature.
9) Examination procedure.

13.2. Test Results

The report should be prepared by the testing personnel and to be issued by the competent authority.

ANNEX A

(Foreword)

Minimum specimen thickness for different Electrical Conductivity at different frequencies during electrical conductivity test by Eddy current method

S.No.	Electrical Conductivity % IACS	Specimen Thickness (mm)	Frequencies (kHz)				
			60	120	240	480	960
1	100	Standard depth of penetration δ,mm	0.27	0.19	0.13	0.10	0.07
		Specimen Thickness t,mm	0.81	0.57	0.40	0.29	0.20
2	95	Standard depth of penetration δ,mm	0.28	0.20	0.14	0.10	0.07
		Specimen Thickness t,mm	0.83	0.59	0.42	0.29	0.21
3	90	Standard depth of penetration δ,mm	0.28	0.20	0.14	0.10	0.07
		Specimen Thickness t,mm	0.85	0.60	0.43	0.30	0.21
4	85	Standard depth of penetration δ,mm	0.29	0.21	0.15	0.10	0.07
		Specimen Thickness t,mm	0.88	0.62	0.44	0.31	0.22
5	80	Standard depth of penetration δ,mm	0.30	0.21	0.15	0.11	0.08
		Specimen Thickness t,mm	0.91	0.64	0.45	0.32	0.23
6	75	Standard depth of penetration δ,mm	0.31	0.22	0.16	0.11	0.08
		Specimen Thickness t,mm	0.94	0.66	0.47	0.33	0.23
7	70	Standard depth of penetration δ,mm	0.32	0.23	0.16	0.11	0.08
		Specimen Thickness t,mm	0.97	0.68	0.48	0.34	0.24

8	**65**	**Standard depth of penetration δ,mm**	**0.33**	**0.24**	**0.17**	**0.12**	**0.08**
		Specimen Thickness t,mm	**1.00**	**0.71**	**0.50**	**0.36**	**0.25**
9	**60**	**Standard depth of penetration δ,mm**	**0.35**	**0.25**	**0.17**	**0.12**	**0.09**
		Specimen Thickness t,mm	**1.05**	**0.74**	**0.52**	**0.37**	**0.26**
10	**55**	**Standard depth of penetration δ,mm**	**0.36**	**0.26**	**0.18**	**0.13**	**0.09**
		Specimen Thickness t,mm	**1.09**	**0.77**	**0.55**	**0.39**	**0.27**
11	**50**	**Standard depth of penetration δ,mm**	**0.38**	**0.27**	**0.19**	**0.13**	**0.10**
		Specimen Thickness t,mm	**1.15**	**0.81**	**0.57**	**0.40**	**0.29**
12	**45**	**Standard depth of penetration δ,mm**	**0.40**	**0.28**	**0.20**	**0.14**	**0.10**
		Specimen Thickness t,mm	**1.21**	**0.85**	**0.60**	**0.43**	**0.30**
13	**40**	**Standard depth of penetration δ,mm**	**0.43**	**0.30**	**0.21**	**0.15**	**0.11**
		Specimen Thickness t,mm	**1.28**	**0.91**	**0.64**	**0.45**	**0.32**
14	**35**	**Standard depth of penetration δ,mm**	**0.46**	**0.32**	**0.23**	**0.16**	**0.11**
		Specimen Thickness t,mm	**1.37**	**0.97**	**0.68**	**0.48**	**0.34**
15	**30**	**Standard depth of penetration δ,mm**	**0.49**	**0.35**	**0.25**	**0.17**	**0.12**
		Specimen Thickness t,mm	**1.48**	**1.05**	**0.74**	**0.52**	**0.37**
16	**25**	**Standard depth of penetration δ,mm**	**0.54**	**0.38**	**0.27**	**0.19**	**0.13**
		Specimen Thickness t,mm	**1.62**	**1.15**	**0.81**	**0.57**	**0.40**
17	**20**	**Standard depth of penetration δ,mm**	**0.60**	**0.43**	**0.30**	**0.21**	**0.15**
		Specimen Thickness t,mm	**1.81**	**1.28**	**0.91**	**0.64**	**0.45**
18	**15**	**Standard depth of penetration δ,mm**	**0.70**	**0.49**	**0.35**	**0.25**	**0.17**

		Specimen Thickness t,mm	**2.09**	**1.48**	**1.05**	**0.74**	**0.52**
19	**10**	**Standard depth of penetration δ,mm**	**0.85**	**0.60**	**0.43**	**0.30**	**0.21**
		Specimen Thickness t,mm	**2.56**	**1.81**	**1.28**	**0.91**	**0.64**
20	**5**	**Standard depth of penetration δ,mm**	**1.21**	**0.85**	**0.60**	**0.43**	**0.30**
		Specimen Thickness t,mm	**3.62**	**2.56**	**1.81**	**1.28**	**0.91**
21	**1**	**Standard depth of penetration δ,mm**	**2.70**	**1.91**	**1.35**	**0.95**	**0.67**
		Specimen Thickness t,mm	**8.10**	**5.73**	**4.05**	**2.86**	**2.02**

$$\delta = \sqrt{\frac{\rho}{\Pi \mu f}}$$

$$\rho\ (micro - ohm - cm) = \frac{172 \cdot 41}{\sigma\ (\%IACS)}$$

$$\mu = \mu_0 \times \mu_r$$

$$\mu_r = 1$$

$$\mu_0 = 4\pi \times 10^{-7}\,\frac{\text{Henry}}{\text{meter}}$$

$$t\ (\min) = 3\delta$$