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शक्ति विद्युतीय उपकरणों के चुम्बकीय परिपथ के लिए इस्पात चद्दरों की परीक्षण विधि

(दूसरा पुनरीक्षण)

Indian Standard

METHODS OF TESTING STEEL SHEETS FOR MAGNETIC CIRCUITS OF POWER ELECTRICAL APPARATUS

(Second Revision)

(Incorporating Amendment No. 1)

ICS 77.140.50; 77.140.40; 29.040.10

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FOREWORD

This Indian Standard (Second Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Wrought Steel Products Sectional Committee had been approved by the Metallurgical Engineering Division Council.

This standard was first issued in 1955 and subsequently revised in 1963. While reviewing the standard in the light of experience gained during these years, the Committee decided to revise it to bring it in line with the present practices being followed internationally.

The main modification in this revision relates to incorporation of test methods for insulation resistance test, resistivity, ductility, density, size and shape measurement and tests on insulation coating. This modification has become necessary in view of the fact that these tests have been incorporated in all major standards of the world. All the tests are given in details so that many laboratories in this country can get guidance in installing equipment to carry out these tests.

In the preparation of this standard, assistance has been derived from the following overseas standards:

IEC 404-2 : 1978 Magnetic materials, Part 2: Methods of measuring of magnetic, electrical and physical properties of magnetic sheet and strip, issued by International Electrotechnical Commission (IEC).

DIN 50642 June 1975 Testing of metallic materials — Testing of shape variation of electrical steel sheet and strip and determination of internal stresses, issued by DIN Germany.

JIS C-2550-1986 Japanese industrial standards — Methods of tests for magnetic steel sheet and strip, issued by Japanese Standards Association.

BS 6404 : Part 2 : 1985 Magnetic materials, Part 2: Methods of measurement of magnetic electrical and physical properties of magnetic sheet and strip, issued by British Standards Institution.

BS 6404 : Section 84 : 1986 Specification for cold rolled non-oriented magnetic steel sheet and strip delivered in the finally annealed state, issued by British Standards Institution.

1991 Annual Book of ASTM Standards Section 3, Volume 03.04 Magnetic properties, metallic materials for thermostats, electrical resistance and heating contacts, issued by American Society for Testing and Materials.

This edition 3.1 incorporates Amendment No. 1 (July 2001). Side bar indicates modification of the text as the result of incorporation of the amendment.

In reporting the result of a test made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'.

Indian Standard

METHODS OF TESTING STEEL SHEETS FOR MAGNETIC CIRCUITS OF POWER ELECTRICAL APPARATUS

(Second Revision)

1 SCOPE

1.1 This standard prescribes methods of test for determining the requirements of magnetic steel sheets and strips used for the construction of magnetic circuits of power electrical apparatus.

1.2 It covers the methods for the measurement of magnetic, electrical and physical properties and insulation coating test of magnetic steel sheets and strips.

2 REFERENCES

The following Indian Standards are necessary adjuncts to this standard:

IS No.	*Title*
648 : 1994	Non-oriented electrical steel sheets and strips for magnetic circuits (*fourth revision*)
3024 : 1996	Grain oriented electrical steel sheets and strip (*first revision*)
13795 (Part 1) : 1993	Glossary of terms relating to special alloys: Part 1 Magnetic materials

3 TERMINOLOGY

3.1 For the purpose of this standard, the definitions given in IS 13795 (Part 1) : 1993 shall apply, in addition to the following.

3.2 Apparent Power, P_a — The product (volt-amperes) of the rms exciting current and applied rms terminal voltage in an electric circuit containing inductive impedance. The components of this impedance due to the winding will be linear, while the components due to the magnetic core will be non-linear. The unit of apparent power is volt-ampere VA.

3.3 Apparent Power, Specific, $P_{a\,(B,f)}$ — The value of the apparent power divided by the active mass of the specimen, that is, volt-amperes per unit mass. The values of voltage and current are those developed at a maximum value of cyclically varying induction *B* and specified frequency *f*.

3.4 Core Plate — A generic term for any insulating material, formed metallurgically or applied externally as a thin surface coating, on a sheet or strip stock used in the construction of laminated and tape wound cores.

3.5 Density — The ratio of mass to volume of material. The cgs unit is g/cm^3.

3.6 Eddy Current — An electric current developed in a material due to induced voltages developed in the material.

3.7 Electrical Steel, Grain Oriented — A flat rolled silicon-iron alloy usually containing approximately 3 percent silicon, having enhanced magnetic properties in the direction of rolling and normally used in transformer cores.

3.8 Electrical Steel, Non-oriented — A flat rolled electrical steel which has approximately the same magnetic properties in all directions.

3.9 Frequency, Cyclic, *f* — The number of hertz (cycle/second) of a periodic quantity.

3.10 Hertz, Hz — The unit of cyclic frequency, *f*.

3.11 Hysteresis Loss, Rotational — The hysteresis loss that occurs in a body when subjected to a constant magnetizing force, the direction of which rotates with respect to the body, either in continuously cyclic, or in a repeated oscillatory manner.

3.12 Insulation Resistance — The apparent resistance between adjacent contacting laminations, calculated as a ratio of the applied voltage to conduction current. This parameter is normally a function of the applied force and voltage.

3.13 Magnetostriction — The change in dimensions of a body resulting from magnetization.

3.14 Stacking Factor (Lamination Factor, Space Factor), *S* — A numeric, less than unity and usually expressed as a percentage, which is defined as the ratio of the uniform solid height h of the magnetic material in a laminated core to the actual height h' (core build-up) when measured under a specified pressure S is thus equal to the ratio of the volume of magnetic material in a uniform laminated core to the overall geometric volume in the core.

4 TEST ITEMS

4.1 The test shall be made for the following items in conformity with the provisions of Section 1 to Section 11.

4.2 Magnetic Tests

4.2.1 a.c. magnetization characteristic tests, iron loss tests and apparent power tests at commercial frequency.

4.2.2 d.c. magnetization characteristic tests.

4.3 Electrical Tests

4.3.1 *Insulation Resistance Test*

4.3.2 *Resistivity Test*

4.3.3 *Determination of Density*

4.4 Physical Tests

4.4.1 *Stacking Factor*

4.4.2 *Ductility Test*

4.4.3 *Internal Stress*

4.5 Size and Shape Measurement

4.5.1 *Size Measurement*

4.5.2 *Thickness*

4.5.3 *Width and Length*

4.5.4 *Cutting Burr Measurement*

4.5.5 *Out of Square*

4.5.6 *Flatness Measurement (Wave Factor)*

4.5.7 *Bowing or Residual Curvature*

4.5.8 *Edge Camber*

4.6 Tests on Insulation Coating

SECTION 1 MAGNETIC TESTING

5 TESTING CONDITIONS

5.1 Temperature

The magnetic tests shall be carried out at 27±5°C.

5.2 Magnetizing Condition

5.2.1 After demagnetizing the specimen, magnetization shall be conducted by applying magnetizing force to it, so that both the positive and negative maximum magnetic flux density induced in the specimen become identical. On a.c. test the discrepancy between the form factors of secondary induced voltage and sine wave shall be within ±5 percent.

6 TEST SPECIMENS

6.1 The practice to be followed for a test lot and selection and preparation of test specimens is as follows.

6.1.1 *Test Lot*

A test lot may be composed of coils or cut lengths. A test lot of coil product may consist of one or more coils having essentially the same treatment and composition.

6.1.2 *Selection and Preparation of Test Specimen*

6.1.2.1 The Epstein test sample shall be the standard specimen for determinations of the magnetic properties of flat rolled electrical steels, except when otherwise established by mutual agreement between the manufacturer and the purchaser.

6.1.2.2 The standard Epstein test specimen shall be composed of test strips preferably cut from test sheets in a manner shown in Fig. 1(a) or 1(b). One half of the strips are cut parallel and the other half cut perpendicular to the direction of rolling.

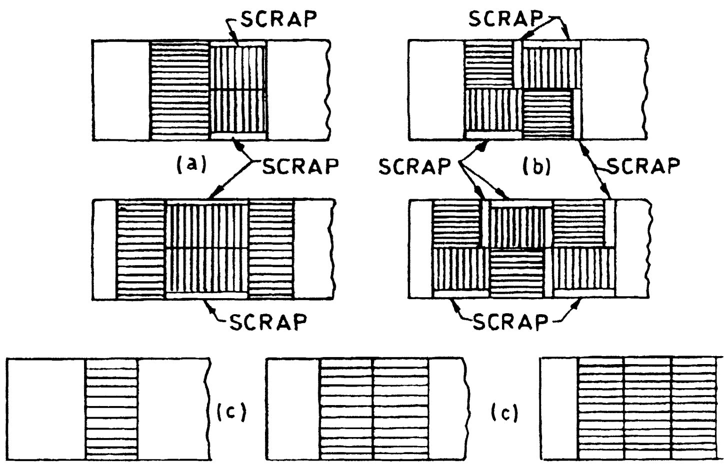

FIG. 1 SUGGESTED DISTRIBUTION OF STRIP TO BE CUT FROM SHEETS FOR MAGNETIC TESTS

6.1.2.3 When less than the total number of strips obtained from the sampled area are needed for the test specimen, the excess strips should be discarded equally from all locations in the sampled areas. For instance, if approximately one fourth of the total strips obtained in excess, every fourth strip should be discarded.

6.1.2.4 The Epstein test specimen shall consist of strips sheared or punched in a width of 30 mm and not less than 280 mm long. For ease of assembling the specimen in the test frame, it is desired to use strips slightly longer than 280 mm and a length of 305 mm is recommended.

6.1.2.5 The test strips shall be as nearly rectangular as possible and shall conform to the specified dimensions within ±0.8 mm.

6.1.2.6 The test strips shall be cut with sharp shears or dies to avoid excessive burring or distortion.

6.1.2.7 For grain oriented steel sheets, the strips shall be cut parallel to the direction of rolling according to Fig. 1c. The samples of oriented material before testing shall be stress relief annealed after cutting at a temperature of 800±20°C in a non-oxidizing, carbon free atmosphere. They shall be held at full temperature for a minimum period of 15 minutes and cooled in the furnace to below 100°C before removal.

6.1.2.8 For non-oriented steel sheets, the strips shall be cut as per **6.1.2.2** and shall be tested without any heat treatment. The test may also be carried out after ageing at a temperature of 225°C for 24 hours, if agreed upon between the manufacturer and the purchaser.

6.1.2.9 From material in coil form, prepare the test strips from test sheets cut from one or both ends of the coil.

6.1.2.10 From material in cut length form, two or more test sheets shall be taken from the test lot.

6.1.2.11 The minimum number of test pieces to be cut in the case of the standard thickness of sheet shall be as under:

Thickness of Sheet mm	*No. of Test Pieces* *Min*
1.00	12
0.65 0.50	16
0.35 0.27	20

NOTE — In no case shall the specimen consist of less than twelve strips and shall be a multiple of four.

6.1.2.12 The total weight of the sheets shall be not less than 400 g and it should be determined within ±1 g.

6.1.2.13 When the cross sectional area of sheet material test specimens is required, it shall be calculated from the measurements of weight and length using a density value in accordance with **6.1.2.14**.

6.1.2.14 *Density*

Unless otherwise specified by the manufacturer, the following densities may be assumed for calculation purposes.

Silicon Content *Percent*	*Assumed Density* g/cm^3
Up to 0.5	7.85
Over 0.5 to 2.0	7.75
Over 2.0 to 3.5	7.65
Over 3.5 to 5.0	7.55

Method of determination of the density of magnetic sheet shall be as per Section 6.

SECTION 2 STANDARD TEST METHOD FOR ALTERNATING-CURRENT MAGNETIC PROPERTIES OF MATERIALS AT POWER FREQUENCIES USING WATTMETER, AMMETER, VOLTMETER METHOD AND 25-cm EPSTEIN TEST FRAME

7 SCOPE

7.1 This test method covers tests for the magnetic properties of basic flat-rolled magnetic materials at power frequencies (25 to 400 Hz) using a 25-cm Epstein test frame and the 25-cm double- lap-jointed core with corner setting. It covers the determination of core loss, volt-amperes, rms and peak exciting current, and a.c. permeability and related properties of flat-rolled magnetic materials under a.c. magnetization.

7.2 This test method provides a test for core loss and exciting current at moderate and high inductions up to 15 kG (1.5 T) on non-oriented electrical steels and up to 18 kG (1.8 T) on grain oriented electrical steels.

7.3 The frequency range of this method is normally that of the commercial power frequencies 50 to 60 Hz.

7.4 This test method also provides procedures for calculating a.c. impedance permeability from measured values of rms exciting current and for a.c. peak permeability from measured peak values of total exciting currents at magnetizing forces up to about 150 O_e (12 000 A/m).

7.5 The specimen for this test shall be selected and prepared for testing in accordance with provisions of **6** of Section 1.

8 BASIC CIRCUIT

8.1 Figure 2 shows the essential apparatus and basic circuit connections for this test. Terminals 1 and 2 are connected to a source of adjustable a.c. voltage of sinusoidal waveform and sufficient power rating to energize the primary circuit without appreciable voltage drop in the source impedance. The primary circuit switches S_1, S_2 and S_3 as well as all primary circuit wiring should be capable of carrying very much higher currents than normally are encountered, in order to limit primary circuit resistance values that will not cause appreciable distortion of flux wave form in the specimen when relatively high non sinusoidal currents are being drawn. A primary circuit current rating of 30 A is usually adequate for this purpose. Although the current drain in the secondary circuit is quite small, the switches and wiring of these circuits should be rated for at least 10 A to ensure that the lead resistance is so small that the voltage available at terminals of all instruments is imperceptibly lower than the voltage at the secondary terminals of the Epstein test frame.

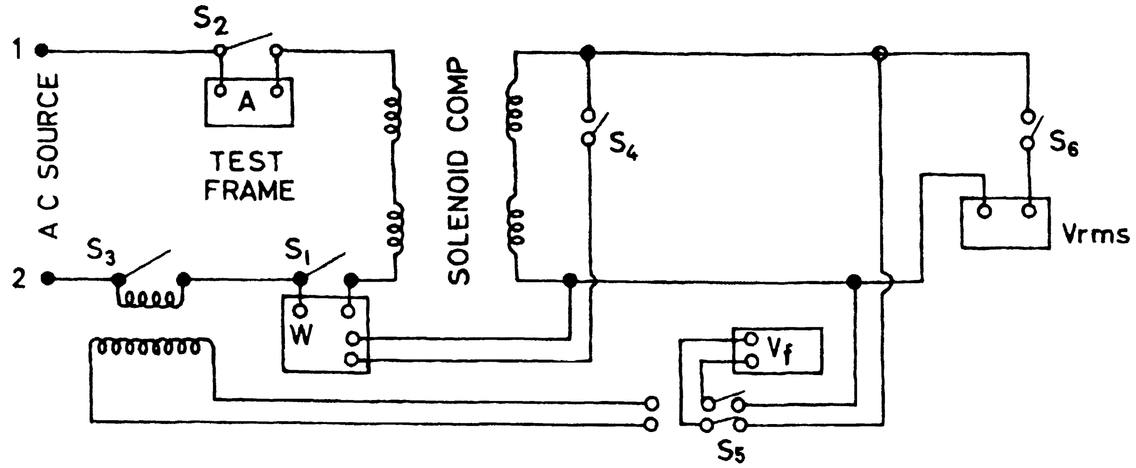

FIG. 2 BASIC CIRCUIT DIAGRAM FOR WATTMETER METHOD

9 APPARATUS

9.1 The apparatus shall consist of as many of the following component parts as are required to perform the desired measurement functions.

9.1.1 *Epstein Test Frame* (Fig. 3)

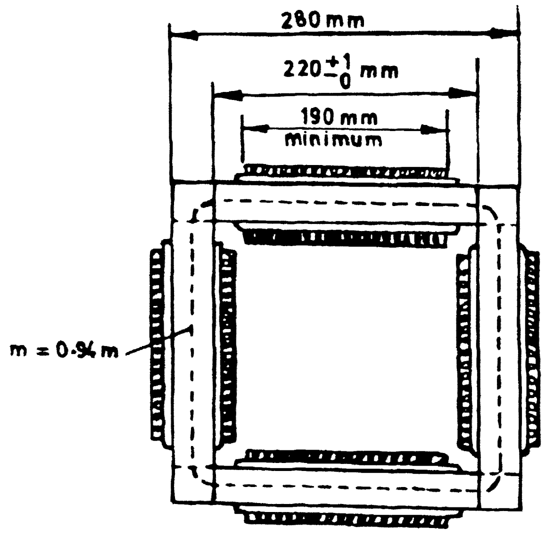

FIG. 3 25-cm EPSTEIN FRAME

9.1.1.1 The test frame shall consist of four solenoids (each having two windings) surrounding the four sides of the square magnetic circuit, and a mutual inductor to compensate for air-flux within the solenoids. The solenoids shall be wound on nonmagnetic, nonconducting forms of rectangular cross section appropriate to the specimen mass to be used. The solenoid shall be mounted so as to be accurately in the same horizontal plane, and with the centre line of solenoids on opposite sides of the square, 250±0.3 mm apart. The compensating mutual inductor may be located in the centre of the space enclosed by the four solenoids if the axis of the inductor is made to be perpendicular to the plane of the solenoid windings.

9.1.1.2 The inner or potential winding on each solenoid shall consist of one fourth of the total number of secondary turns evenly wound in one layer over a winding length of 191 mm or longer of each solenoid. The potential windings of the four solenoids shall be connected in series so their voltages will add. The outer or magnetizing winding shall consist of one fourth of the total number of primary turns evenly wound over the winding length of each solenoid. These individual solenoid windings, too, shall be connected in series so their magnetizing forces will add. The primary winding may comprise up to three layers using two or more wires in parallel.

9.1.1.3 Primary and secondary turns shall be wound in the same direction, with the starting end of each winding being at the same corner junction of one of the four solenoids. This enables the potential between adjacent primary and secondary turns to be a minimum through out the length of the winding, thereby reducing errors due to electrostatic phenomena.

9.1.1.4 The solenoid windings on the test frame may be of any number of turns suited to the instrumentation, mass of specimen, and test frequency. Windings with a total of 700 turns are recommended for tests in the frequency range of 25 through 400 Hz.

9.1.1.5 The mutual inductance of the air-flux compensating inductor shall be adjusted to be the same as that between the test-frame windings and within one turn of the compensator secondary. Its windings shall be connected in series with the corresponding test-frame windings so that the voltage induced in the secondary winding of the inductor by the primary current will completely oppose or cancel the total voltage induced in the secondary winding of the test-frame when no sample is in place in the solenoids.

9.1.2 *Flux Voltmeter*, V_f

A full wave true average responding type voltmeter, with scale reading in average volts multiplied by 1.111, so that its indications will be identical with those of true rms meter on a pure sinusoidal voltage, shall be provided for evaluating the peak value of the test induction. To produce the estimated accuracy of the test under this method the full scale meter error shall not exceed 0.25 percent (*see* Note). Meters of 0.5 percent or more error may be used at reduced accuracy. The resistance of the flux voltmeter shall not be less than 1 000 ohms per volt of full-scale indication, and should have a resistance high enough (3 000 to 10 000 ohms per volt) to avoid calibration and linearity errors but not high enough to introduce electrostatic errors if used with the mutual inductors as a peak ammeter (*see* **9.1.6**). A variable resistance, standard-ratio transformer or other variable scale multiplying device may be employed to permit the flux voltmeter to be adjusted to indicate directly in units of flux density if the combination of basic instrument and scale multiplying device conforms to the specification stated above.

NOTE — Inaccuracies in setting the test voltage produced errors approximately two times as large in the core loss. The error in exciting current at 15 kG (1.5 T) caused by voltage error may be 10 to 20 times as large as the voltage error. An effort should be made to maintain the calibration at 0.25 percent (or better) of the true voltage reading at all scale points from half-scale to full-scale deflection. Voltage scales should be such that the instrument is not used at less than half-scale deflection. Care should also be taken to avoid errors due to temperature and frequency effects in the instrument.

9.1.3 *RMS Voltmeter*, V_{rms}

A true rms-indicating voltmeter shall be provided for evaluating the form factor of the voltage induced in the secondary winding and for evaluating the instrument losses. The accuracy of the rms voltmeter shall be the same as that specified for the flux voltmeter. The resistance of the rms voltmeter shall not be less than 500 ohms per volt of full-scale indication.

9.1.4 *Wattmeter*

9.1.4.1 *Electrodynamometer wattmeter*, *W*

A reflecting type electrodynamometer wattmeter is desirable for all specimen masses and necessary for specimens lighter in mass than about 6 g/mm of strip length (*see* Fig. 1b). For specimens weighing more than this, a direct indicating low-power-factor electrodynamometer wattmeter of highest available sensitivity may be used. For this later type of instrument a 5 percent power-factor type is desirable so that readings will not have to be taken at less than 25 percent of full-scale indication. The rated accuracy of measurement of the wattmeter, at the frequency of test and for unity power-factor loads, shall not be poorer than 0.25 percent of full-scale deflection. For general testing, resistance of the potential circuit of this instrument should not be less than 100 ohms per volt full-scale for each voltage range, and the inductance of the potential circuit should be such that the inductive resistance at the test frequency will not exceed 1 ohm per 1 000 ohms of resistance of this circuit unless the potential circuit is compensated for its reactance. If tests are to be made at 15 kG (1.5 T) on 'half-and-half' grain specimen, the resistance of the wattmeter potential coil circuit must not be less than 5 000 ohms for each ohm of inductive reactance in the potential circuit unless the instrument is adequately compensated for errors due to its reactance (*see* Note 1). For tests at inductions up to 10 kG (1.0 T) the current coils of the wattmeter should not have a resistance or reactance which exceeds 1 ohm. For tests at 15 kG (1.5 T) the current coil resistance or reactance should not exceed 0.25 ohms (*see* Note 2). For power frequency testing of high loss material at any induction or for general testing at high inductions it is desirable to have the current coil resistance and reactance as low as 0.1 ohm. The current rating of the wattmeter coils for low induction testing or at moderate inductions for oriented material may be 1 or 2 ampere. Generally when testing at 15 kG or higher a current-coil rating of 5 ampere or more is required (*see* Note 3).

NOTES

1 Failure to observe these limitations may necessitate correction for phase-angle errors in the indications of the wattmeter. A variable resistance or other suitable variable-scale multiplying device may be employed to permit the wattmeter to indicate directly in watts per unit mass if the combination of the basic instrument and multiplier conforms to the specifications stated above.

2 This is necessary to avoid excessive distortion of flux waveform in the test specimen due to nonlinear impedance voltage drops in series with the primary winding of the Epstein frame.

3 This may be necessary to avoid objectionable or destructive temperature rise in the current coils. For general testing at very high inductions the wattmeter current coils should have a rating of 10 ampere or more.

9.1.4.2 *Wattmeter other than electrodynamometers*

It is anticipated that new developments in instrumentation will provide electronic, thermal, or other types of wattmeters which may be useful at very lower power factors while retaining sufficient accuracy of measurement for use under provisions of this method. When any such wattmeter has satisfactorily demonstrated its ability to meet the requirements of **9.1.4.1** and to maintain required accuracy levels of **11** it shall be acceptable for use with this method and may replace the electrodynamometer instrument.

9.1.5 *RMS Ammeter, A*

A true rms-indicating ammeter is needed if measurements of exciting current are to be made. A nominal accuracy of 1.0 percent of full-scale or better is required for this instrument. The instrument must have very low internal impedance to avoid contributing to the distortion of the flux waveform.

9.1.6 *Devices for Peak-Current Measurement*

9.1.6.1 *Mutual-inductor peak ammeter*

A means of determining the peak value of the exciting current is required if evaluation of the a.c. magnetizing force is to be made by the peak-current method. An air-core mutual inductor used in conjunction with a flux voltmeter comprise the apparatus most frequently used for this measurement at 50 or 60 Hz. Use of this device is based on the same theoretical considerations that dictate the use of the flux voltmeter on the secondary of the test frame to measure the peak inductions; namely, that when a flux voltmeter is connected to a test coil the flux voltmeter indications are proportional to the peak value of flux linking the coil. In the case of an air-core mutual inductor the peak value of its flux (and hence the indications of the flux voltmeter connected to its secondary winding) will be proportional to the peak value of its primary current. A mutual inductor used for this purpose must have reasonably low primary impedance so that its insertion will not materially affect the primary circuit conditions, and yet must have sufficiently high mutual inductance to provide a satisfactorily high voltage to the flux voltmeter for primary currents corresponding to the desired range in the magnetizing force H_p. The secondary impedance of the mutual inductor is important in relation to the current in this circuit and should be low if any significant secondary current is drawn by a low impedance flux voltmeter. In any case, the addition of the flux voltmeter should not change the "mutual inductor secondary terminal" voltage by more than 0.25 percent. The voltage waveforms are extremely peaked under normal test conditions and the flux voltmeter should be capable of handling the high crest factor. Under sinusoidal calibration procedures as indicated, the crest factor capabilities of the meter are not checked, and thus care should be exercised that the crest capabilities are adequate. It is important that the mutual inductor to be located in the test equipment in such a position that its windings will not be linked by a.c. leakage flux from other apparatus. Care should be taken to avoid locating it so close to any magnetic material or any conducting material that its calibration and linearity might be affected.

9.1.6.2 *Electronic peak-to-peak ammeter*

Even at commercial power frequencies there can be appreciable error in the measurement of H if winding capacitances and inductances and flux voltmeter errors begin to become important at some of the higher harmonic frequencies occasioned by the extremely nonsinusoidal character of the voltage waveform induced in the secondary of the mutual inductor by the nonsinusoidal exciting-current waveform. In such cases the crest or peak-current measurements may be made with an electronic voltmeter whose indications are proportional to the peak-to-peak value of the voltage drop that results when the exciting current flows through a low value of standard resistance connected in series with the primary winding of the test-frame. This electronic peak-to-peak reading voltmeter should have a nominal full-scale accuracy (*see* Note) of at least 3 percent at the test frequency and be able to accommodate voltages with a crest factor of up to approximately 5. Care must be exercised that the standard resistor (usually in the range 0.1 to 1.0 ohm) carrying the exciting current has adequate current carrying capacity and is accurate to at least 0.1 percent in value. It must have negligible temperature and frequency characteristics under the conditions applying in this method. If desired, the value of the resistor may be such that the peak-reading voltmeter indicates directly in terms of H, provided that the resistor otherwise confirms to the limitations stated above. Normally this resistor will replace the mutual inductor in the circuit of Fig. 2 and the shorting switch S_3 is used to remove this extra resistance from the primary circuit when not in use.

NOTE — Because electronic voltmeters are more subject to change of calibration than conventional instruments, they should be used only where means is also provided for frequent and convenient checking of their calibrations to ensure maintenance of the accuracy requirements.

9.1.7 *Power Supply*

An a.c. power supply capable of satisfying the magnetizing condition as given in **10.4** shall be used. The stability of voltage and frequency while testing shall be within ±0.2 percent.

10 PROCEDURE

10.1 Prior to testing, check the specimen strip for length to see that they conform to the desired length to within 0.8 mm. Also check the specimen to see that no dented, twisted, or distorted strip has been included. Strips having readily noticeable shearing burrs also may be unsuitable for testing. Weigh the specimen on a scale or balance capable of determining the mass within an accuracy of 0.1 percent.

10.2 Divide the test specimen strips into four groups containing equal numbers of strips having very closely the same mass, for testing. Insert the strips (always a multiple of four in number) into the test-frame solenoids one at a time, starting with one strip in each of two opposite solenoids and then inserting a strip into each of the other two solenoids so that these later strips completely overlap the former tap at the four corners (*see* Fig. 4). This completes one layer of strips constituting a complete flux path with four overlapped joints. Build up successive layers in the same fashion until the specimen is completely assembled. With specimens cut half with and half across grain, arrange all the parallel or “with grain” strips in two opposite solenoids and all the cross-or transverse-grain strips in the other two opposite solenoids.

10.3 If the specimen strips are reasonably flat and have a reasonable area of contact at the corners, a sufficiently low reluctance is usually obtained without resorting the pressure on the joints. When the joints are unavoidably poor, the use of light pressure on the joints, with the use of nonmagnetic corner weights of about 200 g, is permissible although it may introduce some additional stresses in strain-sensitive materials.

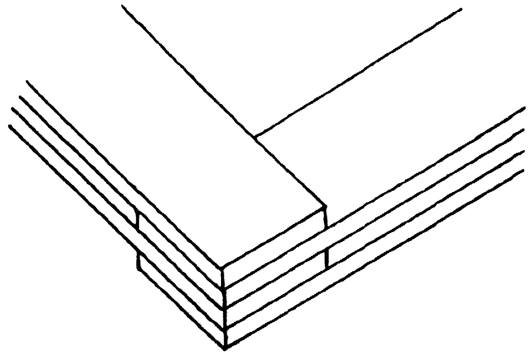

FIG. 4 DOUBLE-LAPPED JOINTS

10.4 Demagnetization

When measurements of any magnetic property are to be made at inductions below 10 kG (1.0 T), first demagnetize the specimen. Accomplish this by initially applying a voltage sufficient to magnetize the specimen to an induction above the knee of its magnetization curve (where the exciting current increases sharply for small increase in induction) and then decrease the voltage slowly and smoothly (or in small steps) to a very low induction. After this demagnetization, make tests immediately (to obtain a test value within 2 or 3 minutes) for the desired test points. Make tests at several values of induction in order of increasing induction values. Demagnetization may often be omitted for the test frequency of 50 H_z.

10.5 With the required apparatus connected as in Fig. 2 and with terminals 1 and 2 connected to the power source, then with switches S_2, S_3 and S_4 closed, S_5 closed to the test frame size, and S_1 and S_6 open, adjust the voltage of the power supply to a point where the flux voltmeter indicates the value of voltage calculated to give the desired test induction in accordance with the equation of **11.1**. Because the action of the air-flux compensator causes a voltage equal to that which would be induced in the secondary winding by the air-flux to be subtracted from that induced by the total flux in the secondary, the induction calculated from this voltage will be the intrinsic induction $B_i = (B - \mu_o H_p)$. In most cases the values of intrinsic induction, B_i, are not sufficiently different from B to require that any distinction be made. Where $\mu_o H_p$ is no longer insignificantly small compared to B_i, as at very high inductions, determine the value of B by adding to B_i either a measured value of $\mu_o H_p$ or a nominal value known to be reasonably typical of the class of material being tested.

10.6 Core Loss

When the voltage indicated by the flux voltmeter has been adjusted to the desired value, read the wattmeter. Some users, particularly those having wattmeters compensated for their own losses (or burden), will desire to open switch S_5 to eliminate the flux voltmeter burden from the wattmeter indication others will likely choose to have S_5 and S_6 closed when measuring the losses, so that all instruments may be read at the same time. In the later case the combined resistance load of the flux voltmeter, rms voltmeter, and potential circuit of the wattmeter will constitute the total instrument burden on the wattmeter. Exercise care so that the combined current drain of the instruments does not cause an appreciably large voltage drop in the secondary circuit resistance of the test-frame. In such a case the true induction in the specimen may be appreciably higher than is apparent from the voltage measured at the secondary terminals of the test-frame. In any event, power due to any current drain in the secondary circuit at the time of reading the wattmeter must be known so it can be subtracted from the wattmeter indications to obtain the net watts due to core loss.

10.7 Obtain the specific coreloss of the specimen in watts per unit mass at a specified frequency by dividing the net watts by that portion of the mass of the specimen constituting the active magnetic flux path (which is less than the mean geometric path length) in the specimen. Equations and instructions for computing the active mass of the specimen and the specific coreloss are given in **11.2**.

10.8 Measure the rms value of the secondary voltage by having both S_5 and S_6 closed, and the voltage adjusted to indicate the correct value of flux volts. On truly sinusoidal voltage both voltmeters will indicate the same voltage, showing that the form factor of the induced voltage is 1.111. When the voltmeters give different readings, the ratio of the rms value to that indicated by the flux voltmeter reveals the ratio by which the form factor of the induced voltage deviates from the desired value of 1.111. Determining the induction from the readings of flux voltmeter assures that the correct value of peak induction is achieved in the specimen, and hence that the hysteresis component of the coreloss is correct even if the wave form is not strictly sinusoidal; but the eddy-current component of the coreloss, being due to current resulting from a non-sinusoidal voltage induced in the cross section of the strip, will be in error depending on the deviation of the induced voltage from the desired sinusoidal wave shape. This error in the eddy-current component of loss can be readily corrected by calculations based on the observed form factor and the approximate percentage of eddy-current loss for the grade of material being tested if the correction is reasonably small. The equations involved in determining this correction is given in **11.3**.

10.9 RMS Exciting Current

Measure the rms exciting current when required, by having S_1 and S_3 closed; S_2, S_4, and S_6 open; and S_5 closed to the test-frame side; then with the ammeter on a suitable scale range, adjust the voltage to the correct flux voltmeter for the desired test induction. When the setting of voltage is correct, open S_5 and read the ammeter with no current drain in the secondary circuit. If S_5 is kept closed to monitor the induction during the current reading the current drain of the flux voltmeter will be included in the ammeter indication. If exciting current is to be reported in terms of ampere-turns per unit path length, volt-amperes per unit mass, or permeability from impedance, calculate the values of these parameters from the equation given in **11.4**.

10.10 Permeability

When permeability from peak current is required, determine the peak value of the exciting current for a given induction by having S_3 open to insert the primary of the mutual inductor, S_1 and S_2 closed to protect the ammeter and wattmeter from the possibility of excessive currents. S_4 and S_6 open to minimize secondary loading, and S_5 at first closed to the test-frame side. Then adjust the voltage to the current value for the desired induction, at this point through S_5 to the mutual inductor side to observe the corresponding value of flux volts (E_{fm}) at the secondary of the mutual inductor. For use in this manner at full accuracy the flux voltmeter must be such that the restrictions of **9.1.6.1** are met. Equations involved in the determination of peak current and H_p by the mutual inductor method are given in **11.6**.

10.10.1 Various types of a.c. permeability may be determined from measurements described in these methods. It should be understood that these a.c. permeabilities are in reality mathematical definitions each based on different specified assumptions. Therefore their individual values may differ considerably from each other and from the normal d.c. permeability, μ.

10.11 If the peak reading voltmeter and standard resistors are used instead of the mutual inductor and flux voltmeter for determining peak current, follow the same procedure as for the mutual inductor method except use switch S_5 only on the test-frame side because a separate meter indicates the peak current value. Equations involved in the determination of peak current and H_p by the peak-reading voltmeter method are given in **11.6**.

11 CALCULATIONS

11.1 Calculate the value of the flux voltage, E_f in volts, at the desired test induction in the specimen (when corrected for flux due to H in the material and in the air space encircled by the test winding through the use of the required air-flux compensator) in accordance with the following basic equation.

$$E_f = 4.443\ B_i\ AN_2 f$$

where

- B_i = maximum intrinsic flux density, in tesla (T);
- A = effective cross-sectional area of the test specimen in square metres (m^2);
- N_2 = number of turns in secondary winding, and
- f = frequency, in cycles per second (H_z).

In the case of Epstein specimens, where the total number of strips is divided into four equal groups comprising the magnetic circuit, the mass of the specimen in each of the four legs of the magnetic circuit becomes m/4, and the effective cross-section, A in square metres, of each leg is:

$$A = m/4l\rho$$

where

- m = total mass of specimen strip in kg,
- l = length of specimen strips in m (usually 0.28 or 0.305m), and
- ρ = standard assumed density of specimen material in kg/m^3.

Then, in the Epstein frame:

$$E_f = (\ 1.111 B_i\ m N_2 f\ )/l\rho$$

For testing of Epstein specimen at 50 Hz and a secondary winding of 700 turns the equation simplifies to:

$$E_f = (3.888 \times 10^4 B_{im})/l\rho$$

11.2 Core Loss Calculation

To obtain the specific core loss of the specimen in watts per unit mass, it is necessary to subtract all secondary circuit power included in the wattmeter indication before dividing by the active mass of the specimen, so that for a specific induction and frequency the specific core loss in watts per kg is as follows:

$$P_{c(B\ ;\ f)} \text{ or } P_{c/m} = (\ W - E^2/R\ )/m_1$$

where

- W = watts indicated by the wattmeter,
- E = rms volts for the secondary circuit,
- R = parallel resistance of wattmeter potential circuit and all other secondary loads in ohms, and
- m_1 = active mass in kg.

In the 25-cm Epstein frame it is assumed that 0.94 m is the effective magnetic path with specimen strips 0.28 m or longer. For the purpose of computing coreloss the active mass m_1 of the specimen (less than the total mass) is assumed to be as follows:

$$m_1 = 0.94 \text{ m}/4l = 0.235 \text{ m}/l$$

where

- m = the total specimen mass in kg, and
- l = actual strip length in m.

The equation giving the specific core loss in watt per kilogram of Epstein specimens then becomes;

$$P_{c(B\ ;\ f)} = (\ W - E^2/R\ )1/0.235\ m$$

11.3 Form Factor Correction

The percent error in form factor is given by the following equation:

$$F = (100\ E/E_f) - 100$$

assuming (*see* Note 1) that:

Observed $P_{c(B\ ;\ f)}$ = [(corrected $P_{c(B\ ;\ f)}$)/100]h + (corrected $P_{c(B\ ;\ f)}$)Ke/100

The corrected coreloss, which shall be computed when F is greater (*see* Note 2) than ±1 percent is:

Corrected $P_{c(B;f)}$ = (observed $P_{c(B;f)}$)100/($h + Ke$)

where

- Observed $P_{c(B;f)}$ = specific core loss calculated by the equations in **11.2**,
- h = percentage hysteresis loss at induction B,
- e = percentage eddy-current loss at induction B, and
- K = $(\ E/E_f\ )^2$

Obviously, $h = 100 - e$ if residual losses are considered negligible.

The value of h and e in the above equation are not critical when waveform distortion is low. Typical values of eddy current loss at 50 Hz for the common classes of materials, strip thicknesses and specimen form are shown in Table 1.

NOTES

1 In determining the form factor error it is assumed that the hysteresis component of core loss will be independent of the form factor if the maximum value of induction is at correct value (as it will be if a flux voltmeter is used to establish the value of the induction) but that the eddy-current component of core loss, being the function of the rms value of the voltage, will be in error for nonsinusoidal voltages. While it is strictly true that frequency or form factor separations do not yield true values for the hysteresis and eddy-current components. Yet they do separate the core loss into two components, one which is assumed to vary as the second power of the form factor and the other which is assumed to be unaffected by form factor variations. Regardless of the academic difficulties associated with the characterizing these components as hysteresis and eddy-current loss, it is observed that the equation for correcting core loss or waveform distortion of voltage based on the percentages of first-power second-power of frequency components of the core loss does accomplish the desired corrections under all practical conditions if the form factor is accurately determined and the distortion not excessive.

2 It is recommended that tests made under conditions where the percent error in form factor, F, is greater than 10 percent be considered as likely to be in error by an excessive amount, and that such conditions be avoided.

Table 1 Eddy-Current Loss
(*Clause* **11.3**)

Material	Specimen	Assumed Eddy-Current Loss, Percent at 50Hz for Strips Thicknesses				
		0.27 mm	0.30 mm	0.35 mm	0.50 mm	0.65 mm
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Nonoriented	Half Longitudnal and Half Transverse	—	—	20	30	40
Nonoriented	Longitudinal	—	—	25	35	45
Oriented	Longitudinal	50	50	60	—	—

11.4 RMS Exciting Current

RMS exciting current is often normalized for circuit parameters by converting to the following forms:

RMS exciting force, $N_1 I/l_1 = N_1 I/0.94$
$= 1.064 N_1 I$, A/m or

Apparent a.c. magnetizing force, $H_z = \sqrt{2}\, N_1 I/l_1$
$= 1.504 N_1 I$, A/m

where

N_1 = number of turns in primary winding,
I = rms value of exciting current, and
H_z = apparent a.c. magnetizing force A/m.

For the 700-turn Epstein frame,

Apparent a.c. magnetizing force, $H_Z = 1053.I$, A/m
Specific exciting power, $P_{(z\,;\,f)} = EI/m_1$, exciting rms VA/kg.

where

m_1 = active specimen mass in kg, and
I = rms in amperes.

11.5 Permeability

11.5.1 For various types of applications, certain types of a.c. permeability data (in *H*/*m*) are more useful than others.

11.5.2 One type of a.c. permeability directly related to the rms exciting current (or rms excitation) or a.c. impedance is characterized by the symbol μ_z and is computed as follows (*see* Note 1):

$$\mu_z = B_i/H_z = 0.665\, B_i/N_1 I$$
$$= (0.950 \times 10^{-3}) B_i/I \text{ for the700 turn-frame}$$

where

B_i = Teslas, and
I = rms amperes (*see* Note 2).

NOTES

1 For simplification and convenience in the calculation of a.c. permeabilities the value of B_i is used to replace B_m in the permeability equation. This entails no loss of accuracy until $\mu_o H_p$ becomes appreciable in magnitude when compared to the value of B_i. If greater accuracy is essential, B_m or ($B_i + \mu_o H_p$) should be used to replace B_i in these equations. The magnetic constant μ_o is equal to 4p × 10^{-7}H/m.

2 H_z is computed from the rms value of the complex exciting current by assuming a crest factor of $\sqrt{2}$. Thus it is based on a sinusoidal current having a rms value equal to the rms value of the complex current.

11.5.3 For control in the production of magnetic materials, it is often desirable to determine an a.c. permeability value that is more directly comparable to the d.c. permeability of the specimen. This is accomplished by evaluating H_p from the measure peak value of the exciting current at some value H_p sufficiently above the knee of the magnetization curve that the component of the exciting current is appreciably greater than the core-loss component. Such a test point for many commercial materials is an H_p value of 796 A/m. Permeability determined in this way is characterized by the symbol μ_p, and is computed as follows (*see* Note 1):

$$\mu_p = B_i/H_p$$

where

H_p = peak exciting magnetizing force evaluated from measurements of peak current made either with the permeability-inductor or peak-reading-voltmeter methods [*see* **9.1.6.1** and **9.1.6.2**] and in accordance with the equation in **10.6**.

11.6 H_p from Peak Exciting Current

To evaluate peak exciting current (or peak exciting magnetizing force, H_p) by the mutual-inductor method, the relationship between secondary flux volts and peak value of primary current for the mutual inductor must be established at the desired frequency. This must be done by passing a sinusoidal current through the primary of the mutual inductor and reading the resulting “open-circuit” secondary flux volts, E_{fm} with a flux voltmeter of very high impedance. Then a calibration constant can be established such that, for the frequency of calibration:

$$K_m, \text{ flux } V/\text{peak } A = E_{fm}/I_p = E_{fm}/I\sqrt{2}$$

where

I_p = peak value, and

I = rms value of the calibrating sinusoidal current.

Then, at the calibration frequency:

$$H_p\text{,A/m} = N_1 I_p/l_1 = N_1 E_{fm}/0.94K_m$$
$$= 1.064 N_1 E_{fm}/K_m = 744.7(E_{fm}/K_m)$$

for the 700-turn test frame. Often the actual mutual inductance of the inductor is known from a.c. bridge or d.c. ballistic measurements. In that case, it can be shown that:

$$E_{fm}\text{, flux } V = 4.443 f L_m I_p$$

where

L_m = mutual inductance in Henry, and

$$H_p\text{,A/m} = N_1 E_{fm}/4.443 f L_m l_1 = 0.2394 N_1 E_{fm}/f L_m$$

If L_m is made exactly 33.52 mH, then for test at 50 Hz in the 700-turn Epstein frame:

$$H_p = 100\ E_{fm}$$

11.6.1 The magnetizing force from the peak value of the exciting current may also be determined by the peak-reading voltmeter method that involves the measurement of the peak value of voltage drop across a small resistor carrying the exciting current. The relationship between H_p, the peak voltage across the standard resistor, R_o, and peak exciting current I_p is:

$$E_p = R_o I_p \text{ or } I_p\text{,}A = E_{p\text{-}p}/2R_o$$

where

$E_{p\text{-}p}$ = peak to peak value in volts of the symmetrical voltage drop across R_o.

The magnetizing force from peak exciting current is then:

$$H_p\text{,A/m} = N_1 E_{p\text{-}p}/2R_o l_1 = 0.5319 N_1 E_{p\text{-}p}/R_o$$

If the standard resistor is made exactly 0.3723 ohms, then for tests at all frequencies in the 700-turn Epstein frame,

$$H_p = 1\,000.E_{p\text{-}p}$$

In **11.6**, the permeability from peak exciting current will be (*see* Note 1 of **11.5.2**);

$$\mu_p = B_i/H_p$$

12 PRECISION AND BIAS

12.1 This is a basic method and although its true bias is not known it is assumed to be the same as its precision.

12.2 Precision of core loss test at 50 Hz is estimated to be within 1 percent for nonoriented materials core loss at 10 kG (1.0 T) and for oriented material at 15 kG(1.5 T). Precision at 15 kG(1.5 T) on nonoriented material is estimated at ±3 percent. The precision of exciting current measurement is estimated at ±5 percent at commercial power frequencies.

13 AGEING TEST

13.1 The samples shall be subjected to accelerated ageing test for 24 hours at a temperature of 225°C.

13.2 Subject to agreement, the ageing test shall be performed for 600 hours at a temperature of 100°C. Intermediate measurements can be made after 200 and 400 hours in order to ensure that the ageing has finished at the end of 600 hours.

SECTION 3 STANDARD TEST METHOD FOR DIRECT-CURRENT MAGNETIC PROPERTIES OF MATERIAL USING THE BALLISTIC METHOD

14 SCOPE

14.1 This test method covers d.c. ballistic testing for the determination of basic magnetic properties of materials in the form of double lapped testing cores. It includes tests for normal induction and hysteresis taken under conditions of steep wave front reversals of the direct-current magnetizing force.

14.2 This test method shall be used in conjunction with Section 1.

14.3 This test method is suitable for a testing range from very low magnetizing forces up to 200 *O*e or more (15.9 kA/m or more). The lower limit is determined by integrator sensitivity and the upper limit by heat generation in the magnetizing winding. Special techniques and short duration testing may extend the upper limit of magnetizing force.

14.4 Testing under this test method is inherently more accurate than other methods. When specified dimensional or shape requirements are observed, the measurements are a good approximation to absolute properties. Test accuracy available is primarily limited by the accuracy of instrumentation.

14.5 This test method permits a choice of test specimen to permit measurement of properties in any desired direction relative to the direction of crystallographic orientation without interference from external yoke system.

14.6 The acceptable minimum width of strip used in such test specimens is also sensitive to the material under test.

15 APPARATUS

15.1 Epstein Test Frame — Same as **9.1.1**.

15.2 d.c. Power Supply

The preferred source of d.c. current is high quality linear power supply of either unipolar or bipolar operation. The power supply must exhibit high stability and very low ripple in order to achieve the most accurate results. Programmable bipolar operational amplifier power supplies are satisfactory for this type of testing. Other stable source of d.c. current such as storage batteries is permitted.

15.3 Main-Current-Control Rheostat, R_1

When nonprogrammeable sources of d.c. current such as storage batteries are used, rheostats must be used to control the current. These rheostats must have sufficient power rating and heat-dissipating capability to handle the largest test current without undesirable changes in resistance and, therefore, magnetizing current during conduct of the test.

15.4 Hysteresis-Current-Control Rheostat, R_2

The hysteresis-current-control rheostat, when required, must have the same power rating and resistance as the main-current-control rheostat.

15.5 Ammeter, *A*

Measurement of the magnetizing current can be accomplished with either a d.c. ammeter or a combination of a precision shunt resistor and d.c. voltmeter. The meters and shunt resistor, if used, must have an accuracy of atleast 0.25 percent. To improve test accuracy multirange digital ammeters or voltmeters are preferred. Autoranging capability is desirable for convenience but is not essential for this test method. If analog meters are used, the ranges must be such that all test readings are made in the upper two-thirds of the scale.

15.6 Reversing Switch, S_1

Due to the low resistance nature of the magnetizing circuit, it is imperative that high quality switches be used. Changes in switch resistance upon reversal will cause deviation from the cyclically magnetized condition which if excessive will impair test accuracy and precision. Experience has shown that mercury switches are the best suited for this application. Knife blade switches or mechanical or electrically operated contactors can also be used provided the requirement for uniform and equal contact resistance can be maintained. Due to the presence of leakage currents in the open condition, solid state relays are not permitted. The difficulties inherent in the use of main current reversing switches can be minimized by use of linear power supplies capable of accepting a remote programming signal. Such power supplies are permitted provided that the magnetizing current is equal (to within ±0.1 percent) in either polarity when normal induction testing is conducted, current reversals can be conducted with no overshoot or oscillation and the magnetizing current is truly zero for the zero current programming signal.

15.7 Hysteresis Switch, S_2 (When Required)

This switch should conform to requirements given in **15.6**.

15.8 Integrator, *F*

Due to their superior accuracy, stability and ease of operation, electronic charge integrators are the preferred means of measuring magnetic flux. Integrators utilizing either operational amplifier and capacitor feedback (analog integrator) or pulse counting are permitted. The accuracy of the integrator must be better than 1 percent full scale. If analog display meters are used to read the value of flux, the measurement should be made on the upper two-thirds of the scale. Analog integrators must have drift adjust circuitry and the drift should not exceed 100 Maxwell-turns (10^{-6} Wb turns) per minute on the most sensitive range. It is also desirable that the integrator have appropriate scaling circuitry to permit direct reading of either flux (j) or flux density (B). Ballistic galvanometers or moving coil fluxmeters are allowed provided the 1 percent full scale accuracy requirement is met.

15.8.1 By agreement between the parties, a ballistic galvanometer or charge integrator may replace the flux meter.

15.8.2 When a Ballistic Galvanometer is used, this should be of periodic time not less than 7 seconds.

16 CALIBRATION

16.1 Calibration of Integrator

Practical operating experience has shown that provided a proper warm up period is allowed, electronic indicators require infrequent calibration and unlike ballistic galvanometers, calibration is not an integral part of this test method. When calibration is required it can be accomplished with either a mutual inductor or a volt-second source. Due to their traceability to the fundamental units of voltage and time, volt-second sources are the preferred means of calibration. The accuracy of either the mutual inductor or volt-second source must be better than the rated full scale accuracy of the integrator.

16.2 Calibration of Ballistic Galvanometer

The galvanometer scale and B-circuit may be calibrated using current reversals in the mutual inductor. The following equation shall be used to determine the calibration values:

$$I_c = BNA/(L_m \times 10^5)$$

where

- I_c = current required for reversal in the primary of the mutual inductor L_m to calibrate the B-circuit for a desired deflection in A,
- B = flux density in the test specimen at calibrated deflection in G,
- N = number of turns in B-sensing coil,
- A = cross sectional area of test specimen in cm^2, and
- L_m = value of calibrating mutual induction in units of mH.

The equation can also be written as.

$$I_c = \text{j } N/(L_m \times 10^5)$$

where j = BA or total magnetic flux, M_x

16.2.1 Using the above equation substitute in the value of flux density B, which corresponds to the desired calibration flux density and the values of the specimen area turns and mutual inductance. This gives the value of current which must be reversed in the mutual inductor. Set this value of current through the mutual inductor and observe, the galvanometer deflection on current reversal. The value of the calibrating resistor is then adjusted to make the galvanometer deflection on current reversal swing from zero to the desired scale deflection for the calibrated deflection point. Usually the scale is calibrated to make the deflections on reversal equal to the B value of calibration or some simple multiplier of it.

16.3 For basic material evaluation the galvanometer shall be calibrated with sufficient number of current values to provide a calibration curve which is accurate to 0.1 percent of full scale or 0.2 percent of smallest scale division. When desired because of non linearity or other reasons the test deflection points may be calibrated independently without completing a full scale calibration.

17 PREPARATION AND ASSEMBLY OF TEST SPECIMENS

17.1 The test specimen shall be cut from the sheet selected at random from the batch of 5 tonnes or part thereof to be tested. A specimen shall have the same width as the Epstein test specimen. For non-oriented sheets, one half of pieces shall be cut parallel to and the other half perpendicular to the direction of rolling as given in Fig. 1a and 1b. For oriented sheets the pieces shall be cut parallel to the direction of rolling as shown in Fig. 1c. The total number of test pieces taken for this test shall not be less than 12.

17.2 All the strips shall be cut from a single sheet and shall be distributed symmetrically over the entire area of the sheet as far as practicable.

17.3 The strip shall be weighed accurately before assembling and their mean cross section calculated from the formula:

$$A = m/\text{r } l$$

where

- A = mean cross section of the test strips in m^2,
- m = total mass of the strips in g,
- r = density in g/m^3, and
- l = mean length of the test strips in m.

18 PROCEDURE

18.1 In Fig. 5 the d.c. power source supplies magnetizing current measured by ammeter A. Rheostats R_1 and R_2 and switches S_1 and S_2 determine the magnitude and direction of the current as required by the various operations. In general, three types of switching operation are required in ballistic testing. One is reversal magnetizing-current direction without change of magnitude as required for establishing a cyclically magnetized condition and in normal induction tests. This is accomplished by throwing switch S_1 from one side to other. A second is reduction of magnitude of magnetizing current without change of direction. This operation is required to measure points on the hysteresis loop in the first quadrant. This is done by opening switch S_2. The third operation combines reversal of magnetizing current direction with a reduction in magnitude. This operation is required to measure points on the hysteresis loop in the second and third quadrants. Obtain this reversal and reduction by simultaneously throwing switch S_1 from one side to the other and opening switch S_2. Use care to be sure S_2 is opened before S_1 is reclosed for reversal. When determining the hysteresis loop, switches S_1 and S_2 must be operated to traverse the loop in the same direction between successive measurements so as to preserve the cyclically magnetized state of the test specimen.

18.2 Demagnetize the test specimen immediately prior to testing. To demagnetize with direct current, first establish a magnetizing force sufficiently large to cause the flux density in the specimen to reach a value greater than the knee of the normal induction or magnetization curve. Then slowly reduce the magnetizing current to zero while simultaneously operating the reversing switch at one half second or longer intervals. An auxiliary circuit using a time delay relay to effect switch reversal will make this operation more reproducible and less tedious. When the test specimen consists of thin strip (less than 0.001 m thick) alternating current demagnetization using 50 Hz or lower frequency and autotransformers can be used.

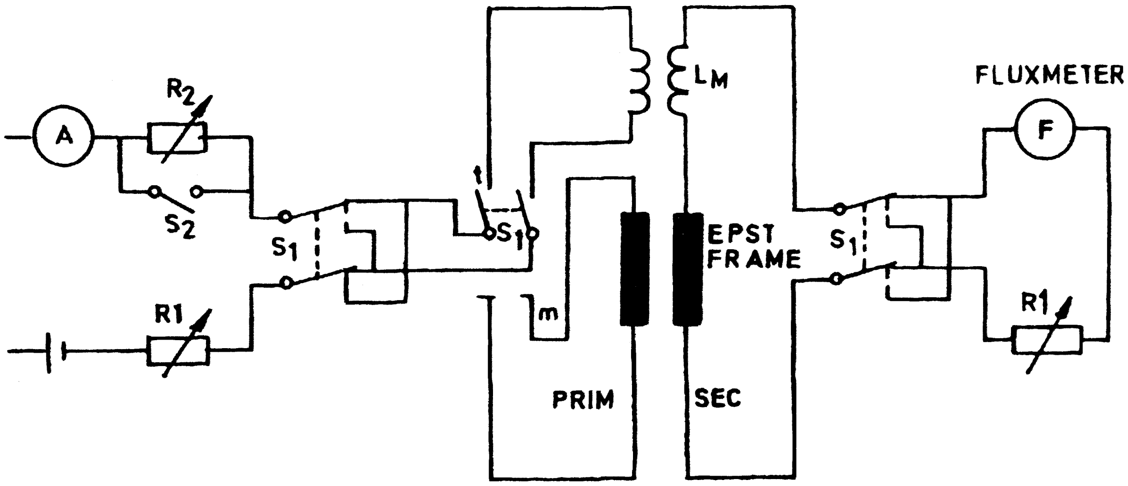

FIG. 5 CIRCUIT FOR D.C. TESTING

18.3 To obtain the flux density (B) corresponding to a specific magnetizing force (H), establish the proper magnetizing current using equation 1, cycle the reversing switch several times to establish the cyclically magnetized condition, zero the integrator and execute the proper switching procedure as found in **18.1**. The value of the flux or flux density can then be computed from the integrator reading. Additional test points on the normal induction curve can be obtained without demagnetization if they are obtained in ascending order of B or H. Otherwise it is necessary to demagnetize prior to additional testing.

18.4 To obtain the magnetizing force corresponding to a specific flux density, a procedure similar to **18.3** is used with the exception that the magnetizing current, and therefore magnetizing force must be found by trial and error. If the specified flux density is exceeded, demagnetization is usually required before proceeding further unless operating at very low flux densities.

18.5 Electronic integrators do not determine flux densities directly, rather the change in flux linkages (N2_o) is measured. This result is converted to changes in flux density by division by the specimen cross-sectional area A, and number of secondary turns, N_2. To determine the actual value of flux density the starting or reference points must be known. In the case of normal induction or magnetization curve measurements, it is customary to zero the integrator and measure the change in flux density for a fully reversed change in magnetizing current. In this instance, the true value of flux density is one half of the total change in flux density. For hysteresis loop determination, the integrator is zeroed at the point of maximum magnetization. The resulting change in flux density is equal to the difference in flux density between the point of maximum magnetization current and the point corresponding to the hysteresis loop measurement current.

19 CALCULATION

19.1 The mean magnetizing force applied to the test specimen by the current through the magnetizing coil is determined from the equation:

$$H = NI/l_1 \qquad \text{... (1)}$$

where

H = magnetizing force, A/m

N = number of turns in magnetizing coil N_1,

I = current through the magnetizing coil in A, and

l_1 = mean magnetic path length in m.

19.2 The Epstein test frame coils are built considerably larger than the test specimen cross sectional area. To avoid the need for manual air-flux correction a compensating mutual inductor is built into the test-frame. This means that the flux density measurements are intrinsic flux density, B_i, measurements. To obtain normal flux density, B, the following equation must be used:

$$B = B_i + \mu_o H \qquad \text{... (2)}$$

where

B = normal flux density of test sample in T,

B_i = intrinsic flux density of test sample in T,

H = magnetizing force, A/m, and

μ_o = magnetic constant of free space (in SI system μ_o = 4 p × 10^{-7} H/m).

19.3 Permeability is calculated as follows:

$$\mu = B/H = (B_i/H) + \mu_o \qquad \text{... (3)}$$

where μ = normal permeability, H/m.

20 REPORT

20.1 When normal induction (flux density) values or hysteresis-loop points have been measured for the purpose of reporting basic material properties the following shall be reported along with the test data.

20.2 Heat treatment or other processing applied to the test specimen prior to testing.

20.3 When permeability is reported, the corresponding values of B or H must be reported.

20.4 When hysteresis-loop properties are reported, the values of peak magnetizing force or peak flux density used shall be reported.

20.5 When saturation or other flux density values are reported, the value of magnetizing force must be reported.

21 PRECISION AND BIAS

21.1 The accuracy of determining magnetizing force H is usually dependent on the accuracy of current measurement, and ability to maintain identical current after reversal and in the accuracy of determining magnetic path length. For the Epstein frame, due to corner joints, there is some uncertainty as to the true path length, the determination of H will be within ±2.0 percent.

21.2 The accuracy of determining flux density, B, is usually dependent on the quality of integrator calibration, on the uniformity of material and accuracy of determining the cross sectional area of the test specimen. When the best instrumentation and calibrations are used, the flux density, B, will be determined within ±1 percent.

21.3 When permeability is calculated the errors associated with both B and H are included. For the Epstein test-frame the material permeability determinations should be within ±3 percent.

SECTION 4 STANDARD TEST METHOD FOR SURFACE INSULATION RESISTIVITY OF SINGLE-STRIP SPECIMENS

22 SCOPE

22.1 This test method covers a means of testing the surface insulation resistivity of single strips or punchings of flat rolled electrical steel under predetermined conditions of voltage, pressure and temperature.

22.2 The term surface insulation resistivity used in this method refers to the effective resistivity of a single insulative layer tested between applied bare metal contacts and the base metal of the insulated test specimen. It is not the same as the terms interlamination resistance, interlaminar resistance, which refers to the average resistivity of two or more adjacent insulative surface in contact with each other.

22.3 The apparatus is popularly known as Franklin Tester.

23 SUMMARY OF TEST METHOD

Ten metallic contacts of fixed area are applied to one of the surfaces of the specimen and electrical contact is made with the base metal by two drills. The effectiveness of the surface insulation is then indicated by a measurement of average electrical current flowing between the contacts and the base metal under specified applied voltage. This measurement can be used directly as an indicator of insulation quality or may be converted to an apparent surface insulation resistivity value.

24 SIGNIFICANCE AND USE

24.1 This test method is particularly suitable for quality control in the application of insulating coatings.

24.2 Insulating quality of a coating is measured by a current that ranges from zero for a perfect insulator to 1.00 A for a perfect conductor.

24.3 Single readings should not be considered significant since the nature of the test device and specimen are such that successive measurements of a specimen often yield different values.

25 APPARATUS

25.1 The apparatus, as shown in Fig. 6 and 7 shall consist of the following.

25.2 Test Head

The test head shall consist of a mounting block on which parts are assembled.

25.3 Two parallel longitudinal rows of five vertically mounted steel rods free to move axially against surrounding spiral springs or other means to apply equal pressure.

25.4 Brass, stainless steel or other suitable metallic contact button on each rod, but insulated from it. Articulation of tips improves contact by compensating for minor misalignments. Avoid soft metals, poor conductors or metals subject to oxidation or attack by solvents used in cleaning. Due to low-voltage circuitry (0.5 V) all contacting surfaces must be kept clean. Full area contact of tips to core plate is needed to avoid decreases in Franklin amperage. Check with known samples or standard test lots. The total contact area of the ten contact buttons shall be 6.45 cm^2.

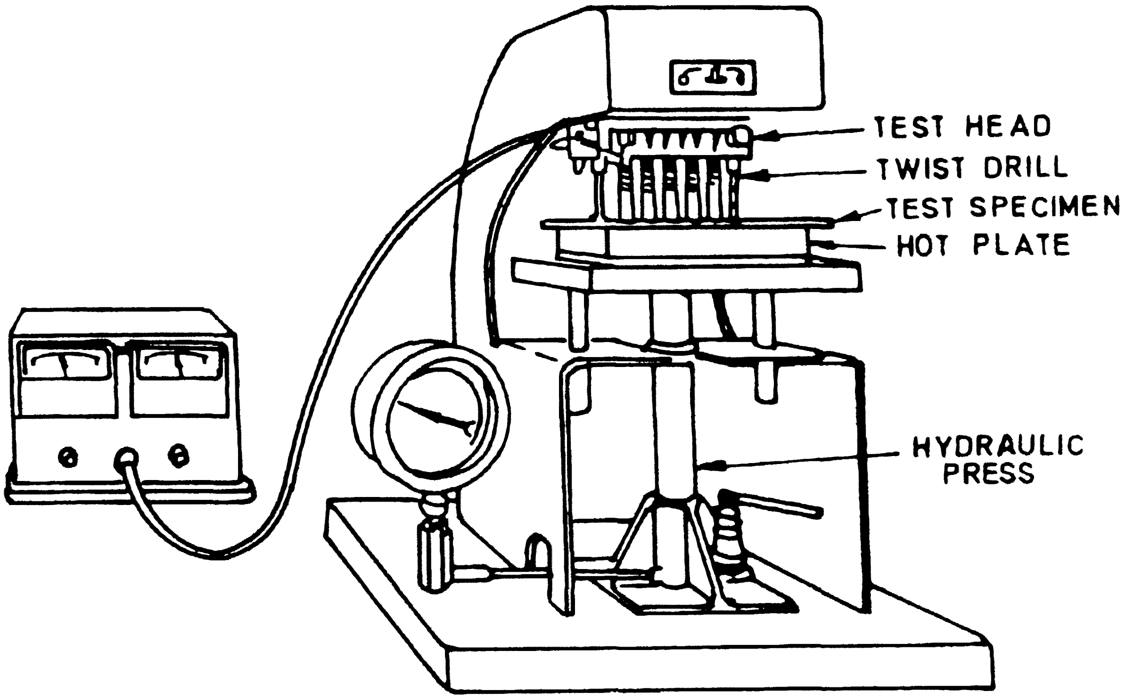

FIG. 6 APPARATUS OF SURFACE INSULATION RESISTIVITY MEASUREMENT

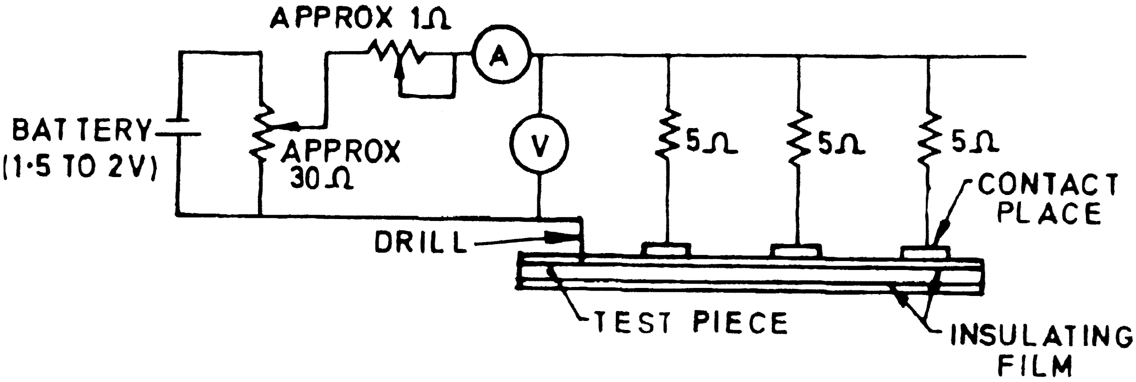

FIG. 7 CONNECTIONS FOR CONTACTS AND RESISTORS

25.5 A 5 ohms (± 0.1 percent) resistor connected to each contact button. Contacts with their individual resistors shall be connected in parallel as shown in Fig. 7.

25.6 Electrical contact with the base metal is made through two 3 mm diameter twist drills (preferably carbide tipped) or hardened and pointed rods. These are vertically mounted and spring loaded in spiral slotted sleeves to impart a twist while piercing the coating.

25.7 Hydraulic Press

The hydraulic press shall have a capacity of 10 000 N, with mountings to accommodate the test head, test specimens or punchings and a hot plate. The press and hot plate must provide a smooth, flat and rigid support for the test specimen.

25.8 Hot Plate

The hot plate shall be such that the test specimen can be heated to the temperature of test with automatic control to maintain the test temperature.

25.9 Test Head Power Supply

The instrument may be operated from batteries or from a voltage regulated d.c. power supply. For battery operation, either storage or dry cell types may be used with appropriate control rheostats for setting voltages during tests. Commercial power supplies are available for use with this equipment.

25.10 The voltage regulated d.c. power supply should be capable of voltage regulation of atleast 0.5 percent at 0.5 V during load changes from zero to 1.0 A and line voltage variations of ±10 percent. This maintains the voltage adequately accurate during test and eliminates the necessity for manual voltage adjustments.

25.11 Ammeter

The zero to 1.0 A ammeter should be D'Arsonval type rated for 1 percent or better accuracy. This provides needed scale resolution for low and high resistance coatings. A digital ammeter with zero to 1 A range and with better accuracy may be used. Digital read out should have two or three places after the decimal.

25.12 Voltmeter

When batteries are used the d.c. voltmeter range would normally be zero to 2.0 V. If a voltage regulated power supply is used, better resetability may be obtained by use of a zero to 0.5 V d.c. voltmeter. To avoid poor agreement between instruments, the voltmeter should be a type rated for one percent or better accuracy and preferably should have a sensitivity of at least 1 000Ω/V (The current drawn by the voltmeter appears as an error in the ammeter reading. *See* **27.1** for the correction). A digital voltmeter with similar capabilities may also be used.

25.13 Hot Plate Power Supply

The plate power supply and temperature controlled equipment should be capable of automatic temperature control and variable setting features. It may use thermocouples or other temperature sensing elements, but must be able to maintain temperature of the hot plate within celsius degrees of the set temperature.

26 TEST SPECIMEN

26.1 The width and length of a specimen strip shall be greater than the width and length respectively of the assembly contacts. The suggested minimum specimen size is 50 mm × 125 mm. A minimum of five specimen strips is required.

26.2 By mutual agreement, tests may be run on Epstein test strips. The Epstein specimens may be less satisfactory than the minimum size specimen suggested in **26.1** because of the tilting effect due to burrs, shearing strains and disturbances in the coating.

27 PROCEDURE

27.1 Make polarity connections between the power supply and test head in such manner as to maintain the drills and test specimen body at a positive potential. Connect the voltmeter to show voltage across the test head. When connected in this manner the voltmeter load current will appear as an error current in the ammeter reading and shall be subtracted from the ammeter readings. On short circuit the correct load current is 1.00 A plus the voltmeter current. To eliminate this correction it is permissible to offset ammeter to a zero position when the test head is up (not making contact) to return the ammeter to a zero reading with 0.5 V applied between the head and the test bed plate.

27.2 To ensure correct contact button condition, make a short circuit test occasionally by testing a bare metal surface. When the short circuit current is less than 0.99 A, clean the contacts. The use of solvents for cleaning is preferred to abrasives because the later can result in rounded tips with reduced contact areas.

27.3 The recommended standard pressure for purpose of comparative tests shall be 2.1 MPa. Other pressures, depending upon the applications, may be agreed upon by the manufacturer and the purchaser. If more than one test pressure is to be used, apply the pressures in ascending order. During testing, apply the pressures only once, but an applied pressure may be increased to a higher value.

27.4 If both sides of the specimen are coated do not use the same area to test both sides.

27.5 The recommended standard test temperatures are room temperature or 150°C. Other temperatures and the sequence of temperatures depending upon the application may be agreed upon by the manufacturer and the purchaser. When tests are made at elevated temperatures allow sufficient time (usually 30 seconds) to heat the specimen to the specified temperature.

27.6 Place the specimen on the plate beneath the test head and position it so that all contacts are within the test area when the test head is brought in contact with the specimen. Apply the specified pressure. Adjust the voltage to 0.50 V and read the ammeter.

28 CALCULATIONS

28.1 The average of electrical current measurements is usually acceptable for evaluating surface insulation. Average the current readings for each surface for a minimum of five specimens. The reported value for a test lot shall be the average of both surfaces.

28.2 In the event electrical resistivity value is desired, the average unit resistance per lamination (two surfaces) may be calculated to two significant figures as follows:

$$R_i = (6.45/I) - 6.45 \quad \text{... (1)}$$

where

R_i = average surface resistivity in ohms/cm^2 per lamination (two surfaces), and

I = ammeter reading A.

29 PRECISION

Even with the best practices in design, instrumentation, maintenance and operation, the repeatability and reproducibility of the test method are greatly influenced by the nature of the surfaces of the test specimens. Hence it is not considered possible to state meaningful values for repeatability and reproducibility that are universally applicable.

SECTION 5 DETERMINATION OF RESISTIVITY OF MAGNETIC SHEET AND STRIP

30 SCOPE

This test method covers determination of the resistivity of magnetic sheet and strip.

31 SUMMARY OF METHOD

The electrical resistance of 250 mm long test specimen is measured with a Kelvin type resistance bridge or 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.

32 APPARATUS

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

32.2 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 point is of no consequence.

32.3 The Kelvin bridge is calibrated to read directly the resistance between the potential points without knowledge of the currents in the specimen. Contact resistance at a 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.

33 TEST SPECIMEN

Strips with a minimum length of 250 mm and a maximum width of 30 mm, as for example Epstein test specimen strips shall be used for the measurement. The oxide or other insulating coating need not be removed except from places where electrical contacts must be made. The current contacts should be in the form of transverse clamps covering at least 80 percent and preferably the entire width of the specimen. The potential contacts can be either knife edge or point contacts.

34 PROCEDURE

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

34.2 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 120 mm.

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

34.4 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 percent of the width. A reliable contact shall be made with the specimen by both the current and potential leads.

34.5 Specimen temperature during test should be about 27 ± 5°C.

34.6 To eliminate errors due to contact potential, take two readings, one direct and one with the current reversed, in close succession.

34.7 The electrical current in the test specimen must be limited to avoid over heating but must be adequate to provide sufficient sensitivity to show an out-of-balance condition when the resistance reading is changed to 0.5 percent 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.

35 CALCULATION

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

$$A = (m/l)\text{r} \quad \text{... (1)}$$

where

A = cross sectional area of test specimen in m^2,

m = mass of test specimen in kg,

l = length of test specimen in m, and

ρ = density of test specimen in kg/m^3.

NOTE — Equation (1) assumes a negligible mass of any coating material.

35.2 Calculate the resistivity from the measured value of electrical resistance and the cross sectional area determined by equation (1) as follows:

$$p = RA/l_2 \qquad \ldots (2)$$

where

P = electrical resistivity of the material in ohm. m,

R = resistance of electrical path in ohm,

A = cross sectional area of electrical path in m^2, and

l_2 = length of electrical path between potential contacts on the test specimen in m.

35.3 The resistivity units in ohm metre shown in equation (2) can be converted to micro ohm cm by multiplying the ohm metre figure by 10^8 micro ohm cm per ohm metre. For example, if the resistivity of a 1 percent silicon plus aluminium steel is 0.25×10^{-6} ohm metre or $0.25 \times 10^{-6} \times 10^8$ micro ohm cm per ohm metre is equal to 25 micro ohm cm.

36 ACCURACY

Accuracy of the method for measuring resistivity of steels of usual surface finish is estimated to be within ±2 percent.

SECTION 6 DETERMINATION OF THE DENSITY OF THE MAGNETIC SHEET

37 SCOPE

Density values normally used in the calculation of the magnetic cross-section of the Epstein specimens in accordance with the equation 1 (*see* Section 5) are those values defined as the conventional density in product standards.

38 METHODS TO BE USED

38.1 The immersion method is a fundamental method of determining density but, in application, requires that the surfaces of the test specimen be essentially free of oxide films or applied coatings. However, in case of arbitration, only this method will be valid.

38.2 For industrial purposes, measurements of electrical resistance on coated or uncoated specimens or determinations of weight percentages of silicon and aluminium contents provide reliable means of establishing densities for commercial iron base flat rolled products.

39 TEST SPECIMEN

Test specimen strips of suitable dimensions, for example Epstein strips may be used for the measurements.

40 IMMERSION METHOD

40.1 In arbitration test, the conventional immersion method must be applied. This method is appropriate only when test specimens without any coating are used. The test specimens should be degreased prior to use in the test.

40.2 By means of hydrostatic balance the test specimen is weighed before and after immersing it in water of known density ρ_w. All air bubbles should be removed from the surface of the test specimen. Then the density ρ_m of the test specimen is given by:

$$\rho_m = m/(m - m_i).\rho_w \qquad \ldots (1)$$

where

ρ_m = density of test specimen in kg/m^3,

ρ_w = density of water in kg/m^3,

m = mass of test specimen in kg, and

m_i = apparent mass of test specimen immersed in water in kg.

In order to obtain comparable results, it is necessary to test at least five test specimens and to average the results.

41 INDUSTRIAL METHODS

41.1 For industrial tests the following methods are recommended.

41.1.1 *Electrical Method*

According to this method the density of magnetic sheet can be determined by measuring the electrical resistance of the test specimen.

41.1.2 The electrical method is applicable only to silicon bearing sheet, the total silicon and aluminium content of which lies between 1 and 5 percent of mass. Aluminium, if present, shall not be higher than 0.4 percent. This later value is also the limit for the total of other common constituents. This method recognizes the fact that both density and resistivity are functions of the aluminium and silicon contents.

41.1.3 The resistance of a test specimen strip is given by:

$$R_e = \rho\, l_e/A \qquad \ldots (2)$$

The test specimen strip is weighed and the total length measured to within ±0.2 percent or better. The electrical resistance is measured according to the procedure described in Section 5. The mass is given by:

$$m = r_m \, lA \qquad \ldots (3)$$

where

R_e = measured electrical resistance of test specimen strip in ohms,

r = resistivity of the test material in ohm m,

r_m = density of the test material in kg/m^3,

m = mass of test specimen in kg,

A = cross section of test specimen strips in m^2.

l = total length of test specimen strip in m, and

l_e = distance between the potential contacts in m (*see* Section 5)

By combining equations 2 and 3, the cross section A and therefore the thickness of test specimen are eliminated.

$$r_m . r = R_e . m/l . l_e \qquad \ldots (4)$$

Density can be read from the curve of r_m against $r_m . r$ as shown in Fig. 8.

In order to obtain comparable results, it is necessary to test at least five test specimens and to average results.

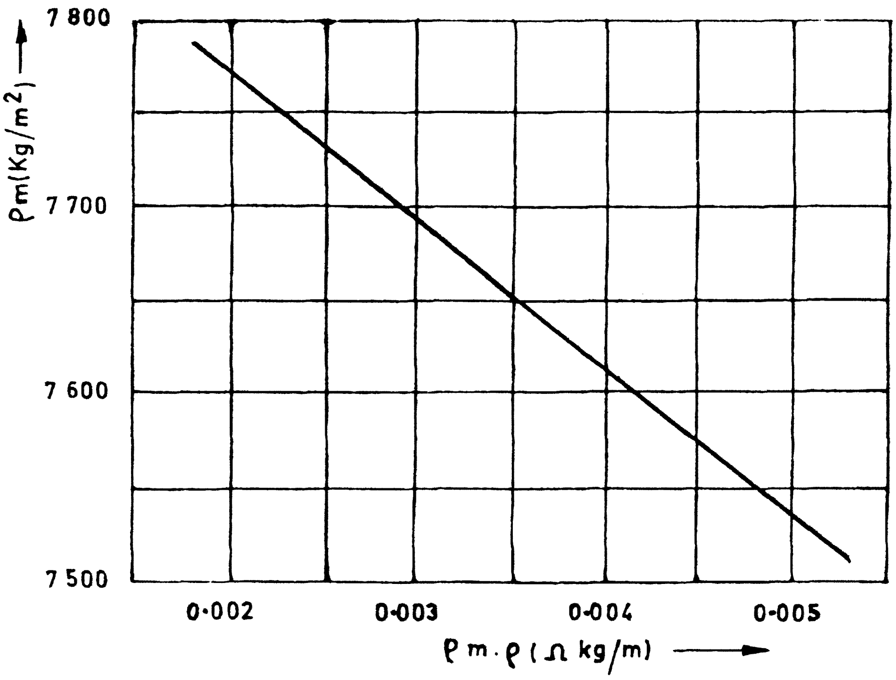

FIG. 8 DENSITY r_m AGAINST PRODUCT $r_m . r$

41.1.4 *Chemical Method*

For iron based alloys the relationship found in practice between density and silicon content or silicon and aluminium content is given by equation:

$$r_m = 7.865 - 65 \, (P_{Si} + 1.7 \, P_{Al}) \qquad (5)$$

where

r_m = density in kg per m^3,

P_{Si} = proportion of silicon (in percent, mass), and

P_{Al} = proportion of aluminium (in percent, mass).

42 REPRODUCIBILITY

The reproducibility of the results obtained from each method is characterized by a standard deviation of the order of 0.2 to 0.3 percent.

SECTION 7 STANDARD TEST METHOD FOR STACKING FACTOR OF MAGNETIC MATERIALS

43 SCOPE

This test method covers measurement of the stacking factor also known as lamination factor of a specimen composed of strips cut from magnetic material.

44 SUMMARY OF TEST METHOD

The laminated test specimen is subject to pressure in a compression device and the resulting volume is then determined from the measured specimen height, width and length. An equivalent solid volume is calculated from the specimen mass and the true density of the specimen material. The ratio of the calculated (equivalent solid) volume to the measured volume is the stacking factor.

45 APPARATUS

45.1 Testing machine

A compression testing machine or other compression device capable of exerting the specified pressure.

45.2 Metal plates

Two flat smooth rigid metal plates with square edges and ends are required. They shall be of sufficient stiffness to ensure practically uniform pressure in the sample. Each plate shall be 215 mm long and have a minimum width of 50 mm so that the area of strips under pressure when testing 30 mm wide specimens will be 6 450 mm^2.

45.3 Measuring Device

The measuring device shall be capable of measuring the height of the stack placed symmetrically with respect to the compression head on either side of the stack. Use of dial gauges capable of measuring with an accuracy of one-hundredth of a millimetre is recommended. Vernier caliper may also be used.

46 SAMPLING AND TEST SPECIMEN

46.1 The test strip shall be selected as representative of surface condition. Core loss test specimens (Epstein test) not less than 16 pieces are normally used for this purpose.

46.2 The test specimens must be composed of strips taken from one lot of steel. It must be representative of surface condition gauge and other variables. The shearing burrs or loose particles shall be carefully removed from the pieces before the test.

46.3 The test specimen shall preferably consists of the number of strips prescribed in Table 2.

Table 2 Number of Test Pieces for Stacking Factor

Thickness, mm	Number of Pieces
(1)	(2)
0.27	28
0.30	28
0.35	24
0.50	16
0.65 and above	16

46.4 Each strip shall have a minimum length of 305 mm and width of 30±0.08 mm.

47 PROCEDURE

47.1 Weigh the test specimens carefully with an accuracy of ±1 g.

47.2 Stack the strips evenly and place them symmetrically between the two flat plates in the compression testing machine.

47.3 Apply pressure so it is distributed uniformly across the test specimen. The recommended standard minimum test pressure shall be 3.5 kgf/cm^2 and is gradually applied.

47.4 Calculate the average separation of the backing plates or stack height at the required pressure from measurements of plates separation.

47.5 When using a compression testing machine make four measurements of the separation, one at each corner of the backing plates.

47.6 When using a compression device designed specifically for determining this factor only two measurements, taken on the longitudinal axis of the strips at each end of the plates will be satisfactory.

48 CALCULATIONS

48.1 Calculate the percentage stacking factor as follows:

$$S = m/wl^{r}\, t \times 100$$

where

S = stacking factor percent,
m = mass of test specimens in kg,
w = width of test specimens in m,
l = length of test specimens in m,
r = density of test specimens in kg/m^3, and
t = measured average separation plate faces in m.

48.2 Length and width dimensions should be known to at least 0.25 percent and preferably to 0.1 percent.

SECTION 8 STANDARD TEST METHOD FOR DETERMINATION OF DUCTILITY

49 DETERMINATION OF DUCTILITY OF NON-ORIENTED ELECTRICAL STEEL SHEETS

This test method covers determination of ductility utilizing Epstein test strips and a bending device for bending the strip over a predetermined radius. It is intended for non-oriented electrical sheet or strip covered under IS 648 : 1994.

50 SUMMARY OF METHOD

A test strip is placed in the special test apparatus designed to clamp one end of the specimen securely while the other end is free to move, but held in tension by a spring. The specimen is repeatedly bent through 180° reversals until a crack appears at the bend or until sudden failure occurs by complete rupture. The number of reversals until failure is taken as a measure of the brittleness.

51 APPARATUS

51.1 The apparatus consists of a set of stationary jaws and a movable arm to which is attached another set of jaws and spring.

51.2 The stationary jaws shall have working edges with radii of approximately 5 mm over which the test specimen is bent. Stationary jaws shall be of the quick clamping type.

51.3 The jaws attached to the movable arm shall allow the specimen to move freely during bending.

51.4 The spring clamped to the free end of the specimen shall provide sufficient tension in the specimen to localize the bend.

51.5 Design of the movable arm shall permit a rotation of approximately 180°.

52 SAMPLING AND TEST SPECIMEN

52.1 The test specimen may be cut from samples used for core loss or other tests.

52.2 The test specimens shall be about 30 mm in width and not less than 152 mm in length.

52.3 The number of test specimens representing each test lot shall not be less than ten.

52.4 The long axis of at least five test specimens shall be in the direction of rolling and at least five at the right angles to the direction of rolling.

52.5 Edges of the test specimens shall be practically free of burrs; filing or machining to remove burrs is permissible.

52.6 When width of the material prevents cutting specimens at right angles to the direction of rolling, all specimens shall be cut in the direction of rolling, and this shall be reported with the test results.

53 PROCEDURE

53.1 Clamp the specimen tightly in the stationary jaws in the bend test machine, Fig. 9, and place in tension by stretching the spring during clamping.

53.2 Bend the specimen through 90° by use of the movable arm and jaws, Fig. 10; then bend it through 180° in the reverse direction. Again bend the specimen through 180° in the first direction and continually through 180° reversals until a crack appears at the bent or until sudden failure occurs by complete rupture.

53.3 Each full 180° bend, including the first 90° bend, shall be counted as one bend in determining the number of bends withstood by the specimen.

54 CALCULATIONS

Express the brittleness of the test lot as the average of the number of bends withstood by the test specimens from that test lot.

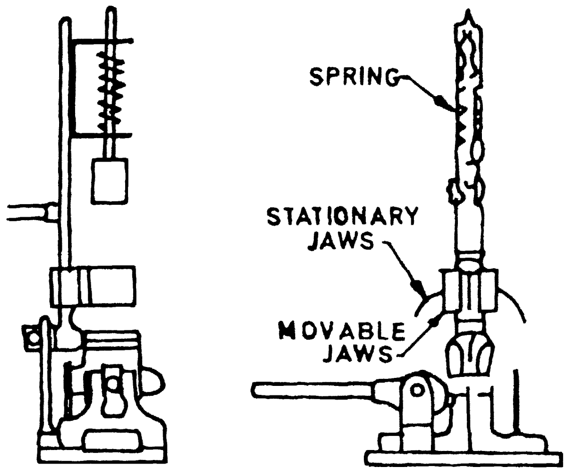

FIG. 9 APPARATUS FOR BEND TEST

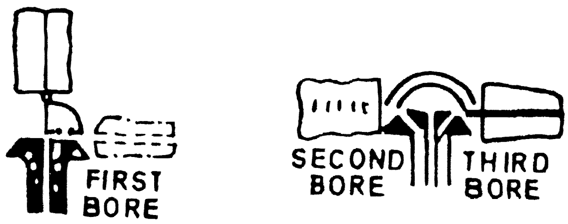

FIG. 10 DIAGRAM ILLUSTRATING METHOD OF MAKING BENDS

55 DETERMINATION OF DUCTILITY OF ORIENTED ELECTRICAL STEEL SHEET

This method covers determination of the ductility of grain oriented electrical steel covered under IS 3024 : 1996 by use of an apparatus known variously as a thinner's brake, hand folder, or an apron brake.

56 SUMMARY OF METHOD

A test specimen representing the full width of grain oriented steel to be tested is bend through an angle of about 160 degree in a thinner's brake. The numbers of breaks, or fractures, occuring along the bend determines the ductility class rating.

57 SIGNIFICANCE AND USE

57.1 This is a specialized bend test for grain oriented electrical steel.

57.2 This test is applicable to grain oriented silicon steel in commercial thickness and widths up to 910 mm.

58 APPARATUS

58.1 The machine required to perform this test is known as a thinner's brake, hand folder, or an apron brake.

58.2 The brake shall be at least 910 mm wide with an opening capacity of approximately 0.90 mm.

58.2.1 The nose bar shall have a 0.80 mm radius.

58.2.2 The bending bar must be movable through an angle of at least 160°.

58.2.3 The movable table or apron shall move around the end of the nose bar at a distance of approximately 6.5 mm.

59 TEST SPECIMEN

59.1 Two specimens are required and they shall be selected from the same general location as that of the magnetic test specimen.

59.2 The specimens shall be cut transversely to the rolling direction and have a length equal to the sheet or strip width and a minimum dimension of 76 mm in the direction of rolling.

59.3 The specimens must be free of rust, ripples and scratches.

60 PROCEDURE

60.1 The test specimen shall be at room temperature at the start of the test.

60.2 Insert the test specimen into the brake and clamp with the direction of rolling perpendicular to the nose bar and 12 to 38 mm under the nose bar, thereby allowing the balance of the specimen width to rest against the bending bar.

60.3 Bend the specimen around the nose bar at a uniform rate by rotating the bending bar through an angle of 160°.

60.4 Remove the specimen from the machine and without straightening the bend, examine the outside face of the bend from surface breaks without magnification.

60.5 Count the breaks and measure for length.

61 INTERPRETATION OF RESULTS

61.1 Classify each test specimen according to the length of number of breaks as shown in the following table which is based on giving a larger numerical class rating corresponding to the larger number of breaks and poorer ductility.

Class Rating	*Condition of Bend*
Class 1	Not more than one break with length not exceeding 8 mm
Class 2	Not more than two breaks with total length not exceeding 15 mm
Class 3	Three to eight breaks, all sizes
Class 4	Nine to fifteen breaks, all sizes
Class 5	More than fifteen breaks, all sizes

61.2 The class ratings shown are based on strip widths of 610 to 910 mm.

61.3 When evaluating steel strip narrower than 610 mm, the number of breaks should be multiplied by the ratio of 610 over the strip width in mm. This converted number of breaks will then determine the class rating.

61.4 The class rating assigned to a test lot shall be the higher numerical class number of the two specimens.

SECTION 9 METHOD OF MEASUREMENT FOR DETERMINATION OF INTERNAL STRESS

62 SCOPE

62.1 This test method specifies determination of internal stress.

62.2 Definition

The variation 'c' from the shearing line is the greatest distance between the related edges of a sheet cut longitudinally. It is a measure of the internal stresses (*see* Fig. 11).

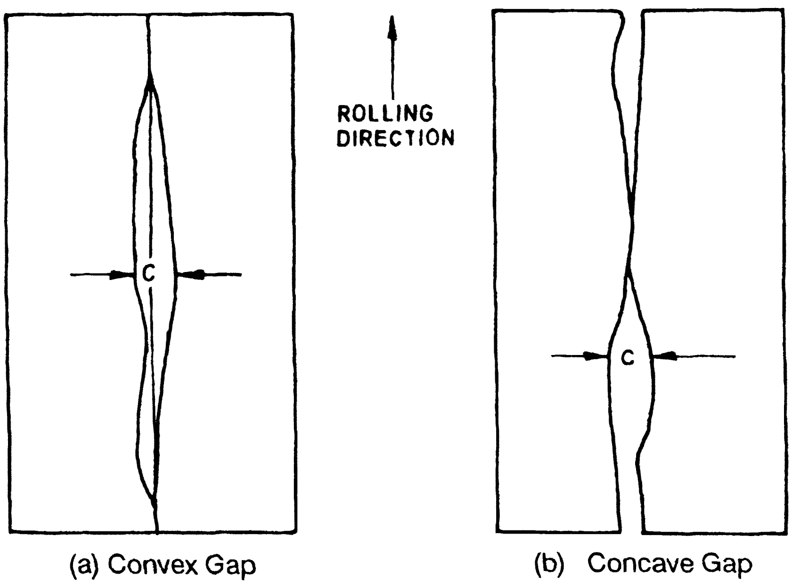

FIG. 11 DEVIATION FROM THE SHEARING LINE DUE TO INTERNAL STRESSES

62.3 Determination of the Variation from the Shearing Line

A specimen of a definite length specified is cut through, parallel to the direction of rolling. The two parts, neither of which may be reversed, are weighed in such a way that they lie flat. The two cut edges are then again placed together until the smallest possible gap is present. The greatest remaining distance between them is measured. The specimen must be at least 1 000 mm long.

62.4 Test Report

Variation 'c' from the shearing line in mm, to the nearest 0.2 mm.

SECTION 10 METHODS OF MEASUREMENT FOR DIMENSIONS AND TOLERANCES

63 SCOPE

63.1 This test method deals with various tests performed to measure size and shape variation, burr and out of square.

63.2 Test Specimens

The test specimen shall consist of a sheet or a length of strip of 2 metres.

64 SIZE MEASUREMENT

64.1 Thickness

Measure the thickness as shown in Fig. 12 at any point situated not less than 25 mm from the edges using a contact micrometer with an accuracy of 0.01 mm. For materials of width less than 80 mm, measure the thickness on the longitudinal axis of the sheet.

64.1.1 Deviation of thickness in transverse direction is defined as the difference of the maximum value and the minimum value in the thickness (excluding the portions from edges of steel strip) measured in transverse direction.

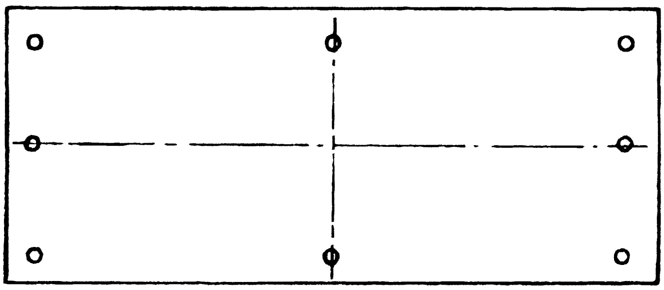

FIG. 12 MEASURING POINTS OF THICKNESS

64.2 Width and Length

64.2.1 *Width*

Measure the width perpendicular to the longitudinal axis of the sheet using a rule or tape measure.

64.2.2 *Length*

The dimensions of cut length shall be as close as practicable to the ordered length. The maximum deviation from the ordered length shall be as per IS 648 : 1994.

64.3 Out of Square

This tolerance applies to cut lengths only and is the greatest deviation on an edge from a straight line at right angles to a side and touching one corner, the measurement being taken as shown in Fig. 13. It can also be measured as one-half the difference between diagonals of cut length sheet.

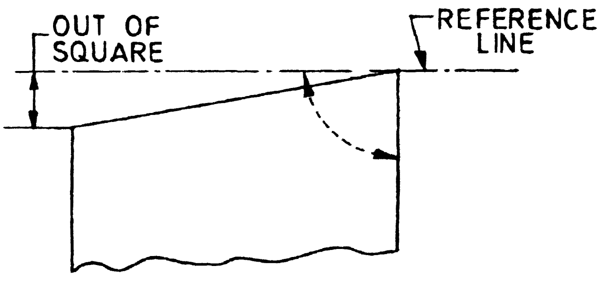

FIG. 13 OUT OF SQUARE TOLERANCE FOR CUT LENGTH

64.4 Cutting Burr Measurement

64.4.1 *Method* 1

Figure 14 shows a stepped checking gauge for measurement of cutting burr on the edge of the sheet. Method of measurement to be as follows.

Place step gauge on the plain surface of the sheet and slide slowly towards cut edge, when the step gauge stops, measure the burr height on the step, where the burr has come in contact.

64.4.2 *Method 2*

Place an external micrometer on a cut part, take the reading (*h*), when the ratchet sound once next remove the micrometer from the cut part and place on a portion nearby and taken the reading (*h*). Take the difference (*h*) of above two reading as the cutting burr [*see* Fig. 15].

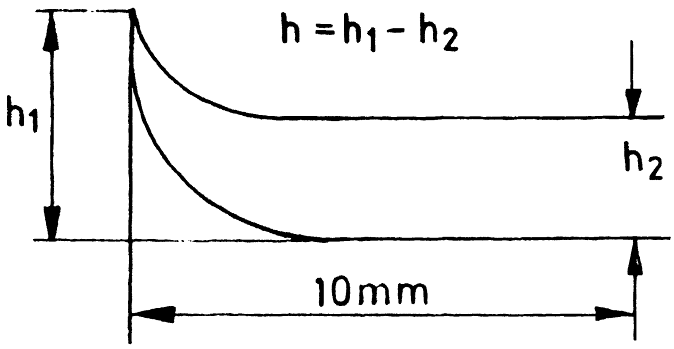

FIG. 14 BURR HEIGHT (*h*)

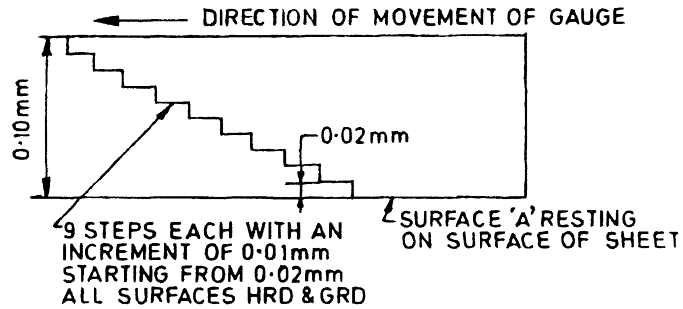

FIG. 15 STEPPED CHECKING GAUGE FOR BURR ON EDGE

65 TESTING OF SHAPE VARIATION

65.1 Deviation from Flatness (Wave Factor)

65.1.1 *Definition*

Variation from flatness in electrical steel sheet takes the form of waviness. Waviness can occur at the edge and in the middle of the sheet and over the entire width of the sheet.

65.1.2 Waviness *W* is the ratio of the height *h* of a wave to the length *l* of the wave.

65.1.3 The height *h* of the wave is the greatest distance between the underside of the sheet and a flat surface.

65.1.4 The length *l* of the wave is the distance over which the sheet rises above the surface plate.

65.1.5 In the case of waviness which does not extend over the entire width of the sheet, the depth of the wave is a further characteristic value. The depth *t* of the wave is deemed to be the greatest distance, measured with a steel rule 20 mm wide and 0.5 mm thick, between the edges of the sheet and the point at which it touches the steel rule (*see* Fig. 16 and 17).

65.1.6 *Determination of Waviness*

The sheet (or length of strip) to be tested is placed on a surface plate sufficiently large so that it does not hang over the edges; then lift up one edge until it is approximately vertical and allow it to fall back freely. Measure the maximum height of the maximum wave (*h*) and the length of the wave (*l*). The percentage wave factor is equal to 100 *h*/*l*.

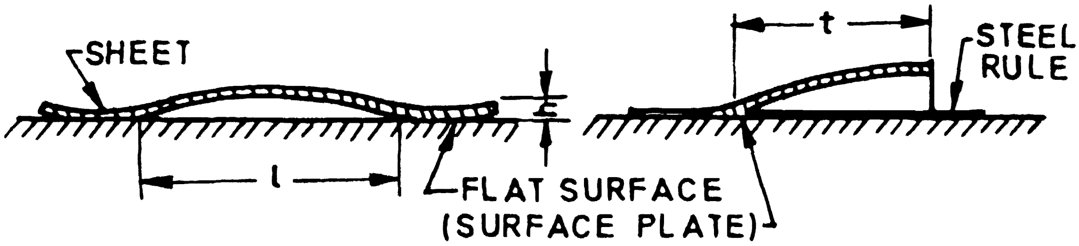

FIG. 16 CHARACTERISTIC VALUES FOR THE DETERMINATION OF WAVINESS

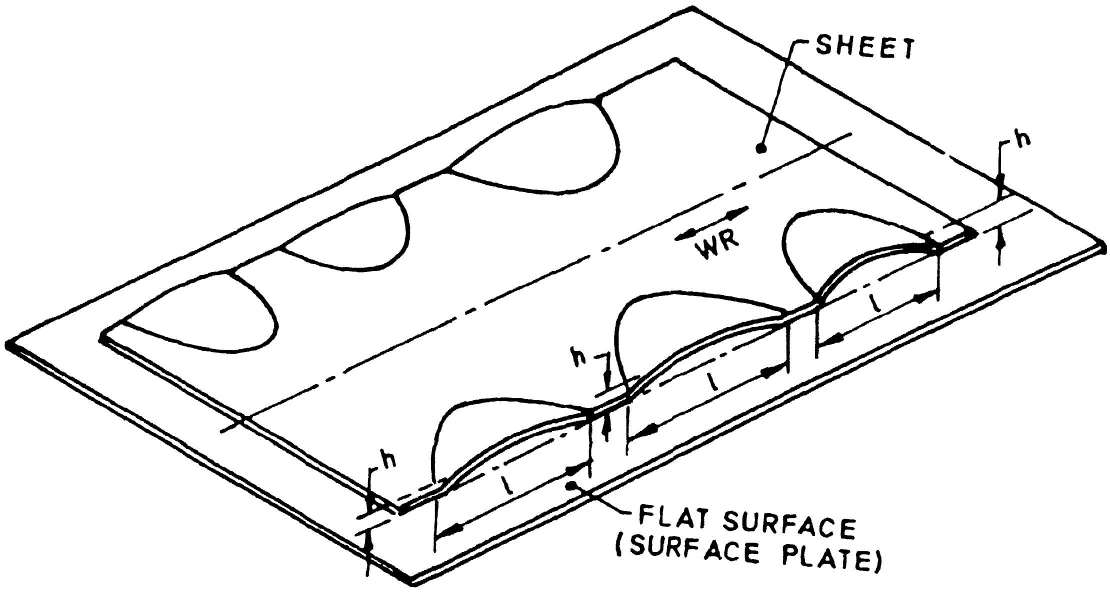

FIG. 17 EXAMPLE OF WAVE FORMATION AT EDGE

65.1.7 In the case of waves which do not extend across the width of the sheet, the depth of the waves is also measured. A scale, 20 mm wide, 0.5 mm thick and of adequate length is slid under the sheet until resistance is felt by means of repeated probing, the greatest distance to the outside edge of the sheet is to be ascertained and read off.

65.1.8 *Test Report*

Length *l* of wave in mm, to the nearest 10 mm. Height *h* of wave in mm, to the nearest 1 mm. Waviness *W* in percent to the nearest 0.1 percent. Depth *t* of wave in mm, to the nearest 5 mm.

65.2 Bowing

65.2.1 *Definition*

Bowing is the residual curvature, in the direction of rolling, of strip unwound from the coil. A measure of bowing is the greatest distance '*a*' between a strip of sheet at least 20 mm wide and with a free length of 250 mm and a vertical surface when the strip is pressed against the vertical surface over a distance of at least 30 mm as shown in Fig. 18. It is desirable to use an Epstein test strip.

65.2.2 *Determination of Bowing*

A sheet atleast 280 mm long and at least 20 mm wide is clamped over a distance of 30 mm in such a way that 250 mm thereof is freely suspended. The distance between the lower edge of the sheet and the vertical wall is measured.

65.2.3 *Test Report*

Bowing '*a*' in mm to the nearest 1 mm.

65.3 Edge Camber or Straightness

65.3.1 *Definition*

The measure of straightness is the greatest distance '*e*' between the concave longitudinal edge of a sheet and a straight edge, of a definite length specified, laid against it. The straight edge must be at least 1 000 mm long (*see* Fig. 19).

65.3.2 *Determination of Straightness*

The sheet is placed flat on a surface plate. After applying a straight edge as per **65.3.1** to the concave longitudinal edge, the greatest distance between the straight edge and the sheet is measured.

65.3.3 *Test Report*

Straightness '*e*' in mm to the nearest 0.2 mm.

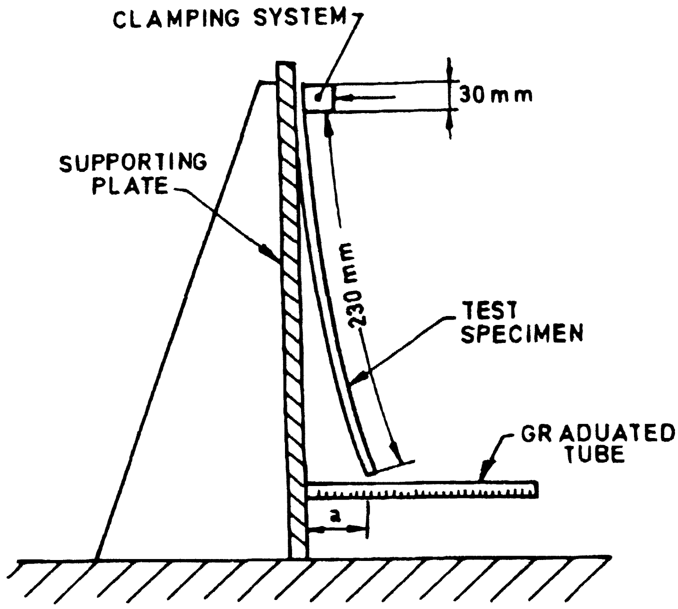

FIG. 18 MEASURING DEVICE FOR BOWING

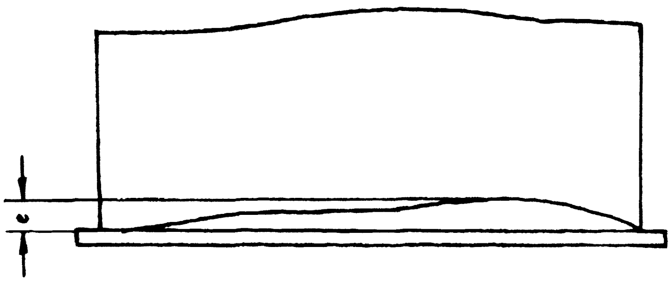

FIG. 19 VERIFICATION OF THE EDGE CAMBER

SECTION 11 TESTS ON INSULATION COATING

66 SCOPE

These test methods deal with various tests performed on insulation coating such as thermal effect on coating, resistance to solvents, resistance to freon, resistance to heat corrosion resistance, adherence test and flexibility test.

67 THERMAL EFFECT ON COATING

Twelve specimen of the coated strip shall be clamped together under a pressure of 1 N/mm^2 approximately and heated in laboratory oven at a temperature 150°C for a period of 7 days. After cooling to the room temperature measure the insulation resistance.

68 RESISTANCE TO SOLVENTS

68.1 Xylene

To check the adherence of coating.

68.1.1 *Sample Size*

Suitable to test facilities. Minimum width of sheet should be 30 mm.

68.1.2 *Method of Test*

Two clean glass beakers should be taken with equal quantity of xylene. The samples should be immersed in one of the beakers. Both the beakers should be heated to boiling for six hours. The samples should be weighed before and after insertion in xylene.

68.1.3 *Test Report*

68.1.3.1 Xylene in beaker with sample should be compared with the xylene in other beaker to check any change in colour.

68.1.3.2 There should be no change in weight of sample which is immersed in xylene.

68.1.3.3 Coating should be checked to see if it has become loose.

68.2 Trichloroethylene

68.2.1 To check resistance of coating to degreasing agent.

68.2.2 *Sample Size*

Suitable to test facilities. Minimum width of sheet should be 30 mm.

68.2.3 *Method of Test*

Procedure same as mentioned in **68.1.2**. Only xylene is replaced by trichloroethylene.

68.2.4 *Test Report*

68.2.4.1 Trichloro ethylene in beaker with sample should be compared with trichloroethylene in other beaker to check any change in colour.

68.2.4.2 There should be no change in weight of sample which is immersed in trichloroethylene.

68.2.4.3 The coating is to be checked to see if it has become loose.

68.3 Transformer Oil

68.3.1 To check resistance of coating to transformer oil.

68.3.2 *Sample Size*

Suitable to test facilities. Minimum width of sheet should be 30 mm.

68.3.3 *Method of Test*

Two clean glass beakers should be taken with equal quantity of transformer oil. The samples should be immersed in one of the beakers. Both the beakers should be heated to 100 – 120°C for eight hours. The samples should be weighed before and after insertion in transformer oil.

68.3.4 *Test Report*

68.3.4.1 Transformer oil in beaker with sample should be compared with the transformer oil in other beaker to check any change in colour.

68.3.4.2 There should be no change in weight of sample which is immersed in transformer oil.

68.3.4.3 Coating should be checked to see if it has become loose.

68.4 Resistance to Freon

This test is valid only for inorganic and inorganic with little organic based insulation coatings.

68.4.1 Electrical steel sheet for the motor cores of completely sealed compressors must have high resistance of insulation coating to freon attacks, because the stators and rotors come in direct contact with the refrigerant and refrigerator oil.

68.4.2 *Sample Size*

Suitable to test facilities.

68.4.3 *Method of Test*

Freon 22 and refrigerator oil to be taken in 1 : 3 proportion in a sealed chamber. Two clean glass beakers should be taken with equal quantity of refrigerant oil of known viscosity. The samples should be immersed in one of the beakers both the beakers should be kept in sealed chamber for 100 hours at 105°C.

68.4.4 *Test Report*

68.4.4.1 Two beakers containing refrigerant oil should be compared for any change in colour.

68.4.4.2 There should be no change in weight of sample which is immersed in refrigerant oil.

68.4.4.3 Coating should not become loose.

68.4.4.4 Viscosity should not change after the test.

68.5 Resistance to Heat

This test is valid for inorganic and inorganic with little organic based insulation coatings.

68.5.1 *Sample Size*

Suitable for test facilities.

68.5.2 *Method of Test*

The samples should be annealed in non-oxidizing atmosphere at a temperature of 800°C for two hours.

68.5.3 *Test Report*

68.5.3.1 The coating should not flake-off or burn-off.

68.6 Corrosion Resistance

68.6.1 *Sample Size*

Suitable for test facilities.

68.6.2 *Method of Test*

The test is to be carried out in a humidity chamber for 96 hours.

68.6.3 *Test Report*

68.6.3.1 The samples should be checked after every 24 hours for rust formation, if any.

68.7 Adherence Test

The surface coating shall be sufficiently adherent so that it does not detach during further coating or chip off at edges during shearing or punching. In the reverse bending test with a bending radius of 5 mm, the surface coating shall not be detached after bending through 90°.

68.8 Flexibility Test

Insulation coating should not peel off during bending through 180° on 12 mm diameter mandrel.

68.9 Coating Thickness

The coating thickness of the steel sheet is to be measured using an instrument based on magnetic induction principle.

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