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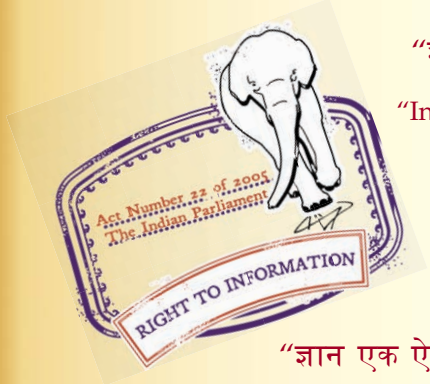

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(Reaffirmed 2003)

Indian Standard

METHODS OF TEST FOR THERMOSETTING SYNTHETIC RESIN BONDED LAMINATED SHEETS

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 7 *March* 1962

Indian Standard

METHODS OF TEST FOR THERMOSETTING SYNTHETIC RESIN BONDED LAMINATED SHEETS

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Indian Standard

METHOD OF TEST FOR THERMOSETTING SYNTHETIC RESIN BONDED LAMINATED SHEETS

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 7 March 1962, after the draft finalized by the Plastics Sectional Committee had been approved by the Chemical Division Council.

0.2 Thermosetting synthetic resin bonded laminated sheets are finding application in increasing quantities in electrical, engineering, chemical and other industries in India. These laminates consist essentially of fibrous sheet materials impregnated or coated with a thermosetting synthetic resin binder and consolidated under high pressure and temperature into solid products characterized by high mechanical strength combined with light weight, good electrical properties, and resistance to moisture, heat and a wide range of chemicals. To serve as a basis in evaluating the quality of the various types of these laminated sheets, the necessity of a standard on methods of test for these sheets was felt.

0.3 Considerable assistance has been derived from the following publications in preparing this standard:

B.S. 2067 : 1953 DETERMINATION OF POWER-FACTOR AND PERMITTIVITY OF INSULATING MATERIALS (HARTSHORN AND WARD METHOD). British Standards Institution.

B.S. 2572 : 1955 PHENOLIC LAMINATED SHEET. British Standards Institution.

B.S. 2782 : PART 3 : 1957 METHODS OF TESTING PLASTICS, PART 3 MECHANICAL PROPERTIES. British Standards Institution.

0.4 Wherever a reference to any Indian Standard appears in this standard, it shall be taken as a reference to the latest version of the standard.

0.5 Metric system has been adopted in India and all quantities and dimensions in this standard have been given in this system. Non-metric

values to which the industry has been accustomed are also given along with metric values, wherever necessary, for the sake of smooth change-over by December 1966.

0.6 In reporting the result of a test or analysis 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*).

1. SCOPE

1.1 This standard prescribes the methods of test for thermosetting synthetic resin bonded laminated sheets of various types.

1.1.1 The method for drawing samples for tests is not covered by this standard and this shall be prescribed in individual material specifications.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions shall apply.

2.1 Direction A and Direction B — Two directions in the plane of a sheet which are mutually at right angles and are related to the surface layers of the sheet. One of these directions is parallel with the machine direction of paper or with either the warp or the weft threads of the fabric.

2.2 Edgewise — A direction parallel to the plane of lamination.

2.3 Flatwise — A direction perpendicular to the plane of lamination.

2.4 Synthetic Thermosetting Resins — Synthetic resins which on heating gradually pass from the fusible stage to one in which they are not only infusible but insoluble in the common solvents and in alkalis.

2.5 Phenolic Resin — Resin produced by condensation of a phenol with aldehydes.

2.6 Synthetic Resin Bonded Laminated Sheet — Laminated sheet in which the bonding medium is a synthetic thermosetting resin.

3. CONDITIONING OF SPECIMENS

3.1 When specimens are required to be conditioned, they shall be subjected to an atmosphere of 65 $\pm$ 5 percent relative humidity at a

temperature of 27 ± 2°C for not less than 24 hours (*see* *IS : 196-1950 Atmospheric Conditions for Testing). Every specimen shall be tested as soon as possible after removal from the controlled atmosphere, and in any case, the test shall be started before three minutes have elapsed.

4. THICKNESS

4.1 Measure the thickness of the sheets in the condition as received with a suitable micrometer at ten points equally spaced around the edges of the sheets.

5. TENSILE STRENGTH

5.1 This test is applicable to sheets of more than 1·6 mm (or $\frac{1}{16}$ in) thickness.

5.2 Number of Tests — Carry out the test on four test specimens, two cut in direction *A* and two in direction *B*.

5.3 Test Specimens — Two alternative types of test specimens are prescribed. The form and dimensions of these two types of specimens shall be as shown in Fig. 1 and Fig. 2. Suitable grips appropriate to the specimen shown in Fig. 1 are shown in Fig. 3. With these grips, the nuts on the bolts inserted through the specimen shall not be screwed up more than finger-tight. Wedge grips shall be used in applying the load to the specimen shown in Fig. 2. Whichever type of grip is used, provision shall be made for self-alignment of the specimen under load by the use of suitable shackles. Measure the thickness of the test piece to the nearest 0·03 mm (or 0·001 in). The thickness of the test piece shall be the thickness of the sheet under test except that where this exceeds 13 mm (or $\frac{1}{2}$ in), the thickness of the test piece shall be reduced to 13 mm (or $\frac{1}{2}$ in) leaving one face of the specimen intact.

5.4 Apparatus — Any standard tensile testing machine capable of measuring the load at fracture to within 1 percent accuracy may be used.

5.5 Procedure — Condition the test specimens as in **3.1**. Fix the specimen in the tensile testing machine, taking care to ensure correct alignment of the test piece. It may be of assistance to interpose an emery cloth between the test piece and the grips, the emery face being in contact with the test piece. Increase the load steadily at such a rate that the minimum specified breaking stress is reached in one and a half to two minutes from the time of the initial application of load.

5.6 Report — Report the arithmetic mean of the two test results in the direction *A* or in the direction *B* whichever is lower, as the tensile

*Since revised.

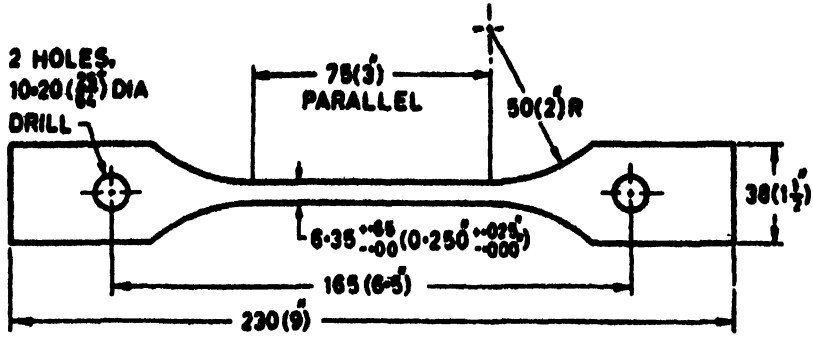


FIG. 1

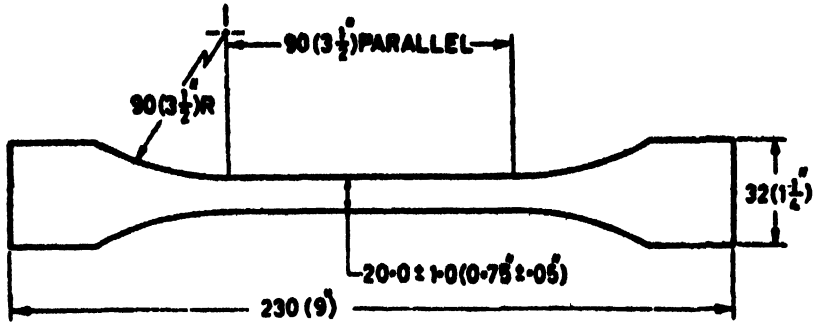


FIG. 2

Dimensions outside the parentheses are in millimetres.

FIG. 1 AND FIG. 2 ALTERNATIVE SPECIMENS FOR TENSILE TEST

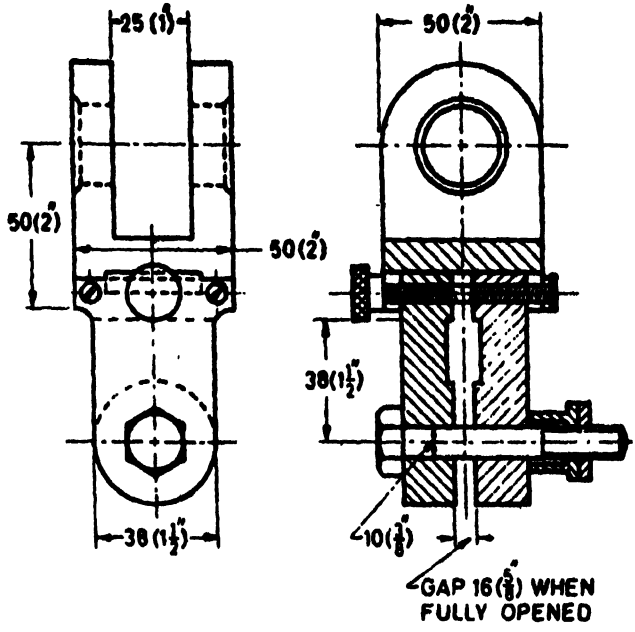
strength expressed in kg/cm² (or lb/in.²) of the original cross-sectional area calculated from the measured dimensions of the specimen.

6. CROSS-BREAKING STRENGTH

6.1 This test is applicable to sheets of more than 1·6 mm (or $\frac{1}{16}$ in.) thickness.

6.2 Number of Tests — Carry out the test on six specimens, three cut with their lengths in direction *A* and three with their lengths in direction *B*.

6.3 Test Specimens — Each specimen shall consist of a rectangular bar of 15·0 ± 0·5 mm breadth and a length of 24 to 30 times the thickness of the sheet measured to the nearest 0·03 mm. The thickness of the test piece shall be the thickness of the sheet under test except that where this exceeds 10 mm (or $\frac{3}{8}$ in.), the thickness of the test piece



Dimensions outside the parentheses are in millimetres.

FIG. 3 GRIPS FOR TENSILE TEST SPECIMEN OF FIG. 1

shall be reduced to 10 mm (or $\frac{3}{8}$ in.) leaving one face of the specimen intact.

6.4 Procedure — Condition the test specimens as in **3.1**. Measure the breadth and thickness of the test piece to the nearest 0·03 mm (or 0·001 in.). Lay the test piece symmetrically across two parallel V-shaped supports with the original face of the sheet in contact with the supports. Keep the distance between the supports equal to 16 times the measured thickness of the test piece, adjusted to the nearest 1 mm (or $\frac{1}{32}$ in.). Apply a load squarely across the width of the test piece by means of a third V-shaped block parallel to and midway between the supporting blocks. The contact edges of the blocks shall have a radius of 1·5 mm and shall be not less than 25 mm long. Increase the load steadily at such a rate that the test piece fractures in 15 to 45 seconds. Note the load at fracture.

6.5 Calculation and Report — Calculate the cross-breaking strength of each test piece as given below:

$$\text{Cross-breaking strength, kg/cm}^2 \text{ (or lb/in.}^2\text{)} = \frac{1{\cdot}5\ WL}{BD^2}$$

where

W = load at fracture in kg (or lb),
L = distance in cm (or in.) between supports,
B = breadth in cm (or in.) of test piece, and
D = thickness in cm (or in.) of test piece.

6.5.1 Report the arithmetic mean of the three values obtained in the direction *A* or of the three values in the direction *B*, whichever is lower, as the cross-breaking strength.

7. SHEARING STRENGTH, FLATWISE

7.1 This test is applicable to sheets of more than 1·6 mm (or $\frac{1}{16}$ in.) thickness.

7.2 Number of Tests — Carry out the test on four specimens, two cut with their lengths in direction *A* and two with their lengths in direction *B*.

7.3 Test Specimens — Each specimen shall be a rectangular bar 6·5 ± 0·3 mm wide and not less than 30 mm long. The thickness of the test specimen shall be the thickness of the sheet under test except that where this exceeds 6·3 mm (or 0·250 in.), the thickness of the specimen shall be reduced by machining to 6·10 ± 0·25 mm (or 0·240 ± 0·010 in.), leaving one face of the specimen intact.

7.4 Apparatus

7.4.1 A punch, die and bolster assembly conforming to dimensions shown in Fig. 4 shall be used. The punch shall be a running fit in the die.

7.4.2 A suitable compression testing machine, capable of developing a load of over 2 metric tonnes, shall be used.

7.5 Procedure — Condition the test specimens as in **3.1**. Measure the thickness and the width of the specimen to the nearest 0·03 mm (or 0·001 in.). Place the specimen, with the unmachined face upwards, in the assembly, the die being screwed home against the specimen in the bolster. The load shall be applied evenly to the specimen by means of the punch at such a rate that the final value at which the specimen shears is reached in 15 to 45 seconds from the time of initial application of the load.

7.6 Calculation and Report — The shearing strength shall be calculated as follows:

$$\text{Shearing strength, kg/cm}^2 \text{ (or lb/in.}^2\text{)} = \frac{W}{2BDK}$$

where

W = load in kg (or lb) at fracture,

B = width in cm (or in.) of specimen,

D = thickness in cm (or in.) of specimen, and

K is a factor with a value 1·048, introduced to allow for the curvature of the sheared surface.

7.6.1 Calculate the arithmetic mean of the two values in direction *A* and two values in direction *B*, and report the lower of the two as the shearing strength of the sheet.

8. COMPRESSION STRENGTH, FLATWISE (PROOF TEST)

8.1 Test Specimen — Prepare a rectangular block 15 mm long, 15 mm wide and 25 mm high, the height being built up with several layers of the material when necessary. When it is necessary to machine a piece of sheet to obtain a specimen of 25 mm thickness, retain one original surface of the machined material. Remove the burrs from all edges of the specimen, including component layers, if any.

8.2 Apparatus — A suitable compression testing machine capable of developing a load over 2 metric tonnes, shall be used.

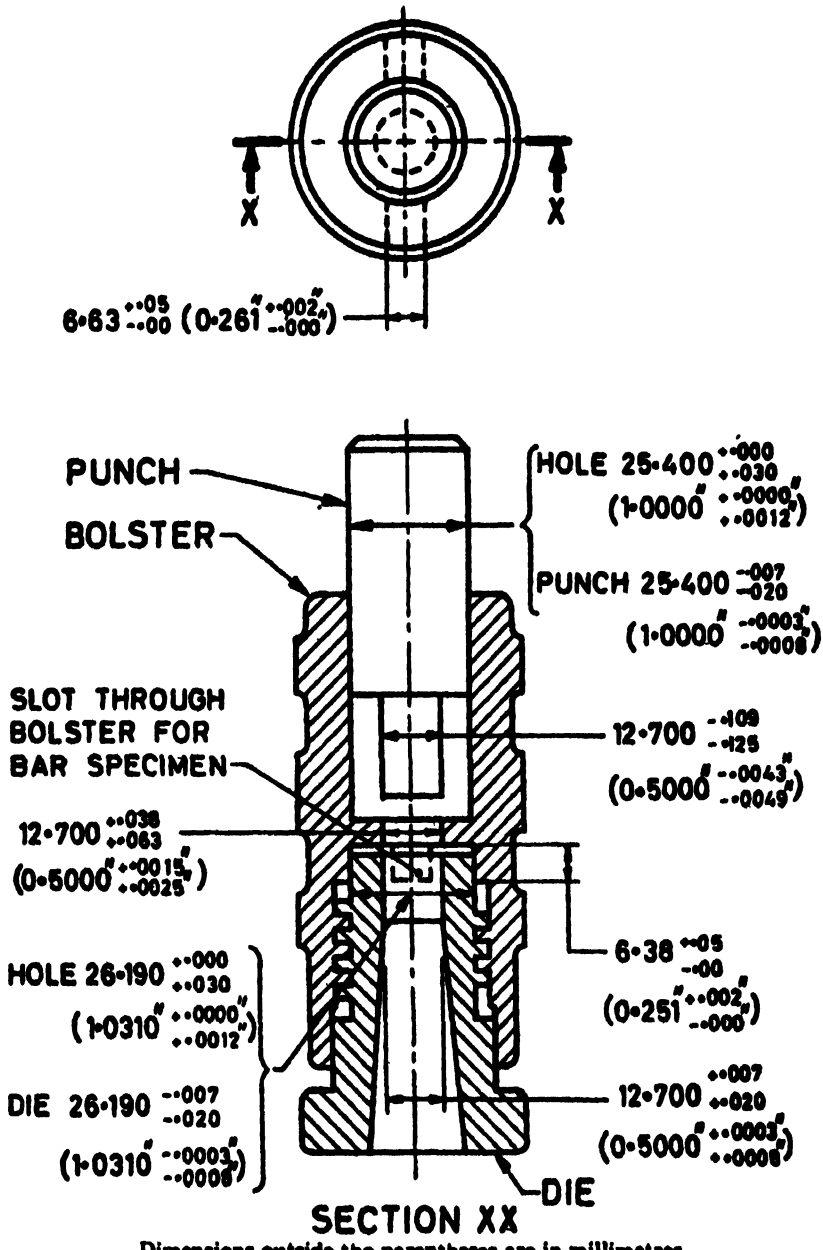
8.3 Procedure — Condition the test specimen as in **3.1**. Place it in the testing machine so that the load is applied perpendicular to the surface of the material. Increase the load at a rate such that a final load to give the required proof stress is reached within 45 seconds from the commencement of application of load. Maintain the final load for one minute, after which release the pressure.

8.3.1 Examine the specimen for cracks, splits or tendency to delaminate easily after the proof loading; the absence of all of these shall be considered as the material having passed the test.

9. IMPACT STRENGTH, EDGEWISE

9.1 This test is applicable to sheets with thickness more than 2·5 mm (or 0·1 in.).

9.2 Number of Tests — Carry out the test on 10 specimens, 5 cut with their lengths in direction *A* and 5 with their lengths in direction *B*.



Dimensions outside the parentheses are in millimetres.

FIG. 4 PUNCH, DIE AND BOLSTER ASSEMBLY FOR SHEARING STRENGTH, FLATWISE TEST

9.3 Test Specimen — If the measured thickness of the sheet exceeds 6·3 mm (or 0·25 in.), cut a rectangular piece of length 63·5 ± 0·5 mm (or 2·50 ± 0·02 in.) and width $12{\cdot}7^{+0{\cdot}0}_{-0{\cdot}1}$ mm (or $0{\cdot}500^{+0{\cdot}000}_{-0{\cdot}005}$ in.). The thickness of the test specimen shall be the thickness of the sheet under test except where this exceeds 12·7 mm (or 0·500 in.), the thickness shall be reduced to $12{\cdot}7^{+0{\cdot}0}_{-0{\cdot}1}$ mm (or $0{\cdot}500^{+0{\cdot}000}_{-0{\cdot}005}$ in.) by the removal of one face, leaving the other face intact. The piece shall be notched across the edge of the lamination as follows:

At a point equal in distance from the ends of one of the long sides, a hole of diameter 2·6 mm (or 0·081 in.) (No. 46 Morse drill) shall be drilled in a direction perpendicular to the plane of laminations and with the centre $11{\cdot}2^{+0{\cdot}0}_{-0{\cdot}1}$ mm (or $0{\cdot}440^{+0{\cdot}000}_{-0{\cdot}005}$ in.) from the edge. The hole shall be opened to the nearer side by a saw cut of width not exceeding 1·8 mm (or 0·070 in.) to produce a symmetrical notch as shown in Fig. 5. Alternatively, a notch of the form shown in Fig. 6 may be machined in the specimen using a suitably formed milling cutter.

If the thickness of the sheet is 2·5 to 6·3 mm (or 0·100 to 0·250 in.) inclusive, the specimen shall be built up as nearly as possible to but not exceeding 12·7 mm (or 0·500 in.) in width by placing together two or more pieces cut from the sheet and notched as described above (*see* Fig. 7).

9.4 Apparatus — The machine shall be of pendulum (Izod) type of rigid construction. The pendulum shall be so constructed that the centre of percussion coincides with the centre of the striking edge. This edge shall have a radius of 3·2 mm (or $\frac{1}{8}$ in.) and shall strike squarely across the full width of the specimen. The velocity of the striking edge at the moment of impact shall be 245 ± 2·5 cm (or 8·0 ± 0·1 ft) per second. The gripping vice shall be so designed that its edge has a radius of 0·4 mm (or $\frac{1}{64}$ in.). The specimen shall be struck at a distance of 22·0 ± 0·5 mm (or 0·866 ± 0·020 in.) from the face of the vice.

9.5 Procedure — Condition the test specimen as in 3.1. On removal from the conditioning chamber, the width of the notched face adjacent to the notch of the test specimen shall be measured to the nearest 0·03 mm (or 0·001 in.). The specimen shall be accurately mounted in the vice of the testing machine as shown in Fig. 8 with the notched side of the specimen facing the striker and the root of the notch level with the horizontal face of the vice.

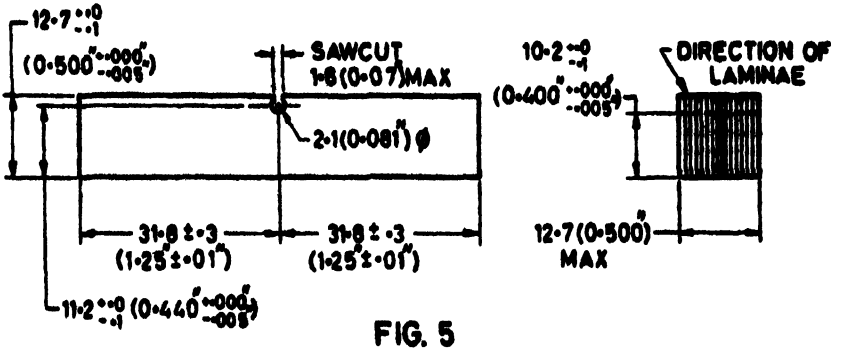


FIG. 5

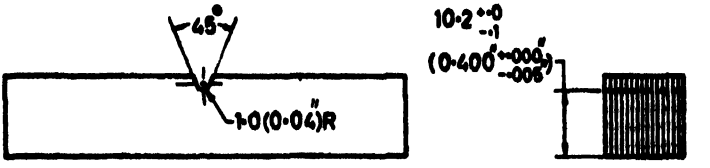


FIG. 6

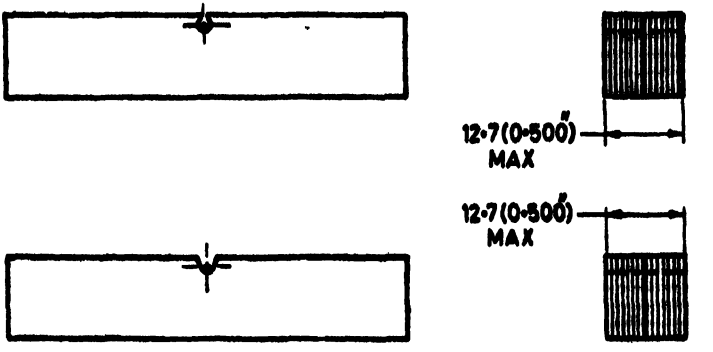


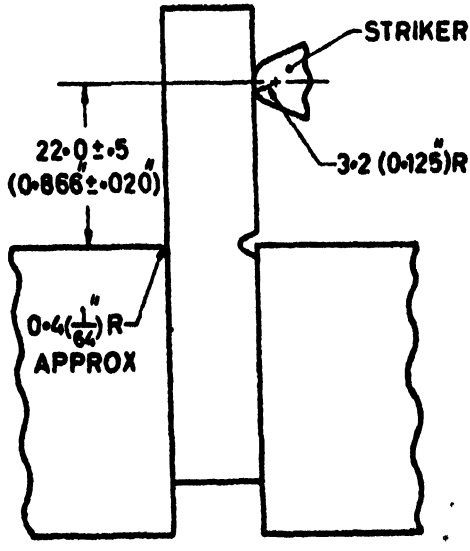
FIG. 7

Dimensions outside the parentheses are in millimetres.

FIGS. 5, 6 AND 7 IMPACT STRENGTH TEST SPECIMENS

The energy of the blow shall be related to the mean energy absorbed by the specimens as follows:

Energy Absorbed	*Energy of Blow*
Not greater than 11·8 kg-cm (or 0·85 ft-lb)	13·8 kg-cm (or 1·0 ft-lb)
Greater than 11·8 kg-cm (or 0·85 ft-lb) but not greater than 34·6 kg-cm (or 2·5 ft-lb)	41·5 kg-cm (or 3·0 ft-lb)
Greater than 34·6 kg-cm (or 2·5 ft-lb) but not greater than 117·6 kg-cm (or 8·5 ft-lb)	138·4 kg-cm (or 10 ft-lb)



Dimensions outside the parentheses are in millimetres.

FIG. 8 MOUNTING OF SPECIMEN FOR IMPACT STRENGTH TEST

9.6 Calculation — The impact strength, edgewise, of the specimen shall be the energy absorbed per 12·7 mm (or 0·500 in.) width of specimen and shall be calculated as follows:

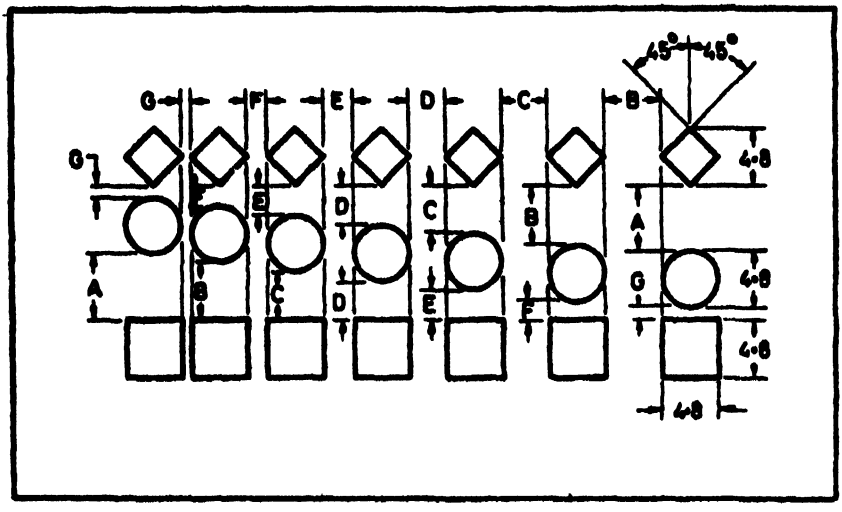
$$\text{Impact strength, edgewise, kg-cm (or ft-lb)} = \frac{\text{energy absorbed in kg-cm (or ft-lb)} \times 12{\cdot}7 \text{ mm (or 0·500 in.)}}{\text{width of notched face of the specimen in mm (or in.)}}$$

9.7 Report — Report the arithmetic mean of the five values of impact strength obtained in the direction *A* or the direction *B* test pieces, whichever is lower, as the impact strength of the material under test.

10. PUNCHING TEST

10.1 Procedure — Pierce in a single operation in a sheet of nominal thickness not exceeding 2·5 mm (or $\frac{3}{32}$ in), a pattern shown in Fig. 9, and examine the pierced specimen for excessive lifting around the holes or excessive cracking between them, the standard of acceptance being agreed to between the purchaser and the vendor.

10.2 Punching test shall be carried out in accordance with the recommendations of the vendor.



A	*B*	*C*	*D*	*E*	*F*	*G*
5·6	4·8	4·0	3·2	2·4	1·6	0·8

All dimensions in millimetres.

FIG. 9 PATTERN FOR PUNCHING TEST

11. RESISTANCE TO HOT OIL

11.1 Procedure — Immerse a specimen approximately 75 mm square for 24 hours in an insulating oil [*see**IS : 335-1953 Specification for Insulating Oil for Transformers and Switchgear (Low Viscosity Type)] at a temperature between 110 and 115°C. Examine the specimen for splitting, blistering, disintegration, or appreciable warping.

NOTE — Hair-line cracks do not constitute splitting.

*Second revision in 1972.

12. WATER ABSORPTION

12.1 Number of Tests — Carry out the test on three specimens.

12.2 Test Specimens — Cut from the sheet, test specimen $38{\cdot}0 \pm^{0{\cdot}5}_{0{\cdot}0}$ mm (or $1{\cdot}500 \pm^{0{\cdot}002}_{0{\cdot}000}$ in) square.

The thickness of the specimen shall be the thicknessof the sheet under test except that where the nominal thickness exceeds 25 mm (or 1 in), the test piece shall be reduced to $25{\cdot}0 \pm 0{\cdot}3$ mm (or $1{\cdot}00 \pm 0{\cdot}01$ in) by machining, retaining one original face. Smoothen the edges of the specimens with No. 0 glass paper.

12.3 Procedure — Condition the specimens as in 3.1. Measure the thickness to the nearest 0·03 mm (or 0·001 in), weigh to the nearest milligram and immerse for a period of 24 ± 1 hr in distilled water [*see* IS : 1070-1960 Specification for Water, Distilled Quality (*Revised*)] at a temperature between 20° and 30°C which shall not vary by more than $\pm$ 2°C. On removal from water, wipe dry the exposed surfaces with blotting paper or clean cloth. Re-weigh the specimen to the nearest milligram and complete the weighing within two minutes of the removal of the specimen from water. Record the increase in weight in milligrams.

12.4 Calculation and Report — Calculate the arithmetic mean of the three results obtained. Also calculate the mean value of the thickness of the three specimens.

When the test has been carried out at an immersion temperature higher than 20°C, calculate the equivalent water absorption at 20°C by applying the correction factor given in Fig. 10. Report this as the water absorption for the mean thickness of the specimen under test at 20°C.

NOTE — Report the temperature of the water at which the test was carried out.

13. ELECTRIC STRENGTH IN OIL, FLATWISE (PROOF TEST)

13.1 This test is applicable for sheets up to and including 5 mm (or $\frac{3}{16}$ in) in thickness.

13.2 Test Specimens — Prepare at least two specimens, each 100 mm square, out of the sheet under test.

13.3 Electrodes — The upper electrode shall consist of a solid cylinder of brass 40 mm in diameter and approximately 40 mm in height. The lower electrode shall be a brass block 80 mm in diameter and approximately 25 mm thick. The two electrodes shall be arranged as shown in Fig. 11. The sharp edges of the electrodes in contact with the specimen shall be rounded to a radius of not more than 1 mm.

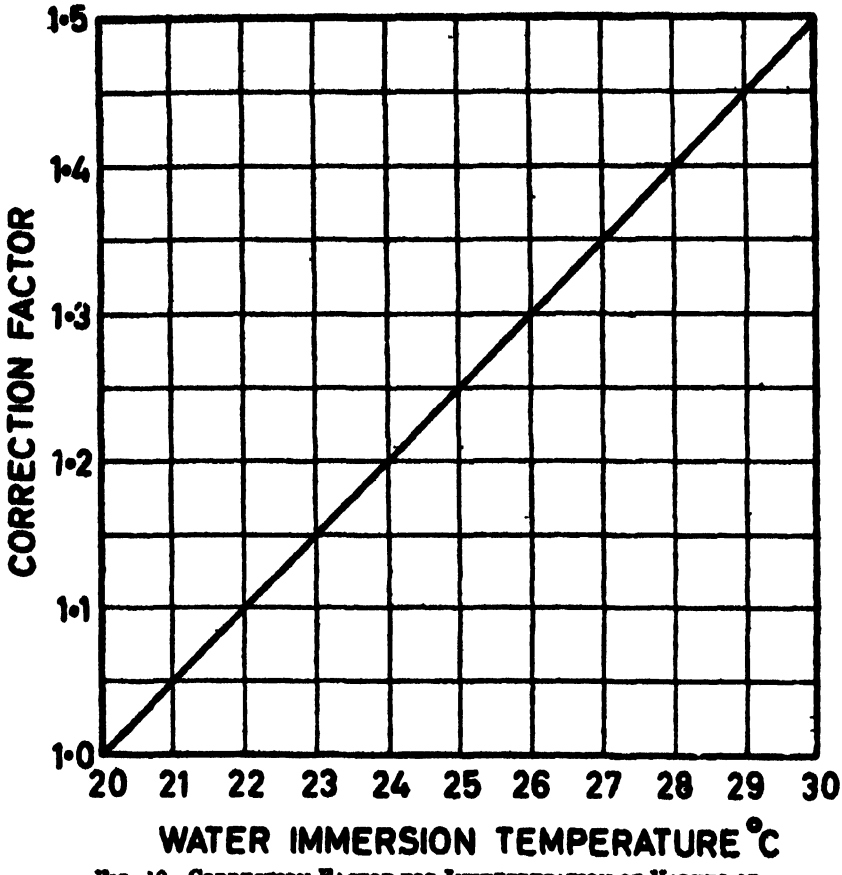
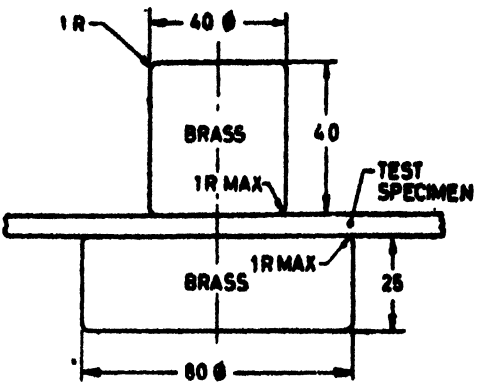


FIG. 10 CORRECTION FACTOR FOR INTERPRETATION OF VALUES OF WATER ABSORPTION

13.4 Procedure — Condition the test specimens as in 3.1. Place the specimen in between the electrodes as shown in Fig. 11 and immerse the whole assembly in insulating oil conforming to *IS : 335-1953 Specification for Insulating Oil for Transformers and Switchgear (Low Viscosity Type). Maintain the temperature of oil at 90 ± 2°C, with the specimen and electrodes immersed, for a period of half to one hour, after which apply an alternating voltage of frequency 50 ± 5 cycles per second between the electrodes. Start with a voltage one third of the specified proof stress and increase at the rate of approximately 1 kV per second to the specified proof stress. Maintain the proof stress for one minute.

*Second revision in 1972.



All dimensions in millimetres.

FIG. 11 ARRANGEMENT OF ELECTRODES FOR ELECTRIC STRENGTH TEST

13.5 The material shall be taken to have passed the test if there is no electrical breakdown with either of the test specimens at the specified proof voltage.

14. ELECTRIC STRENGTH IN OIL, EDGEWISE (PROOF TEST)

14.1 This test is applicable to sheets over 5 mm (or $\frac{3}{16}$ in) thick.

14.2 **Test Specimens** — Prepare at least two specimens each of 100 mm length and 25 mm width. The thickness of the specimen shall be that of the sheet under test. Finish the edges of the specimen that are in contact with the electrodes truly as parallel planes at right angles to the surface of the material, and remove any sharp corners.

14.3 **Electrodes** — Two metal plates, preferably of brass, of sufficient size to cover the edges of the specimen.

14.4 **Procedure** — Condition the test specimens as in 3.1. Place the specimen edgewise in between the electrodes and carry out the test as prescribed under 13.4.

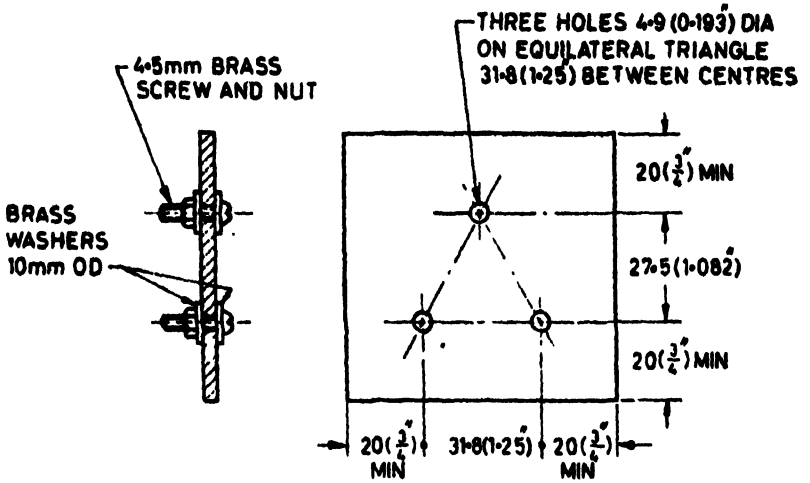
14.5 The material shall be taken to have passed the test if no electrical breakdown occurs with either of the two test specimens at the specified proof voltage.

15. INSULATION RESISTANCE AFTER IMMERSION IN WATER

15.1 This test is applicable to sheets of nominal thicknesses up to and including 25 mm (or 1 in).

15.2 Number of Tests — Carry out the test on two specimens.

15.3 Test Specimens — Cut and drill from the sheet under test two specimens of the form and dimensions shown in Fig. 12, taking care that the three holes drilled are clean and the surfaces of the sheet are not damaged. The surfaces should be cleaned with petroleum solvent to remove dirt. Assemble the 4·5-mm brass screws, nuts and small plain washers to form the three electrodes as shown in Fig. 12.



Dimensions outside the parentheses are in millimetres.

FIG. 12 SPECIMEN AND ELECTRODES FOR INSULATION RESISTANCE TEST

15.4 Procedure — Heat the assembly for 24 ± 1 hr at a temperature of 50° ± 2°C in a hot air oven (*see* Note). After allowing to cool to room temperature, immerse the assembly in distilled water for 24 ± 1 hr at a temperature between 20° and 30°C which shall not vary by more than ± 2°C. On removal from water, wipe dry the exposed surfaces with blotting paper or clean cloth. Measure the insulation resistance between each pair of electrodes at a potential difference of 500 ± 50 V DC after electrification for one minute, at a temperature of 27° ± 2°C in an atmosphere of not more than 75 percent relative humidity. All the readings shall be taken within five minutes of the removal of the assembly from the water.

NOTE — For routine test, pre-drying of the specimen may be dispensed with and the insulation resistance measured under prevailing conditions. However, to form the basis of rejection for non-compliance with the appropriate requirement, testing shall be done under the conditions prescribed in 15.4.

15.5 Calculation and Report — Calculate the arithmetic mean of the insulation resistance between the three pairs of electrodes and record it as the insulation resistance of the test specimen at the immersion temperature.

When the immersion temperature is higher than 20°C, calculate the equivalent insulation resistance at 20°C by applying the correction factor given in Fig. 13 and report this as the insulation resistance at 20°C of the material under test. In case of dispute, the immersion should be in water at 20° ± 2°C for 24 ± 1 hr and the insulation resistance should be measured in an atmosphere of 20° ± 2°C at 65 ± 5 percent relative humidity.

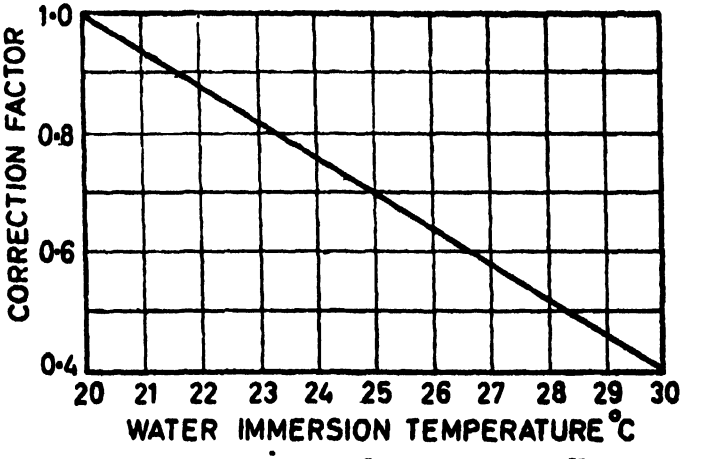


FIG. 13 CORRECTION FACTOR FOR INTERPRETATION OF VALUES OF INSULATION RESISTANCE

16. SURFACE BREAKDOWN IN AIR AFTER IMMERSION IN WATER (PROOF TEST)

16.1 Number of Tests — Carry out the test on two test specimens of size not less than 150 × 100 mm.

16.2 Electrodes — The electrodes shall consist of two solid brass cylinders 40 mm long and 40 mm in diameter. The sharp edges of the electrodes shall be rounded to a radius of not more than 1 mm.

16.3 Procedure

16.3.1 Immerse the test specimen in distilled water maintained at 20° ± 2°C for 18 hours. On removal from water, wipe dry the specimen with a clean cloth.

16.3.2 The test shall be made with an alternating voltage of frequency 50 ± 5 c/s between the electrodes. The test voltage shall be of the approximately sine wave form and during the test, the peak value as determined by spark gap, by oscillograph or by any other approved means, shall not be more than 1·45 times the RMS value. The RMS value of the applied voltage shall be measured by any suitable voltmeter.

16.3.3 The test shall be carried out in air at 20° ± 2°C. The specimen shall be supported on an insulating block at least 75 mm above any earthed body. The electrodes shall be placed with the flat surfaces in contact with one surface of the specimen. The distance between the nearest edges of the two electrodes shall be 25 mm. Commence the test with a voltage one third of the specified proof stress and increase at the rate of approximately 1 kV per second to the specified proof stress. Maintain the proof stress for one minute.

16.4 The material shall be taken to have passed the test if there is no electrical breakdown with either of the test specimens at the specified proof voltage.

17. POWER FACTOR AND PERMITTIVITY (DIELECTRIC CONSTANT)

17.0 The power factor (tan δ) and permittivity of a sheet in the condition as received shall be determined by the Hartshorn and Ward method at a temperature of 20° ± 5°C at a frequency of 1 megacycle per second, or if agreed between the purchaser and the vendor, at a frequency of 10 megacycles per second or 30 megacycles per second.

17.1 Apparatus

17.1.1 *Oscillator* — shown diagrammatically in Fig. 14. The oscillator provides the emf applied to the specimen and its associated test circuit. A range of frequencies is obtained by the use of suitable coils, each coil being tuned over a portion of the total range by means of an air-spaced variable capacitor. A series fed Hartley oscillator is found to be generally satisfactory. If, at any time, doubt is felt about the performance of the oscillator, the latter may be checked by listening to a heterodyne note with another oscillator. If a change of frequency occurs as the test circuit passes through the resonant condition, the change should be considerably less than 1 part in 10 000. Should the change of frequency be greater than 1 part in 10 000, power factor measurement should be carried out at a slightly different frequency. If the change of frequency while passing through resonance is still greater than 1 part in 10 000, the oscillator circuit components should be checked.

17.1.2 *Measuring Circuit* — shown diagrammatically in Fig. 14, consisting of the coil *LR*, two micrometer capacitors M_1 and M_2 and the valve voltmeter *V*.

17.1.2.1 *Coil, LR* — As with the oscillator, suitable measuring circuit coils are required to cover the total frequency range. If the specimen capacitance is such that the resonant frequency is not exactly the frequency required, then an auxiliary capacitor (either variable air capacitor or a small fixed mica capacitor) shall be connected in parallel with the specimen capacitor to give the required frequency. Care shall be exercised in the use of the auxiliary air capacitor because errors due to residual inductance and resistance will rapidly become more serious above 5 megacycles per second. At frequencies between 5 and 30 megacycles per second, suitable small auxiliary fixed mica capacitors may be used.

17.1.2.2 *Micrometer capacitors* — The specimen capacitor M_1 in which the specimen is placed comprises of two circular plates which are usually 50 mm in diameter. The plates may be made of copper or other suitable metal. The distance between the plates shall be adjustable by means of a micrometer head, held in an inverted cup-shaped copper mounting (*see* Fig. 15). The upper (adjustable) plate is connected to the cup-shaped mounting by means of a flexible metal tube in the form of a bellows. The plate is maintained in contact with the end of the micrometer by means of a spiral spring joining the top of the cup mounting to the plate. When the apparatus is in operation, this portion of the assembly is at earth potential.

The lower (fixed) plate is in the form of a boss on a fixed stout copper plate, which is insulated from the upper assembly and from the copper base plate of the assembly by means of pillars made from fused quartz or other suitable insulating material.

A second capacitor, the micrometer incremental capacitor M_2, is formed by a second micrometer head and the lower fixed plate of the specimen capacitor M_1. The barrel of this micrometer head is clamped into a copper extension piece fixed to the upper plate assembly, and its plunger moves in a cylindrical hole in the lower fixed plate.

The resonant circuit inductance, *LR* (Fig. 14), is connected to two terminal points on the upper and lower plate assemblies. Thus, inductance, specimen capacitor M_1 and incremental capacitor M_2 are connected in parallel.

The incremental capacitor M_2 should have a movement of 25 mm and the capacitance change over this movement should be approximately 10 $\mu\mu$F.

Capacitance changes of both capacitors can conveniently be taken from calibration graphs or tables.

17.1.2.3 *Valve voltmeter* — The circuit employed by Hartshorn and Ward is of the balanced valve type, so that no standing current passes through the galvanometer which is connected between the anodes of the two valves employed.

The input valve operates as a detector and may operate on a square law or any other known law. It is used without its base, the leads from its electrodes being connected to the required points by means of the shortest possible lengths of wire. The input is applied to the grid of this valve through a small capacitor to ensure that the input conductance of the voltmeter is small. An essential feature of the voltmeter is that the input impedance shall be substantially independent of the input voltage over the working range. The second valve is specially selected to match the input valve, and the two are arranged in a Wheatstone bridge network with a galvanometer as the indicator. The controls are adjusted so that the galvanometer deflection is zero when the input voltage is zero and the anode currents of the two valves are therefore balanced. The zero of the voltmeter may be checked either by connecting together the two plates of the specimen capacitor or by switching off the high tension supply to the oscillator.

17.1.3 *Power Unit* — The supply to the valve filaments and anodes of the oscillator and the voltmeter may be from a voltage-stabilized unit operating from the mains or from batteries.

17.2 **Test Specimen** — The specimen shall normally be a disc 50 ± 1 mm in diameter. Specimens of smaller diameter are however permissible, and indeed are necessary for material of high permittivity. The most suitable thickness of specimen for a given material is that which will give a capacitance within the range 20 to 100 $\mu\mu$F. It will generally be found in the range 0·50 to 2·50 mm (or 0·020 to 0·098 in.). The specimen shall be sensibly flat and its thickness shall not vary by more than 0·03 mm (or 0·001 in.). The thickness of the specimen may be reduced by suitable machining. The specimen shall be machined from the sheet under test. When it is necessary to reduce the thickness of a specimen to a suitable value, this shall be carried out by machining one of its faces.

17.3 **Electrodes** — When the specimen is 50 ± 1 mm in diameter, it shall be tested with disc electrodes of metal foil 0·03 to 0·05 mm (or 0·001 to 0·002 in.) thick and 50 mm in diameter. The foils shall be applied concentrically to the specimen with the thinnest possible film of petroleum jelly and shall be pressed on to the surfaces and smoothed down until all irregularities are removed. The surface of the foils shall then be cleaned with benzene. Alternatively, metal films of adequate thickness deposited in vacuum, either by sputtering or by volatilization, may be used.

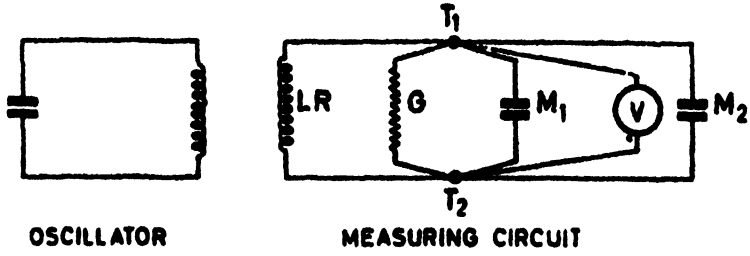


FIG. 14 BASIC FEATURES OF THE MEASURING CIRCUIT

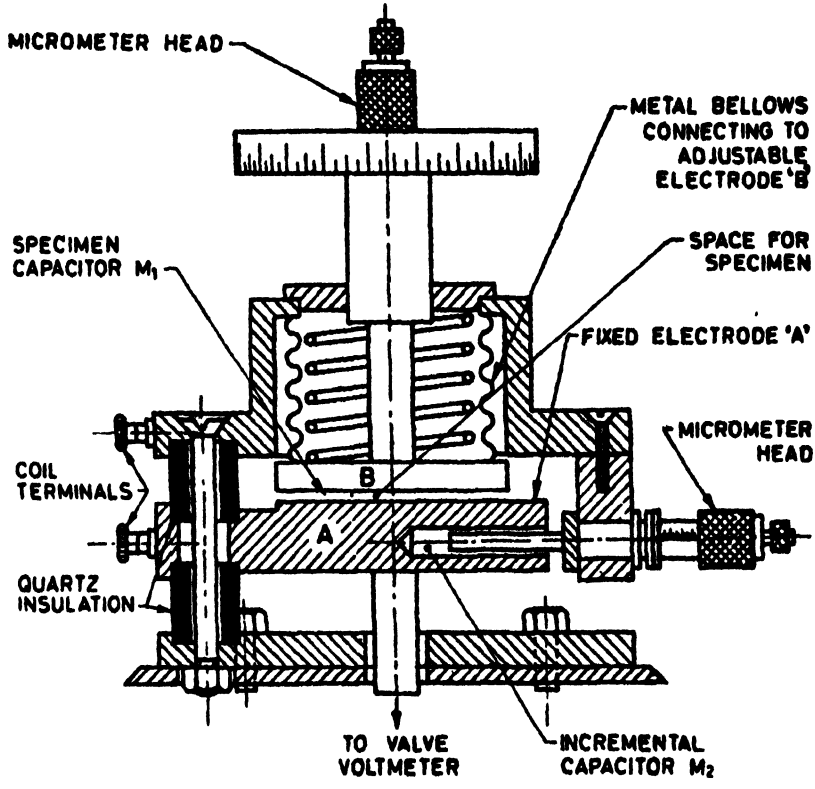


FIG. 15 CAPACITOR ASSEMBLY

If the material is known to be of high permittivity (in which case the specimen and electrodes will usually be less than 50 mm in diameter), the electrodes shall be of one of the following forms:

a) Fired-on silver films of adequate thickness, of the type commonly applied to ceramic materials; or

b) Metal films of adequate thickness deposited in vacuum either by sputtering or by volatilization.

17.4 Procedure — The procedure given under **17.4.1** should be adopted for specimens with power factor not greater than 0·1 or thickness not less than 0·5 mm. For specimens with power factor greater than 0·1 or thickness less than 0·5 mm the procedure given under **17.4.2** should be adopted.

17.4.1 *Procedure for Specimens with Power Factor not Greater Than* 0·1 *or Thickness not Less Than* 0·5 *mm* — Specimens shall be tested in the following manner:

a) The appropriate oscillator and measuring circuit coils shall be connected to the apparatus (*see* **17.1**).

b) The specimen, together with electrodes, if used, shall be placed centrally between the plates of the specimen capacitor M_1, and the adjustable plate screwed gently down so that the specimen is gripped sufficiently to ensure good contact, but without unnecessary compression. The specimen capacitor scale reading shall be noted and used to obtain the corresponding capacitance, C_t.

c) The micrometer incremental capacitor M_2 shall be set by adjusting its micrometer head to the approximate centre of its range, and the oscillator shall then be tuned to the measuring circuit resonant frequency as indicated by peak galvanometer deflection. The frequency shall be checked by reference to the oscillator calibration graph or table supplied with the oscillator. If the frequency is not within the required range, the measuring circuit coil shall be changed.

d) If the correct resonant frequency cannot be obtained as described under **17.4.1** (c), then, provided that the requirements given in **17.1.2.1** are satisfied, the oscillator shall be set to the required frequency and an auxiliary capacitor shall be connected in parallel with the specimen capacitor and resonance obtained by varying this auxiliary capacitor. Care should be taken to ensure that the true resonance is found. In most cases this presents no difficulty, but with close coupling between the measuring circuit and the oscillator, the measuring circuit may respond to a harmonic of the oscillator frequency. To guard against this, the effect of multiplying the oscillator

frequency say by 2, 3, $\frac{1}{2}$ and $\frac{1}{3}$ should be tried until the frequency giving the largest deflection is found.

e) The valve voltmeter controls shall be adjusted to ensure that the voltmeter reads zero when its input voltage is zero. The input voltage shall then be adjusted to give approximately full scale deflection on the galvanometer scale. (On some commercial models of this apparatus, this is achieved by moving the oscillator relative to the voltmeter and on others by varying the output from the oscillator.)

f) The micrometer head of the incremental capacitor M_2 shall be screwed out until the galvanometer deflection is reduced to a convenient fraction $1/q$ (for example $\frac{1}{2}$) of the initial resonant reading and the micrometer reading shall be noted.

g) The micrometer head of M_2 shall then be screwed in until the galvanometer deflection attains its maximum value (which should have remained constant) and then screwed in further until the galvanometer deflection is again reduced in the ratio $1/q$. The reading of the micrometer head shall again be noted, and the difference in capacitance (ΔC_i), corresponding to the difference between these two readings of the micrometer, shall be obtained from the calibration graph or table.

h) To check the square law relation of the valve voltmeter, the difference ΔC_i shall be obtained for values of $q = 2$ and $q = 5$. The value of ΔC_i for $q = 5$ should be twice that for $q = 2$ if the valve voltmeter satisfies the square law relation. With specimens of high power factor it may not be possible to reduce the galvanometer deflection to these fractions of the maximum deflection by means of the micrometer incremental capacitor. In this case, the deflection shall be reduced to a convenient fraction (say $\frac{1}{2}$) of its maximum value, where, for example, $q = \frac{5}{2}$, $\frac{4}{3}$ or $\frac{10}{9}$.

The ratios of the two values of ΔC_i for any two values of q may be found from the following formula:

$$\frac{(\Delta C_i)_1}{(\Delta C_i)_2} = \sqrt{\frac{q_1 - 1}{q_2 - 1}}$$

The ratio of the two values of ΔC_i shall be within $\pm$ 2 percent of that corresponding to the square law relation.

i) The measuring circuit shall be re-tuned to resonance by means of the incremental capacitor M_2 and the specimen shall be removed from between the plates of the specimen capacitor M_1.

k) The movable electrode of the specimen capacitor M_1 shall be adjusted until the measuring circuit is again in resonance, that is the capacitance lost by removing the specimen is restored by decreasing the distance between the capacitor plates. The input voltage shall be adjusted, if required, to give approximately full scale deflection. The specimen capacitor scale reading shall be noted and used to obtain the corresponding capacitance, C_2, from the specimen capacitor calibration graph or table. The edge capacitance, C_e, corresponding to the separation of the plates when the specimen is in the specimen capacitor, shall be obtained as described in 17.6. The capacitance $C_2 - C_e$ $(= C'_e)$ is equal to that of the specimen.

m) The operations described in 17.4.1 (e) to 17.4.1 (g) shall be repeated using the same ratio $1/q$ as before, and the corresponding change, ΔC_2, of capacitance of the incremental capacitor M_2 shall be obtained.

n) The square law relation may be checked at this stage in accordance with 17.4.1 (h).

17.4.2 *Procedure for Specimens with Power Factor Greater Than* 0·1 *or Thickness Less Than* 0·5 *mm* — The power factor and permittivity of specimens whose power factor is greater than 0·1 or whose thickness is less than 0·5 mm, shall be measured by one of the following methods.

17.4.2.1 This method consists of measuring:

a) The power factor and the capacitance of a composite specimen consisting of a thin or high-loss specimen 53 ± 1 mm in diameter and a low-loss material like quartz or polyethylene of the same diameter and thickness. The composite specimen may be held together with a thin film of petroleum jelly, but with no foil between the two discs.

b) The power factor and the capacitance of the low-loss component of the composite specimen.

These measurements shall be done as described in 17.4.1 (a) to 17.4.1 (n). The power factor and the permittivity of the high-loss or thin component of the composite specimen are then found from the results obtained for 17.4.2.1 (a) and 17.4.2.1 (b).

17.4.2.2 This method consists of making measurements on the thin or high-loss specimen alone. The diameter of the specimen is reduced so that its capacitance C_s and the capacitance ΔC_s as determined

in **17.4.1** (k) and **17.4.1** (g) respectively can be measured on the two capacitors M_1 and M_2.

17.5 Calculation and Report

17.5.1 The temperature and frequency of voltage used for testing shall be reported.

17.5.2 *Calculation for Specimens with Power Factor not Greater Than* 0·1 *or Thickness not Less Than* 0·5 *mm*

17.5.2.1 *When specimen diameter is* 50 *to* 54 *mm,* power factor and permittivity shall be calculated by either set of formulæ given under (a) and (b) below:

a) Power factor $(\tan \delta) = \dfrac{\Delta C_i - \Delta C_e}{2 (C_s - C_e) \sqrt{q - 1}}$, and

permittivity $K = \dfrac{144d}{D_1^2} (C_s - C_e)$

b) Power factor $(\tan \delta) = \dfrac{\Delta C_i - \Delta C_e}{2C'_s \sqrt{q - 1}}$, and

permittivity $K = \dfrac{144\, d\, C'_s}{D_1^2}$

where

$C'_s = C_s - C_i + \dfrac{D_1^2}{144\, d_1}$,

C'_s, C_i and ΔC_e are obtained as described in **17.4.1** (b), **17.4.1** (k), and **17.4.1** (m),

C_e = edge correction as determined in **17.6**,

q = value of the fraction used in **17.4.1** (f) or **17.4.1** (h),

d = thickness in mm of the specimen,

d_1 = separation of plates in mm of specimen capacitor when the specimen is between the plates, and

D_1 = diameter in mm of circular plates of specimen capacitor.

NOTE 1 — If there is a linear relationship between the micrometer reading and the capacitance change of the incremental capacitor M_2, the capacitance change $\Delta C_i - \Delta C_e$ can be determined by multiplying the corresponding readings of the incremental capacitor by a constant corresponding to the capacitance change per unit change (millimetres) of the micrometer head reading.

NOTE 2 — The formulæ above are derived on the assumption that the edge capacitance lies wholly in air.

NOTE 3 — When measurements are required to the highest accuracy, then immediately after operations 17.4.1 (f) and 17.4.1 (g) have been carried out, operation 17.4.1 (f) shall be repeated; the reading obtained should be the same or very near the same as before. The capacitance ΔC_t is obtained from the difference between the reading of M_2 obtained from 17.4.1 (g) and the mean of the two readings obtained from 17.4.1 (f). The same procedure is carried out when the specimen has been removed.

17.5.2.2 *When specimen diameter is less than* 50 *mm*, power factor and permittivity shall be calculated by the following formulæ:

$$\text{Power factor } (\tan \delta) = \frac{\Delta C_t - \Delta C_e}{2C'_e \sqrt{q - 1}} \text{ and}$$

$$\text{Permittivity } K = \frac{144\, d\, C'_e}{D^2}$$

where

$$C'_e = C_e - C_t + \frac{D^2}{144\, d_1},$$

ΔC_e is obtained as described under 17.4.1 (m),

q = value of the fraction used in 17.4.1 (f) or 17.4.1 (h),

D = diameter in mm of test specimen,

d = thickness in mm of test specimen,

d_1 = separation of plates of specimen capacitor in mm when the specimen is between the plates,

C_e = capacitance of specimen capacitor obtained as in 17.4.1 (k), and

C_t = capacitance of specimen capacitor obtained as in 17.4.1 (b).

17.5.3 *Calculation for Specimens with Power Factor Greater Than* 0·1 *or Thickness Less Than* 0·5 *mm*

17.5.3.1 *For measurement by method given in* 17.4.2.1.

$$\text{Power factor } (\tan \delta) = \frac{C_1 \tan \delta_e - C_e \tan \delta_1}{C_1 - C_e} \text{ and}$$

$$\text{Permittivity } K = \frac{144\, d\, C_1 C_e}{D_1^2 (1 + \tan^2 \delta)(C_1 - C_e)}$$

where

$\tan \delta_e$ = power factor of composite specimen, consisting of test specimen and low-loss material,

C_e = capacitance of composite specimen. It is equal to the capacitance of the specimen capacitor M_1 with composite specimen out [*see* 17.4.1 (k)], minus the edge capacitance corresponding to the thickness of composite specimen,

$\tan \delta_1$ = power factor of low-loss material,

C_1 = capacitance of low-loss material. It is equal to the capacitance of the specimen capacitor M_1 with low-loss specimen out [*see* **17.4.1** (*k*)], minus the edge capacitance corresponding to the thickness of the low-loss material,

d = thickness in mm of test specimen, and

D_1 = diameter in mm of specimen capacitor plates.

17.5.3.2 *For measurement by method given in* **17.4.2.2** — Calculations shall be done as given in **17.5.2.2.**

17.6 Edge Correction — For sheet material in the form of disc, the edge capacitance, that is the capacitance representing the portion of the electric field located round the edges of the plate electrodes, may be calculated from Kirchhoff's formula:

$$\text{Edge capacitance, } C_e\ (\mu\mu F) = \frac{D_1}{72\pi}\left[\log_e \frac{8\pi D_1 (t+d)}{d^2} + \frac{t}{d}\log_e \frac{t+d}{t} - 3\right]$$

where

D_1 = diameter in mm of the plate electrodes,

t = thickness in mm of the plate electrodes, and

d = thickness in mm of the specimen.

Experience with typical specimens has shown that, if the edge capacitance is derived from the formula on the assumption that the edge capacitance lies wholly in air, the error in the calculated value of specimen capacitance is not likely to exceed 2 percent for any ordinary specimen and in general the error will not exceed 1 percent. The following table gives the values of edge capacitance calculated in this way for different thicknesses of specimen, for a value of t of 5 mm:

Specimen Thickness, d	*Edge Capacitance, C_e*
mm	$\mu\mu F$
0·3	2·0
0·4	1·9
0·5	1·8
0·6	1·7
0·8	1·6
1·0	1·5
1·3	1·4
1·6	1·3
2·1	1·2
2·7	1·1
3·5	1·0

17.7 Note on High Frequencies — With the procedure described in **17.4.1** and **17.4.2**, the resistance of the electrodes becomes appreciable at high frequencies and causes a spurious increase in power factor if the specimen is not flat and of uniform thickness. The frequency at which this becomes noticeable depends on the surface flatness of the specimen, but the effect has been observed at frequencies as low as 10 megacycles per second. If it is suspected that this effect is present, additional measurements of capacitance and power factor shall be made with the electrodes removed from the specimen.

If C_w and $\tan \delta_w$ are the capacitance and power factor of the specimen without electrodes, then the true power factor is given by the formula:

$$\tan \delta_s = \frac{C'_s}{C_w} \tan \delta_w$$

where

C'_s is the capacitance of the specimen with electrodes.

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Savitri Complex, 116 G.T. Road, GHAZIABAD 201001	91-71 19 98
53/5 Ward No.29, R.G. Barua Road, 5th By-lane, GUWAHATI 781003	56 65 08
5-8-56C, L.N. Gupta Marg, Nampally Station Road, HYDERABAD 500001	320 10 84
E-52, Chitaranjan Marg, C- Scheme, JAIPUR 302001	37 38 79
117/418 B, Sarvodaya Nagar, KANPUR 208005	21 68 76
Seth Bhawan, 2nd Floor, Behind Leela Cinema, Naval Kishore Road, LUCKNOW 226005	21 89 23
NIT Building, Second Floor, Gokulpat Market, NAGPUR 440010	52 51 71
Patliputra Industrial Estate, PATNA 800013	26 28 08
Institution of Engineers (India) Building 1332 Shivaji Nagar, PUNE 411005	32 36 35
'Sahajanand House' 3rd Floor, Bhaktinagar Circle, 80 Feet Road, RAJKOT 360002	26 85 86
T.C. No. 14/1421, University P. O. Palayam, THIRUVANANTHAPURAM 695034	32 72 15
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