BRITISH STANDARD

METHODS OF TESTING VULCANIZED RUBBER

PART C 3 : DETERMINATION OF PERMITTIVITY AND POWER FACTOR OF INSULATING SOFT VULCANIZED RUBBER AND EBONITE

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British Standards House, 2 Park St., London, W1Y 4AA

Telegrams: Standards London W1 Telephone: 01-629 9000

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The Rubber Industry Standards Committee, under whose supervision this British Standard was prepared, consists of representatives from the following Government departments and industrial organizations:—

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*Federation of British Rubber and Allied Manufacturers' Associations
*Institution of the Rubber Industry
*Ministry of Supply
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THIS BRITISH STANDARD, having been approved by the Rubber Industry Standards Committee and endorsed by the Chairman of the Chemical Divisional Council, was published under the authority of the General Council on 27th June, 1956.

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This standard makes reference to the following British Standards:

B.S. 870. External micrometers.
B.S. 907. Dial gauges for linear measurement.
B.S. 2067. Determination of power factor and permittivity of insulating materials (Hartshorn and Ward method).

British Standards are revised, when necessary, by the issue either of amendment slips or of revised editions. It is important that users of British Standards should ascertain that they are in possession of the latest amendments or editions.

The following B.S.I. references relate to the work on this standard:—
Committee reference RUC/10/6. Draft for comment CV(RUC) 5413

BRITISH STANDARD

METHODS OF TESTING VULCANIZED RUBBER

Part C 3 : Determination of Permittivity and Power Factor of Insulating Soft Vulcanized Rubber and Ebonite

FOREWORD

This British Standard has been published under the authority of the Rubber Industry Standards Committee. In deciding to issue a revision of the 1950 edition, it has also been considered desirable to publish B.S. 903 in separate parts and the present part replaces Part 34 of 1950. The main differences are in the adoption of metric dimensions and in the layout.

The group of parts in which the prefix letter ' C ' is used covers methods of testing the electrical properties of rubber and ebonite. Further parts in this group have been issued as follows:

Part C 1. Determination of surface resistivity of insulating soft vulcanized rubber and ebonite.

Part C 2. Determination of volume resistivity of insulating soft vulcanized rubber and ebonite.

SECTION 1 DEFINITIONS

For the purposes of this British Standard the following definitions shall apply:—

Permittivity. The ratio of the electric flux density produced in a dielectric medium to that produced in free space by the same electric force. In effect it is the ratio of the capacitance of a condenser having the material as dielectric to the capacitance of a similar condenser having air, or more precisely a vacuum, as dielectric.

Power factor. The sine of the loss angle, i.e. the angle by which the angle of lead of the current falls short of 90 degrees. In effect it is the ratio of the power loss in the material when used as the dielectric of a condenser to the product of the applied voltage and the resultant current. In dielectrics the property normally measured is the tangent of the loss angle; for small values of the loss angle this does not differ appreciably from the sine.

SECTION 2 AUDIO FREQUENCY TEST

2.1 Summary and explanatory note. Permittivity and power factor at audio-frequencies are conveniently measured by means of a resistance-capacitance bridge network, the Schering bridge with Wagner earth attachment being a suitable network. These properties may change considerably with frequency and temperature, and the results of this test are valid for prediction of performance only for a narrow band of frequencies and temperatures in the vicinity of those adopted in the test.

2.2 Test piece

2.21 *Soft rubber.* The test piece shall be a disk with smooth surfaces not less than 100 mm in diameter, or not less than 200 mm in diameter, according to the size of electrodes to be used, and $1{\cdot}25 \pm 0{\cdot}2$ mm in mean thickness. The variation in thickness within a given test piece shall not exceed 0·1 mm.

2.22 *Ebonite.* The test piece shall be a disk not less than 100 mm in diameter, or not less than 200 mm in diameter, according to the size of electrodes to be used, and not exceeding 3·5 mm in mean thickness. With disks approximating to this thickness, the mean thickness of test pieces used for comparative tests shall not vary by more than 1 mm. The variation in thickness within a given test piece shall not exceed 0·2 mm.

NOTE. The thickest permissible ebonite test piece, when tested with the small electrodes, may have a capacitance as low as 15 pF on which most commercial bridges would give a sensitivity of about $\pm 0{\cdot}003$ in tan δ. A further error of about 0·001 may occur on such test pieces when tested on a bridge without a Wagner earth due to the top electrode/guard ring capacitance. The sensitivity improves and the above error decreases with increased test piece capacitance.

2.3 Electrodes. The test piece shall be provided with electrodes and a guard ring. These shall take one of the following forms:—

2.31 *Graphite.* This shall be applied, before conditioning, in the form of a colloidal suspension in water. It is convenient to dilute the graphite suspension with distilled water to the consistency of drawing ink, and then to draw the circular outlines of the electrodes and guard ring on the surface of the test piece, afterwards painting the appropriate areas with the graphite suspension. Alternatively, the graphite may be applied by spraying, suitable stencils being used.

2.32 *Metal foil.* Disks of metal foil about 0·025 mm thick shall be applied, after conditioning, to the flat faces of the test piece, using a very thin coating of petroleum jelly or silicone grease as adhesive. The foil shall be pressed or rolled on to the surface and smoothed down until all irregularities are removed. It shall then be cut to the exact size which it is proposed to use for the electrodes. Alternatively the electrodes may be cut to shape before application. When the material under test is soft rubber, the period between application of the jelly or grease and testing shall be as short as possible.

2.33 *Mercury*. Suitable electrodes which shall be applied after conditioning and which can be modified to give the required dimensions are described in T. I. Jones, *Journal I.E.E.* **74**, 185.

As altered Nov., 1962

2.34 *Metal films*.* Metal films of adequate thickness deposited in vacuo, either by sputtering or by volatilization, shall be applied before conditioning.

When graphite, metal foil or metal film electrodes are used, they and the guard ring shall be supplemented after conditioning by rigid brass backing plates which cover the electrodes.

The electrodes shall be circular, the upper electrode being surrounded by a guard ring. The dimensions of the electrodes, guard ring and plates, if any, shall be as given in Table 1 (see also Fig. 1):—

TABLE 1. DIMENSIONS OF ELECTRODES

	D_1	D_2	D_3 *min.*	D_4 *min.*
	cm	cm	cm	cm
Large electrodes	15·0	15·4	20	20
Small electrodes	5·0	5·4	10	10

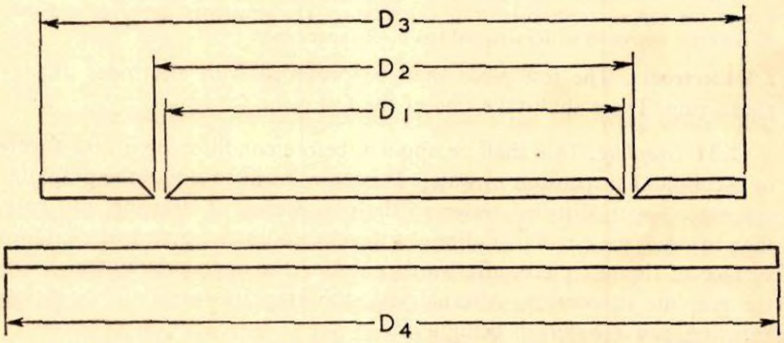

Fig. 1. Backing plate and electrode dimensions for permittivity and power factor test (audio frequency)

2.4 Apparatus

2.41 *Schering bridge with Wagner earth*. A suitable form is shown in Fig. 2 and described below.

* There may be difficulty in applying certain metals to soft rubber.

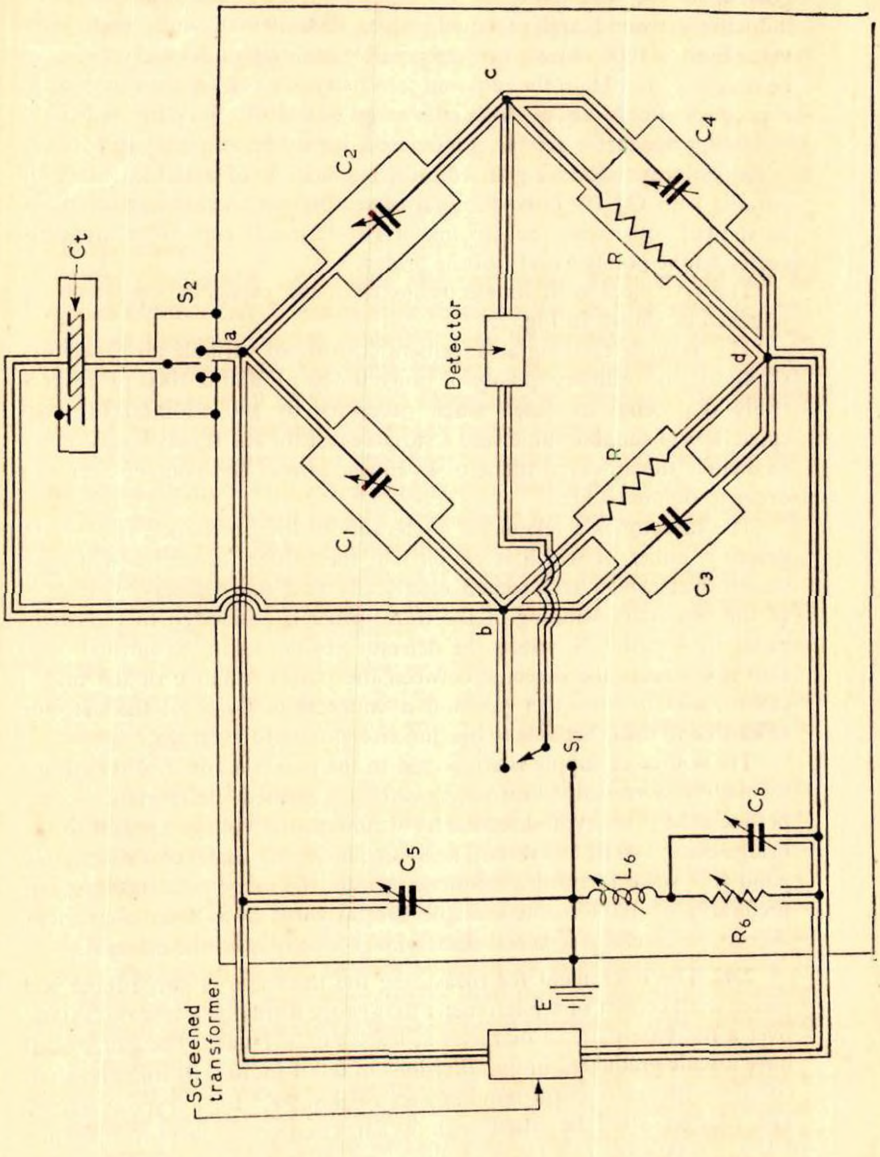

Fig. 2. Schering bridge for permittivity and power factor tests

The capacitor C_1 is a variable air capacitor of good quality having a range of about 0–600 pF and C_2 is a variable air capacitor of reasonably good quality of about the same range as C_1. The ratio arms are non-inductively wound and of equal value, 1000–10 000 ohms, each. The value used is 1000 ohms wherever possible, although a higher value may be necessary to obtain the required sensitivity. C_3 and C_4 are variable air capacitors of ordinary quality and a range of 0–1000 pF. When materials of high power factor are being measured, it may be necessary to connect additional capacitors, e.g. fixed mica capacitors of suitable value, in parallel with C_4. If three-terminal capacitors are used the screening is as shown; otherwise the screens of two-terminal capacitors are connected to the points *b* and *c* of the bridge.

The test piece with its electrodes form the capacitor C_t, which is screened as shown in Fig. 2.

The Wagner earthing arrangement consists of variable air-capacitors C_5 and C_6 of ordinary quality of range 0–500 pF and 0–1000 pF respectively (C_6 being increased when necessary by the addition of fixed capacitors of suitable value) and a variable resistor R_6. It may be necessary to include the air-cored inductor L_6 in one arm of the Wagner circuit in order to obtain balance.

The detector is a telephone, preferably of low resistance, or a valve detector, either of which is coupled to the bridge through a matching transformer which is screened electrically and magnetically. One pole of the secondary winding of the transformer is connected to the earth-point E. A switch S_1 selects the detector positions: in the normal position it connects the detector between the points *b* and *c* of the bridge circuit, and in the other position it connects one side of the detector to earth and the other side to one junction point of the bridge.

The source of supply is connected to the points *a* and *d* of the bridge through a screened transformer with an earthed electrostatic screen between the primary and secondary windings, the voltage applied to the bridge being 100 to 150 volts. The source of supply shall be of reasonably good sine wave form of a frequency within the range 800–1600 c/s, but preferably of 1000 c/s. It shall be several yards away from the bridge unless it is carefully screened electro-magnetically from the detector.

2.42 The instrument for measuring the thickness of soft rubber test pieces shall consist of a micrometer dial-gauge firmly held in a rigid stand over a flat base-plate of diameter at least 2 in. (51 mm). The gauge shall have a scale graduated in unit divisions of 0·001 in. or 0·01 mm and shall comply with the relevant requirements of B.S. 907* for a Type A gauge. The plunger shall be fitted with a flat circular contact of diameter $0{\cdot}150 \pm 0{\cdot}002$ in. ($3{\cdot}80 \pm 0{\cdot}05$ mm), which is square to the plunger and parallel to the base-plate. The dial-gauge shall operate under a sub-

* B.S. 907, 'Dial gauges for linear measurement'.

stantially dead-weight load of 0·85 ± 0·10 oz (24 ± 3 g), equivalent to a pressure on the rubber of about 3 lb/sq. in. (200 g/sq. cm). For the most accurate results, the instrument shall be used as a comparator as recommended in B.S. 907, which also includes notes on the care and use of dial gauges. The dial gauge shall be capable of measuring the thickness at the centre of the test piece.

The thickness of ebonite test pieces shall be measured with a micrometer dial gauge or external micrometer capable of reaching the centre of the test piece and having flat measuring faces between ⅛ in. and ¼ in. diameter (3–6 mm). (See also B.S. 870* and 907.†)

2.5 Procedure

2.51 *Conditioning of samples and test pieces.* Tests should not be carried out less than 24 hours after vulcanization, and for accurate comparisons between different rubbers it may be necessary for these to be tested at substantially the same interval after vulcanization. Samples and test pieces shall be protected from light as completely as possible during the interval between vulcanization and testing.

Before conditioning and applying the electrodes each test piece shall be wiped carefully with absorbent paper or with a soft cloth.

The test pieces shall then be conditioned for not less than 18 hours and not more than 72 hours immediately before test as follows:—

a. Ebonite. Relative humidity 65 ± 5 per cent, temperature 20 ± 5°C.

b. Soft rubber. Relative humidity 65 ± 5 per cent, temperature 20 ± 2°C.

NOTE. See Note under 2.6, Temperature of test.

2.52 *Determination of permittivity and power factor.* When testing by means of the apparatus shown in Fig. 2 the following procedure shall be adopted:—

(i) With the lower electrode of the capacitor C_t connected to the bridge point *a* by means of the switch S_2, the detector shall be connected between the points *b* and *c* of the bridge and C_1 set near its minimum value. The bridge circuit shall be roughly balanced by adjustment of C_2 and C_4, C_3 having been set near its minimum value. The detector shall then be transferred to the Wagner circuit by means of the switch S_1 and balance obtained by adjustment of C_5, R_6, L_6 and C_6. The balancing procedure shall then be repeated, the bridge circuit and Wagner circuit being adjusted alternately until the balances converge.

(ii) With the lower electrode of the capacitor C_t connected to earth by means of the switch S_2, and with the detector connected between points *b* and *c* of the bridge, the bridge circuit shall be rebalanced by adjustment of C_1 and C_4 only. The Wagner and

* B.S. 870, 'External micrometers'.

† B.S. 907, 'Dial gauges for linear measurement'

bridge circuits shall be adjusted alternately as before until the balances converge. C_2 and C_3 shall not be altered during this operation.

(iii) Alternatively the adjustment (i) may be carried out with the lower electrode earthed and C_1 set at a suitable value and adjustment (ii) with the lower electrode connected to the bridge point *a*.

2.6 Temperature of test. The test shall be carried out at a temperature of 20 ± 5°C for ebonite and 20 ± 2°C for soft rubber.

NOTE. A temperature of 20°C for conditioning and testing is not yet practicable for all countries. In tropical countries it is very difficult to maintain conditioning chambers or laboratories at this temperature and an alternative temperature of 27°C is therefore permitted. The tolerances should be as given in Clauses 2.51 and 2.6 for ebonite and soft rubber.

2.7 Calculation of results. Let C_4a and C_4b be the readings of C_4, and C_1a and C_1b the readings of C_1 for balances with the lower electrode connected to *a* and to earth respectively, all readings being expressed in pico-farads.

The permittivity shall be calculated by the formula:

$$\epsilon = \frac{1{\cdot}44\, T\,(C_1b - C_1a)}{D^2}$$

where ϵ = permittivity

T = thickness of test piece in millimetres

D = mean diameter in centimetres $= \frac{D_1 + D_2}{2}$ where D_1 is the diameter of the upper electrode and D_2 is in the inner diameter of the guard ring.

The tangent of the loss angle ($\tan \delta$) shall be calculated by the formula:

$$\tan \delta = \frac{2\pi f\, RC_1b(C_4a - C_4b) \times 10^{-12}}{(C_1b - C_1a)}$$

where f = frequency in cycles per second

R = resistance of the ratio arms in ohms

For values of $\tan \delta$ up to 0·07 the difference between the value of $\tan \delta$ and the power factor ($\sin \delta$) is less than 1 part in 700.

2.8 Report. The report shall state:

1. Permittivity and power factor (for values of power factor greater than 0·07, it shall be stated whether the value refers to the power factor ($\sin \delta$) or to $\tan \delta$).
2. Frequency.
3. Size of electrode.
4. Type of electrode.
5. Temperature of test
6. Thickness of test piece.

SECTION 3 RADIO-FREQUENCY TEST

3.1 Summary and explanatory note. Permittivity and power factor at radio frequencies are conveniently measured by means of the resonance method referred to below, in which the permittivity is obtained from the readings of a micrometer condenser into which the test piece is inserted, while the power factor is determined from the readings of a second micrometer condenser of very small range which serves to measure the sharpness of resonance and hence the power factor. Permittivity and power factor may change considerably with frequency and temperature, and the results of this test are valid for prediction of performance only for a narrow band of frequencies and temperatures in the vicinity of those adopted for the test.

3.2 Test piece. A flat disk 53 $\pm$ 1 mm in diameter shall be used with the apparatus described in B.S. 2067.* The most suitable thickness of test piece is that which will give a capacitance within the range 20–100 pF. It will generally be found in the range 1·00–2·50 mm.

The two faces of the test piece shall be flat. The variation in thickness in a given test piece shall not exceed 0·1 mm.

3.3 Electrodes. After the test piece has been conditioned it shall be provided with electrodes of metal foil 0·025–0·050 mm thick and 50 mm in diameter. The foils shall be applied concentrically to the specimen with the thinnest possible film of petroleum jelly or silicone grease, and shall be pressed on to the surface and smoothed down until all irregularities are removed. When the material under test is soft rubber, the period between application of the jelly or grease and testing shall be as short as possible.

Alternatively, metal films† of adequate thickness deposited in vacuo, either by sputtering or by volatilization, shall be applied and the test piece subsequently conditioned.

3.4 Apparatus. The apparatus shall be as described in B.S. 2067 * or any other apparatus which can be shown to give the same results.

The instrument for measuring the thickness of soft rubber test pieces shall consist of a micrometer dial-gauge firmly held in a rigid stand over a flat base-plate of diameter at least 2 in. (50 mm). The gauge shall have a scale graduated in unit divisions of 0·001 in. or 0·01 mm, and shall comply with the relevant requirements of B.S. 907‡ for a Type A gauge. The dial gauge shall be fitted with a flat contact square to the plunger and parallel to the base-plate and shall operate with a pressure of 200 ± 30 gf/cm^2. For the most accurate results, the instrument shall be *As altered Dec., 1965*

* B.S. 2067, ' Determination of power factor and permittivity of insulating materials (Hartshorn and Ward method) '.

† There may be difficulty in applying certain metal to soft rubber.

‡ B.S. 907, ' Dial gauges for linear measurement '.

used as a comparator as recommended in B.S. 907,* which also includes notes on the care and use of dial gauges. The dial gauge shall be capable of measuring the thickness at the centre of the test piece.

NOTE. It is preferable for the gauge to have a contact of diameter about 4 mm as this may be used on almost all test pieces without any sub-part of the contact overhanging the test piece edge which would increase the contact pressure.

The thickness of ebonite test pieces shall be measured with a micrometer dial gauge or external micrometer capable of reaching the centre of the test piece and having flat measuring faces between ⅛ in. and ¼ in. in diameter (3–6 mm). (See also B.S. 870† and 907.*)

3.5 Procedure

3.51 *Conditioning of samples and test pieces*. Tests should not be carried out less than 24 hours after vulcanization, and for accurate comparisons between different rubbers it may be necessary to ensure that these are tested at substantially the same interval after vulcanization.

Samples and test pieces shall be protected from light as completely as possible during the interval between vulcanization and testing.

Before conditioning and applying the electrodes each test piece shall be wiped carefully with absorbent paper or with a soft cloth.

The test pieces shall then be conditioned for not less than 18 hours and not more than 72 hours immediately before test as follows:

a. *Ebonite*. Relative humidity 65 ± 5 per cent, temperature 20 ± 5°C.
b. *Soft rubber*. Relative humidity 65 ± 5 per cent, temperature 20 ± 2°C.

NOTE. See Note under 3.6, Temperature of test.

3.52 *Determination of permittivity and power factor.* When using the Hartshorn-Ward apparatus the most suitable procedure is that described in B.S. 2067,‡ Clause 7. The test shall normally be carried out at a frequency of approximately 1 Mc/s.

3.6 Temperature of test. The test shall be carried out at a temperature of 20 ± 5°C for ebonite and 20 ± 2°C for soft rubber.

NOTE. A temperature of 20°C for conditioning and testing is not yet practicable for all countries. In tropical countries it is very difficult to maintain conditioning chambers or laboratories at this temperature and an alternative temperature of 27°C is therefore permitted. The tolerances shall be as given in Clauses 3.51 and 3.6 for ebonite and soft rubber.

3.7 Calculation of results. When the Hartshorn-Ward method is used the permittivity and power factor shall be calculated as described in B.S. 2067,‡ Clause 7.

* B.S. 907. 'Dial gauges for linear measurement'.
† B.S. 870, 'External micrometers'.
‡ B.S. 2067, 'Determination of power factor and permittivity of insulating materials (Hartshorn and Ward method)'.

3.8 Report. The report shall state:

1. Permittivity and power factor (for values of power factor greater than 0·07, it shall be stated whether the value refers to the power factor (sin δ) or to tan δ).
2. Frequency.
3. Method of test if other than Hartshorn-Ward.
4. Temperature of test.
5. Thickness of test piece.

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