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Methods for

Measurements in electrostatics

Part 2. Test methods

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Committees responsible for this British Standard

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ERA Technology Ltd.
Electrical and Electronic Insulation Association (BEAMA Ltd.)
European Electrostatic Discharge Association
Federation of Resin Formulators and Applicators (FeKFA)
Federation of the Electronics Industry
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Foreword

This Part of BS 7506 was prepared by Technical Committee PRI/25.

BS 7506 Methods for measurement in electrostatics comprises two Parts:

Part 1: *Guide to basic electrostatics*
Part 2: *Test methods*

The test methods described are those considered most appropriate for electrostatic measurements. Several methods described in this Part are simplified versions of existing British Standards, since for the purposes of electrostatics the range of values of significance may be restricted. The methods described give adequate accuracy and precision in these ranges. In many cases more precise or accurate procedures are available, and for these more specialized standards should be consulted. Part 1 of this standard provides information and guidance on methods for making reliable measurements.

Annex A describes procedures for calibration of the instruments used in the test methods specified. Although calibration is not always deemed to be necessarily prescribed, it is considered advisable to provide guidance.

Annex B provides useful references for additional information.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

1 Scope

This Part of BS 7506 comprises standard methods of measurement, providing reliable means of determining the values of those properties of materials relevant to electrostatic phenomena. The range of values of a property which is significant to electrostatic effects is limited, and it is only useful to measure such a property within this range (for example resistance values between 10^6 Ω and 10^{10} Ω). For this reason, simpler procedures are acceptable, and fewer problems of interpretation arise. For precise measurements of properties outside these ranges reference should be made to more specialized standard methods and to relevant scientific literature.

2 Informative references

This Part of BS 7506 refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on the inside back cover, but reference should be made to the latest editions.

3 Measurement of electric field

3.1 Principle

3.1.1 *General*

Electric fields are measured from the charge induced on a conducting surface. Fieldmeters (used for measuring the field) are of two main types: induction probe and field mill instruments.

3.1.2 *Induction probe instruments*

Induction probe instruments are simple and of relatively low cost. They consist, as shown in figure 1, of a sensing surface with a defined capacitance to earth connected to a very high input impedance amplifier. The signal V (volts) observed at the preamplifier input when a sensing surface of effective area A (m^2) with an input capacitance C (F), is exposed to an electric field E ($\mathrm{V \cdot m^{-1}}$) is given by:

$$V = \varepsilon_0 EA/C$$

where ε_0 is the electric constant ($8.85 \times 10^{-12}\ \mathrm{F \cdot m^{-1}}$).

The effective sensing area will depend on the screening arrangements, and should be calibrated in situ. Zero drift can arise from variation of the bias currents and offset voltages at the preamplifier input. Induction probe instruments have a finite input time constant arising from the input capacitance and inevitable input leakage resistance. Consequently, induction probe instruments are used for relatively short term measurements (tens of seconds) and require to be adjusted to zero reading in a zero electric field environment.

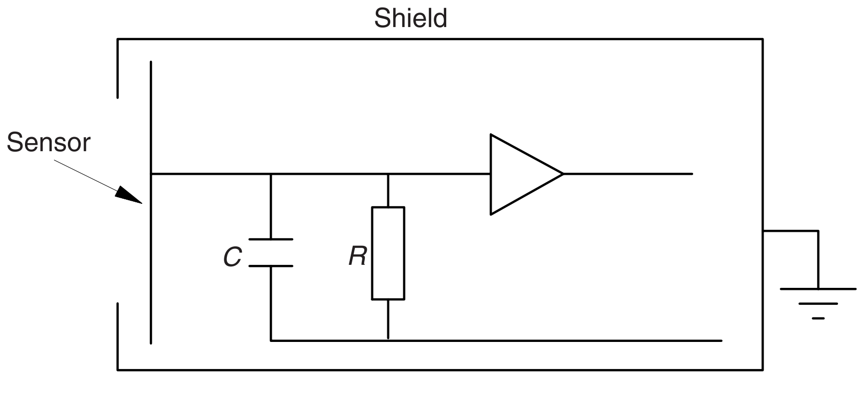


Figure 1. Induction probe fieldmeter

3.1.3 *Field mill instruments*

Field mill fieldmeters overcome the limitations of induction probes by using a rotating chopper, which is normally earthed, to modulate the coupling of the electric field to the sensing surface. The general arrangement is shown in figure 2. So long as the timescale of modulation is suitably shorter than the product of the input capacitance, C, and the effective input resistance to earth, R, then an alternating signal is generated which is independent of the rate of chopping and the value of the input resistor. The response then depends only on the area of the sensing surface A and the value of the input capacitance C. The change of charge induced on the sensing surface is given by dQ:

$$dQ = A\,\varepsilon_0\,dE$$

The peak-to-peak signal V (volts) generated will be:

$$V = dQ/C$$

For a depth of modulation, f, of the observed electric field by the rotation of the chopper:

$$dE = f\,E$$

and

$$V = \varepsilon_0\,f\,E\,A/C$$

Phase sensitive detection of the observed alternating signal after amplification generates an output signal whose strength and polarity relate proportionally and directly to the observed electric field.

3.2 Fieldmeters

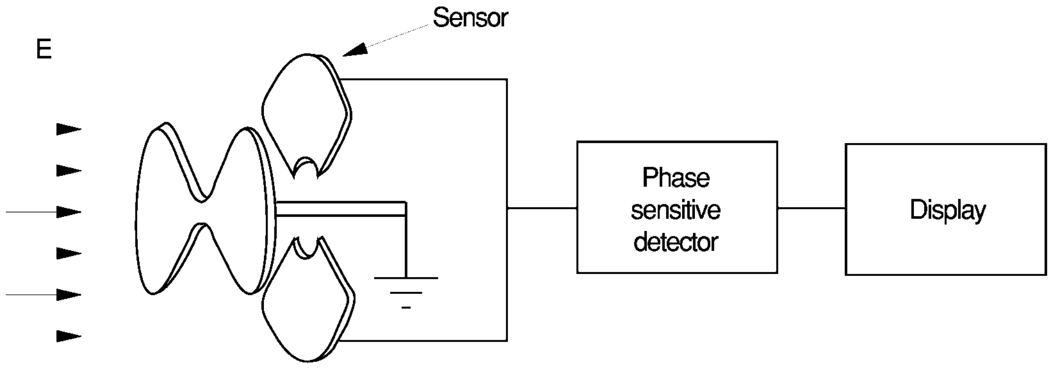
3.2.1 *Construction*

The case of the fieldmeter shall be of a conductive or static dissipative material.

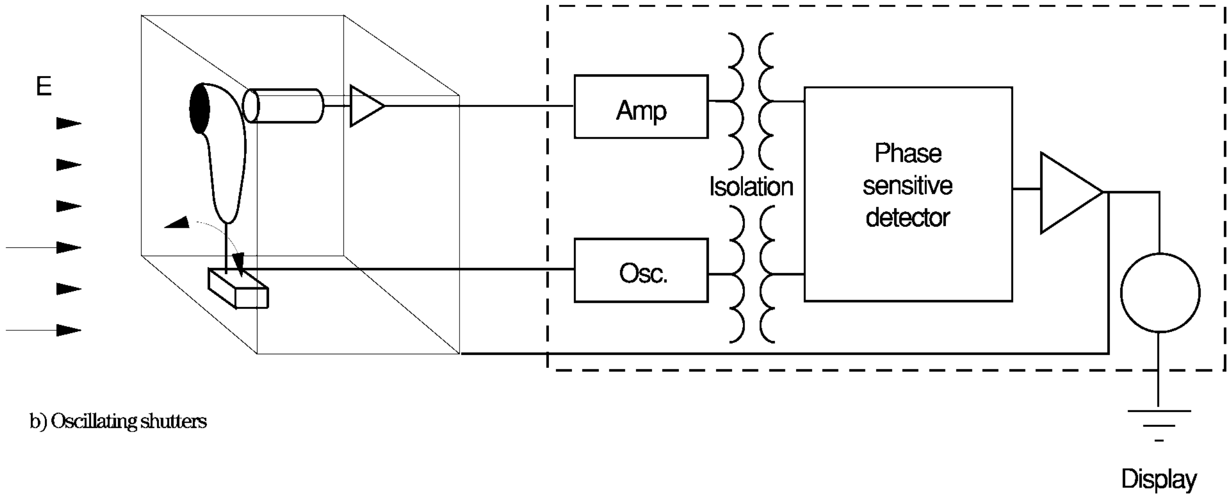
No insulating materials shall be visible on or near the sensing aperture.

NOTE. Insulating materials acquire and retain static charge which will affect the readings and the zero setting. This is particularly important for high sensitivity instruments and for instruments used near air ionizer units.

The sensing aperture of the fieldmeter shall be defined within a flat conducting region of the case, mounted flush with a surrounding surface for application measurements and for calibration. Readings shall relate to the electric field at this aperture.



a) Rotating shutters



b) Oscillating shutters

Figure 2. Field mills with rotating and oscillating shutters

Fieldmeter instruments shall include provision for external adjustment of the zero reading when observing a zero electric field environment. This shall be the only adjustment of basic instrument operation directly accessible by the user.

3.2.2 *Reference potential*

An earth bonding point shall be provided and be clearly identified. The fieldmeter shall be bonded to a defined reference potential, usually earth potential, before and during use.

3.2.3 *Susceptibility to interference*

Operation shall not be adversely affected by exposure to high value or fast changing electric fields; for example from nearby spark discharges.

3.2.4 *Sensitivity*

Fieldmeter instruments are categorized in terms of sensitivity and accuracy.

High sensitivity fieldmeters are able to measure and display values of electric field of 100 $V{\cdot}m^{-1}$ with the zero stable within 50 $V{\cdot}m^{-1}$ over at least 1000 s. A reading of 100 $V{\cdot}m^{-1}$ shall be at least 10 % of an analogue scale reading or at least the second decimal digit of a digital display.

For accurate measurements with field mill instruments the time constant of the input resistance and capacitance shall be at least five times the half cycle time of the minimum chopping frequency of the instrument. Also, the time constants of any high pass noise reduction filtering in signal amplification shall be four to five times the half cycle time multiplied by the number of such filtering stages. To avoid interaction with alternating mains supply signals the chopping frequency shall be at least three times the frequency of the supply.

3.2.5 *Display*

The instrument display, and any signal output, shall give a linear response to electric field, symmetrical with polarity and with no hysteresis. For high accuracy instruments these properties of the instrument shall be within ± 1 % of full scale reading of the operating range and for lower accuracy instruments within ± 5 %. The output time constant at the display shall be less than 1 s.

NOTE. This is particularly important for handheld instruments used to search for sources of static charge. The display shows electric field values with polarity. Scale readings are to be given in $V{\cdot}m^{-1}$ or $kV{\cdot}m^{-1}$ as appropriate.

In battery powered instruments warning shall be given when the battery voltage is at a level at which readings may become unreliable.

3.3 Procedure

If using an induction probe fieldmeter, switch on in a region free of electric fields.

Before starting measurements check and record the zero reading and stability. Check the zero with the fieldmeter looking into a clean metal chamber in which the nearest surfaces are at least 50 mm away from the sensing apertures, avoiding the influence of contact potential and contamination effects. Make readings relative to the instrument zero.

When using an induction probe instrument make measurements within a shorter time relative to the input decay time constant and without re-zeroing.

Ensure that surfaces around the sensing region are clean.

NOTE 1. This is particularly important with high sensitivity instruments and in work involving insulating particles. Insulating particles readily become charged and any such particles deposited in or around the sensing region will offset the instrument zero. Air purging helps prevent particle deposition.

Check the zero reading at appropriate intervals (see item b) and record its value.

NOTE 2. On first use of a particular fieldmeter it is important for the user to carry out the following checks.

a) Bond the instrument to earth.

b) Switch the instrument on in a region free of static charges and electric fields and check the stability of the zero reading over times comparable to the times needed for the measurements.

c) Switch the instrument on in a field-free region and move it to observe a constant high value of electric field, for example a steady voltage on a metal plate at a stable distance. Observe the rate of change of reading and estimate the input decay time constant. After a time return it to a field-free region and check if the zero reading has changed.

3.4 Expression of results

The results of electric field measurements are the values of electric field observed at particular times in $V{\cdot}m^{-1}$.

3.5 Test report

The report shall include at least the following information:

a) the number and date of this standard;

b) date and time of measurements;

c) location, arrangement and time when measurements made;

d) ambient temperature and relative humidity in measurement region;

e) identification of instrumentation used and date of most recent calibration.

4 Measurement of potential

4.1 Principle

The potential of a conducting object may be measured by direct connection to an electrostatic voltmeter or voltmeter with a suitably high input impedance.

The potential of a charged surface, insulating or conducting, may be measured by the electric field which it creates at a nearby fieldmeter held at a fixed potential, usually earth.

A more accurate measure is obtained if the potential of the fieldmeter is adjusted to give zero field at the fieldmeter, the potential of the meter then being equal to that of the surface or location in the volume, described usually as the 'voltage follower configuration'.

The potential of a localized region in a volume can be measured using a fieldmeter in either a simple or a voltage follower configuration as above.

4.2 Fieldmeters and voltmeters

4.2.1 *Simple configuration fieldmeter*

The potential of a surface is calculated from the electric field at a nearby electrostatic fieldmeter at earth or a defined potential.

Induction or field mill fieldmeter instruments shall be as described in **3.2**.

The electric field between the body and the fieldmeter is usually non-uniform and the surface voltage is not a simple product of the electric field E (V·m^{-1}) and the separation distance d (m). A geometric factor f may need to be used; for plane surfaces which have a radial extent less than five times the separation gap the correction factor will be affected by the size and form of the surface on which the potential is measured.

NOTE. In these circumstances the factor f may be determined by calibration (see annex A) or computer modelling of the particular geometric arrangement. The potential is is given by:

$$V = Efd$$

For accurate measurements it is necessary that the fieldmeter is well separated from the object to minimize added capacitance but near enough to avoid the influence of charges and potentials on other nearby objects and surfaces. Instruments used solely for measurement of potential are used at fixed distances from the objects to be measured and are calibrated directly in units of potential.

NOTE. The simple fieldmeter can also be used in a region of space charge for measurement of local space potential.

4.2.2 *Fieldmeter used as voltmeter*

When using a fieldmeter the potential of a conducting body is measured by connection to an electrode mounted in a fixed geometrical relationship to the fieldmeter, the whole being shielded from the surrounding environment. The assembly is calibrated to indicate the potential of the connected body.

The input capacitance of the electrode and connecting leads shall be small in comparison with the self-capacitance of the object under test.

4.2.3 *Fieldmeter connected in voltage follower configuration*

a) *Surface potential*

The potential of an insulating or conducting surface is measured using a fieldmeter close to the surface and adjusting the potential of the fieldmeter so that the indicated field is brought to zero, usually achieved dynamically with a feedback circuit. The applied potential is then equal to the potential of the surface to be measured.

Voltage follower probes can be used to measure the potential of any charged surface, solid or liquid. The main advantages are the low added capacitance, the lack of influence of separation distance and the good accuracy of measurement. The main disadvantage is the risk of damage by electrical discharges if voltage changes occur faster than the ability to follow the voltage.

Measurements using a voltage follower probe only require the probe to be sufficiently close to the surface for the response to relate only to the local voltage of the surface and to be unaffected by charges on any other nearby surfaces.

b) *Space potential*

When an earthed fieldmeter is introduced into a potential distribution it will perturb the distribution and create an electric field at the sensing aperture linearly related to the potential which existed at the fieldmeter location before the fieldmeter was introduced. The degree of perturbation depends on the diameter of the fieldmeter sensing head. The relation between the local space potential V and the observed electric field E (V·m^{-1}) and the diameter d (m) of the fieldmeter is given by:

$$E = f\,V/d$$

where f is a factor near unity.

This relationship can be tested and the factor f checked by applying a voltage to a battery powered fieldmeter to null the reading. The relationship remains true so long as the fieldmeter sensing head is reasonably far away (several diameters) from nearby earthed surfaces and structures and the ambient field in the space is low compared to the field values observed.

When fieldmeters are used as potential probes it is necessary for the electric field at the fieldmeter to be below the level at which corona or water spray discharges can occur.

NOTE. Local electrical discharges can generate local space charge which will affect readings.

4.2.4 *Electrostatic voltmeter*

Electrostatic voltmeters operate by using the electrostatic force between conductors at different potentials to move an indicating pointer. They can be used to measure potential differences between conducting bodies, one of which is at a reference potential, usually earth.

The input capacitance of an electrostatic voltmeter (including the connecting conductors) shall be small compared to the self-capacitance of the object being measured.

4.2.5 *Other high resistance voltmeters*

High input resistance voltmeters are used to measure potentials so long as the product of the input resistance of the meter and the capacitance of the object being measured is long compared to the time needed for measurement. The decay time constant of the system shall be checked and recorded.

4.3 Procedure

4.3.1 *Preparation*

Switch on the measuring instrument and allow it to stabilize. Check the zero of the instrument before making measurements.

4.3.2 *Measurement of potential of conducting surfaces*

Measure the potential of a conducting body by any of the methods listed in **4.2** with the restrictions on position, resistance and capacitance indicated.

4.3.3 *Personnel potential*

Measure the potential acquired by a person walking on flooring, moving on a chair or rubbing against furnishings by one of the following methods.

a) Measurement of potential by connection to an electrostatic voltmeter or fieldmeter with an auxiliary electrode.

NOTE 1. Care is needed to avoid leakage or induction of charge to the connecting lead.

b) A person's potential may be measured by holding a battery powered fieldmeter at a known distance from an earthed surface.

NOTE 2. A geometrical factor f is usually needed for interpretation of the reading.

4.3.4 *Space potentials*

Measure the potential of a localized region in a volume using a fieldmeter in either a simple (see **4.2.1**) or a voltage follower (see **4.2.3**) configuration.

4.4 Expression of results

Record the values of potential obtained from measurements at particular times as V or kV.

4.5 Test report

The report shall include at least the following information:

a) the number and date of this standard (date and time of measurements);

b) location, arrangement and conditions when measurements made;

c) ambient temperature and relative humidity in measurement region;

d) identification of instrumentation used and date of most recent calibration.

5 Measurement of charge

5.1 General

The net electrostatic charge on an object or on a quantity of liquid or solid material is measured by enclosing it in an isolated, screened conducting chamber known as a Faraday pail. If all the charge introduced into the pail couples to the inside of the pail with no residual coupling to external surroundings then the net quantity of charge introduced appears as induced charge of the same sign and magnitude on the outside of the pail and is available for measurement either directly or as associated potential or current.

The charge introduced does not need to be conducted to the inside walls and the method is equally effective for insulating materials and for conductors.

5.2 Conditioning

NOTE. Although the measurement of quantity of charge is not affected by the environmental conditions, the electrical characteristics of materials can vary with temperature and the absorption of moisture.

For reference purposes measurements shall be made at two levels of humidity. Unless otherwise specified these conditions shall be (23 ± 2) °C, (50 ± 5) % r.h. and (23 ± 2) °C, (15 ± 2) % r.h. Materials shall be conditioned for 16 h to 24 h before measurements are taken.

For measurements in industrial situations the ambient temperature and relative humidity shall be recorded.

5.3 Apparatus

NOTE. The apparatus used comprises a Faraday pail into which the charge is transferred, the magnitude of the charge being measured by an ancillary procedure.

The Faraday pail consists of a conducting enclosure (usually in the shape of a simple open topped circular cylinder) mounted within a conducting earthed shield on high quality insulation.

The basic form of a Faraday pail system for measurement of charge is shown in figure 3. For accurate measurements the following dimensional requirements shall be fulfilled.

a) For less than 1 % leakage of the total flux from charged objects in a Faraday pail, the pail shall have a depth to diameter ratio greater than 1.4.

b) For less than 5 % leakage the depth to diameter ratio shall be greater than 0.8.

c) The charged objects introduced shall occupy not more than the lower 30 % of the Faraday pail.

d) To avoid interference from external charges the aperture in the shield shall be no larger than 1 pail entrance diameter spaced at least this distance above the pail entrance aperture.

The insulation mounting the pail, and the connections and cabling to any external charge measurement circuits shall be designed and constructed to avoid charge leakage and trapped charge effects. The performance of insulation is dependent on its mechanical rigidity, leakage resistance, piezo-electric characteristics and tendency to moisture absorption.

NOTE. To minimize problems with contact potentials in high sensitivity instruments it is recommended that all surfaces (including the earthing contact) are gold plated.

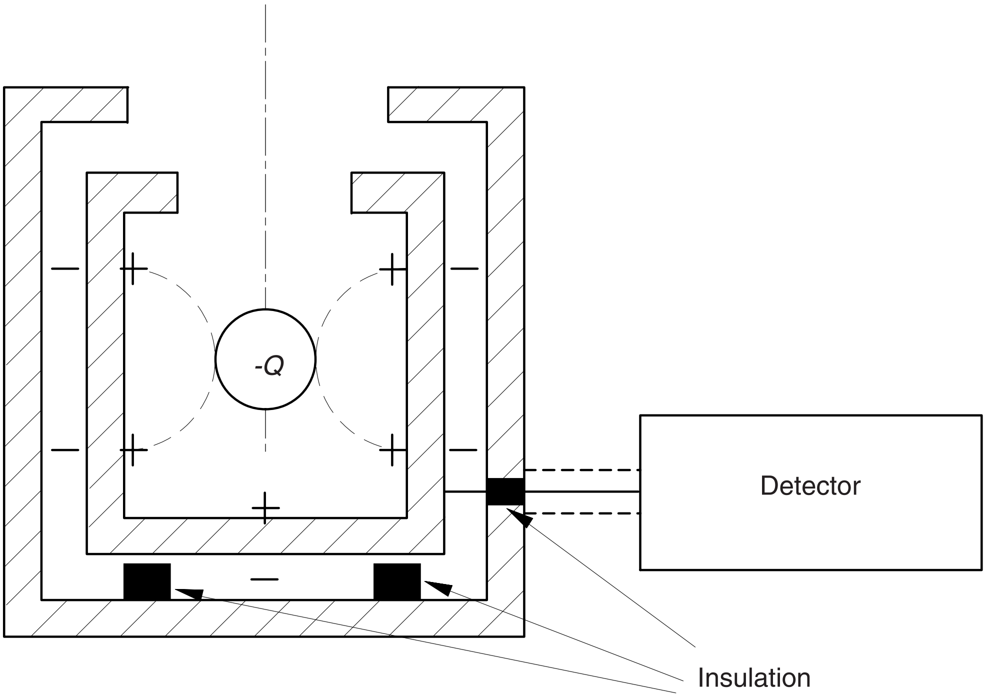


Figure 3. The Faraday pail

5.4 Measurement of charge on Faraday pail

Charge shall be measured using one of three methods.

a) Measure the charge induced on the outside of the pail with an electrometer amplifier in which the charge sensitivity is defined by a feedback capacitor (C). Ensure that the design and construction of the electrometer circuit and connections from the Faraday pail avoid leakage and microphonic effects and minimize input offset currents and voltages. Determine the zero charge reading by isolating the amplifier input, connecting the pail to earth and then measuring the apparent charge value.

b) Measure the voltage increase of the pail using a fieldmeter or electrostatic voltmeter with the charge calculated from the change in voltage in relation to the capacitance of the pail system. Ensure that in this mode the capacitance of the pail system is much larger than the capacitance of the charged object to be measured (20 to 100 times) so that the change in pail voltage is small compared to the initial voltage of the object.

NOTE 1. Additional capacitors may be added to adjust sensitivity. C is the value of the total capacitance.

Determine the zero reading using a fieldmeter by connecting the pail to earth.

c) With continuous charge generation measure the total quantity of charge by integration of the current into the Faraday pail, as indicated by a low resistance meter between the pail and earth.

NOTE 2. Zeroing of current integration measurement requires isolation of the pail from the circuit and checking the zero of the current measurement circuit.

Indicate the quantity of charge transferred to the pail by a direct reading display or calculate it from the measured capacitance and voltage.

5.5 Procedure

5.5.1 *Preparation*

In preparation for measurement make the following preliminary checks.

a) Properly bond the operator and all instrumentation to earth.

b) Remove all materials likely to retain static charge from the vicinity of the area of test. If the operator is wearing garments made of artificial fibre, replace or cover by a suitable static dissipative overgarment.

c) Check the drift of the displayed reading after zeroing and after introduction of some charge.

d) Check the absence of influence of the test environment and system, where possible by making measurements with materials or objects expected to give insignificant charge generation (for example a metal object sliding out of an earthed metal tube).

5.5.2 *Conduct of tests*

Drop samples directly into the pail with no contact to intermediate surfaces. Measure the charge introduced as the difference between the readings before and immediately after introducing the sample.

Allow time to observe both zero drift before introduction of charge and decay of reading after the peak following introduction of charge. Calculate the quantity of charge introduced from the difference between the readings extrapolated to the mid-point time of introduction of the charge.

NOTE. For the transfer of objects into the pail it is important to use the minimum area of contact in the pick up arrangement and avoid any sliding action against insulating surfaces at pick up and release.

Make checks that the method of transfer introduces negligible charge when the charge transfer is expected to be zero. If tests are carried out in a flammable atmosphere then carry out earthing of the pail to remove charge in a safe manner.

Repeat each test measurement five times unless otherwise specified.

Record the temperature and relative humidity of the test environment.

5.6 Expression of results

Charge values are read either directly from a display or calculated from individual parameter measurements using the relationship:

$$Q = CV$$

where:

Q is the charge (coulombs);

C is the capacitance (farads);

V is the voltage (volts).

The capacitance C is either the capacitance of the Faraday pail (including added capacitance) or the feedback capacitor of the electrometer measurement system.

If current to ground is measured then charge is calculated by integrating the current over the duration of the period of measurement.

In studies involving the flow of materials or liquids the mass or volume transferred over the period of measurement shall be measured so that values of charge per unit mass ($\mathrm{C{\cdot}kg^{-1}}$) or per unit volume ($\mathrm{C{\cdot}m^{-3}}$) may be calculated.

Measurements shall be repeated five times so that average values and standard deviations can be calculated and reported unless otherwise specified in product specifications.

5.7 Test report

The report shall include at least the following information:

a) date and time of measurements;

b) description and/or identification of sample tested;

c) method of charging and charging conditions;

d) values of average charge and mean square deviation for each set of conditions or samples;

e) mass or volume of material collected where relevant;

f) ambient temperature and relative humidity at start and end of measurements;

g) identification of instrumentation used and date of most recent calibration.

6 Measurement of charge density

6.1 Principle

The density of electrostatic charge on a surface or in a volume is measured by the electric field observed at an electrostatic fieldmeter.

6.2 Surface charge density

A uniform density of charge σ ($C{\cdot}m^{-2}$) over a surface produces an electric field E ($V{\cdot}m^{-1}$) to a nearby large isolated conducting parallel plane surface. This field is given by:

$$E = \sigma / 2\varepsilon_0$$

where ε_0 is the electric constant ($8.854 \times 10^{-12} Fm^{-1}$).

If the diameter of the conducting surface is large compared to the spacing from the charged surface then the electric field in the central region does not depend upon the spacing. The conducting surface in these measurements is a fieldmeter and associated mounting plate or guard.

Where static charge is present on two sides of a dielectric layer the charge density, σ in the above equation, is the algebraic sum of the charge densities on both sides.

The charge density on individual sides of such an insulating layer is measured by placing it against an earthed metal plate or cylinder. The charge on the surface contacting the plate is closely coupled to the plate and will produce no external field. The charge on the outer surface will produce an electric field able to be measured by a nearby fieldmeter. The charge density σ_1 on a sheet of thickness, t (m), and relative permittivity, ε, generating a field, E, at a distance d (m) away is given by:

$$E = \sigma_1 \; t / \varepsilon\varepsilon_0 \, d$$

In studies where the charge density may vary over the surface the resolution for variation is approximately the sensing aperture diameter provided that the separation distance is no greater than one sensing diameter.

6.3 Volume charge density

The mean density of electrostatic charge within a volume may be determined either by measuring the electric field at the conducting boundary of the chamber containing the charge or by using a fieldmeter to measure the maximum space potential created by the distributed charge.

For a spherical chamber of radius a (m), with a uniform charge density σ ($C{\cdot}m^{-3}$), the maximum space potential V and the boundary electric field E are related as follows:

$$V = \sigma\, a^2 / \; (6\varepsilon_0)$$

$$E = a\sigma / \; (3\varepsilon_0)$$

When the charge distribution is not uniform, the relationship between the local potential and charge density is found by analytical calculation or by computer modelling. The geometric boundary shape may be either the boundary of the overall chamber containing the electrostatic charge or the boundary of a smaller sampling chamber.

6.4 Apparatus

6.4.1 *General*

Induction probe or field mill fieldmeter instruments shall be as described in **3.2**. Field mill instruments shall be used for continuous and long term measurements.

6.4.2 *Surface charge density*

For accurate measurements the fieldmeter sensing aperture is mounted flush with the inner surface of a large guard plate. This plate is spaced at least 1.5 sensing aperture diameters from the test surface. For measurements to 5 % accuracy the conducting plane shall have a radial extent of 9 sensing aperture diameters and for 1 % a radial extent of 15 sensing aperture diameters.

Precautions such as radiusing edges shall be taken to avoid risks of electrical discharges to the charged surface.

The response time of the fieldmeter shall be short in comparison to the ratio of the fieldmeter aperture to the speed of movement of moving charged material.

6.4.3 *Space charge*

For a vessel which is large compared to the size of the fieldmeter, the potential at any point V is calculated from the electric field E, observed with an earthed fieldmeter at that point, as follows:

$$V = kEd$$

where:

d is the diameter of the fieldmeter (in m);

k is a constant approximately equal to 1.0.

The fieldmeter shall be at least five diameters away from any earthed surfaces or structures.

When the charge distribution is uniform the value of the space charge density is calculated from:

$V = \rho a^2 / (6\varepsilon_0)$

where

a is the radius of the enclosure;

ρ is the space charge density.

6.5 Expression of results

Values of charge density shall be given as $\mathrm{C{\cdot}m^{-2}}$ or $\mathrm{C{\cdot}m^{-3}}$.

6.6 Test report

The report shall include at least the following information:

a) number and date of this standard;

b) date and time of measurements;

c) description of the material, vessel or environment tested;

d) description of arrangements for measurement;

e) values of charge density in $\mathrm{C{\cdot}m^{-2}}$ or $\mathrm{C{\cdot}m^{-3}}$;

f) temperature and humidity during tests;

g) identification of instruments used and date of most recent calibration.

7 Measurement of charge decay

7.1 Principle

Two techniques are described, which are very similar in most features of procedure. They do, however, measure different types of charge, and may give very different results, particularly for non-isotropic materials. It is essential that great care be exercised in choosing the correct method in any instance, taking into account both application and material. The method chosen should be that which most closely models the actual situation.

The first method determines the self-dissipation of static charge by a material by depositing a small area of charge on the surface by means of a corona discharge and observing the surface potential by means of a fieldmeter.

The second method determines the dissipation of charge from a charged electrode placed on the surface by applying a potential to the electrode, disconnecting the voltage source and observing the decrease in potential in the same way.

7.2 Conditioning

NOTE. The electrical properties of materials vary with temperature and the absorption of moisture.

For laboratory measurements materials and samples shall be conditioned for 16 h to 24 h at (23 ± 2) °C and (50 ± 5) % r.h. and at (23 ± 2) °C and (15 ± 2) % r.h.

For measurements in practical situations the ambient temperature and relative humidity shall be recorded.

The material shall be tested as received. Loose dust may be removed by gentle brushing or by blowing with clean, dry air. Liquid cleaning agents should not be used to clean the surface.

7.3 Apparatus

7.3.1 *Physical design features*

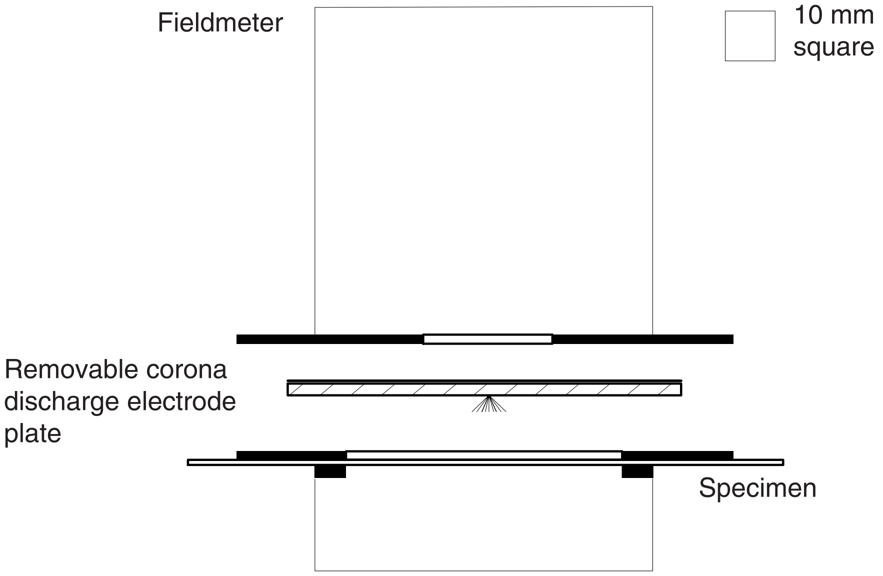
The basic arrangement and relevant dimensions of the two forms of the test apparatus are shown in figures 4 and 5.

All mechanical dimensions shall have a tolerance of ± 5 % , unless otherwise specified.

The test aperture for corona deposition and measurement of deposited charge shall be 50 mm diameter. The corona points are mounted in a 10 mm diameter circle on a movable insulating plate, backed by a screening layer and are 10 mm above the centre of the test aperture. The fieldmeter sensing aperture shall be 25 mm above the centre of the test area. When the plate with the corona points is moved fully away, the test area shall be clear up to the plane of the fieldmeter sensing aperture.

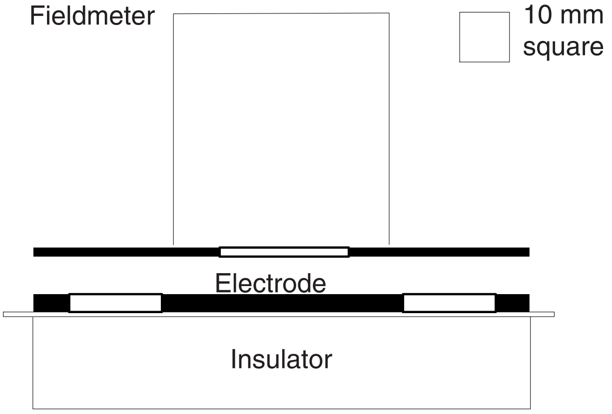
The test aperture for measurement of contact dissipation of charge shall be 150 mm and the fieldmeter shall be 25 mm above the electrode surface.

Although not indicated in figures 4 and 5, the field meter shall be adequately screened from all high voltage points.



NOTE. All conducting materials other than electrodes are earthed.

Figure 4. Self-dissipation of charge



NOTE. All conducting materials other than electrodes are earthed.

Figure 5. Dissipation of charge from electrode

7.3.2 *Containment of test material*

With an installed material the test aperture in the instrument baseplate shall be rested directly on its surface. Sheet or flexible materials shall be supported as follows.

a) For self-dissipation testing of material without integral earthed layer, the material shall be clamped to the baseplate by an earthed metal annular ring coaxial with the test aperture. See figure 4. The clamping ring shall have an internal diameter of 50 mm and at least a 5 mm radial width. The shield over the reverse side of the test area shall be earthed and at least 25 mm away over the whole test area.

b) For electrode dissipation of these materials, the material shall be supported by a charge-free insulating layer of thickness 25 mm, and shielded on the reverse side. See figure 5.

c) For testing of material with integral earthing layer, or intended to be used against an earthed plate or sheet, the material shall be clamped between the baseplate and a flat earthed metal plate with the earthing layer connected to earth.

Powders and liquids shall be contained in earthed conducting vessels with a depth of at least 10 mm over the whole test aperture area. The surface shall be as close to the test aperture as compatible with continued satisfactory operation and with minimum ingestion of material into the instrument mechanisms.

7.3.3 *Charging electrodes*

7.3.3.1 *Corona charge deposition (self-dissipation test)*

NOTE 1. The corona method provides a rapid and repeatable non-contact means of depositing charge with controllable magnitude and polarity.

Corona charging is achieved with a number of discharge points on a 10 mm diameter circle 10 mm above the middle of the test area. The exact size and distribution of charge on the material is not well defined, particularly with the more conductive surfaces, but the arrangement provides a consistent pattern of deposited charge and decay time measurements.

The initial voltage developed by the deposited corona charge shall be at least twice the applicable hazard threshold voltage. If this cannot be achieved then this is reported and the highest value attainable shall be used.

NOTE 2. The corona charge deposition time should be as short as possible, and preferably less than 25 ms.

NOTE 3. However, with more conductive surfaces the initial voltage may not reach the required value when a longer time (possibly up to about 2 s) may be used.

The equipment for charge deposition shall move fully away from the region of fieldmeter observation in less than 50 % of the minimum decay time to be measured, or 20 ms, whichever is the greater.

NOTE 4. For corona voltages of 7 kV to 8 kV the initial surface voltage with relatively highly insulating materials will be up to about 3000 V. For materials with fast charge decay rates the initial voltage may be much lower, e.g. only 50 V to 100 V.

7.3.3.2 *Contact dissipation*

For simulation of a small object the electrodes shall be 80 mm in diameter and 3 mm thick.

For simulation of a human body on flooring materials, an electrode 80 mm in diameter and weighing 2.5 kg shall be used. In this case the capacitance of the electrode to earth, unless otherwise specified, shall be 150 pF.

7.3.4 *Fieldmeter*

The fieldmeter shall be a field mill instrument able to measure the surface voltage with an accuracy of ± 5 V to below 40 V, with a response time (10 % to 90 %) $\leq$ 0.01 s. The stability of the zero shall allow measurement of surface voltage with this accuracy over the longest decay times to be measured.

During charge deposition and decay time measurements the fieldmeter sensing aperture shall be well shielded from any connections or surfaces at high voltage and any insulating surfaces in the apparatus.

The influence of residual surface charging shall contribute less than 10 V to measurement of surface voltage. This shall be tested by making decay time observations on a fully conducting metal surface.

7.3.5 *Decay time measurement*

Measurement of decay times shall be made using one of the following:

a) oscilloscope recording of the fieldmeter signal;

b) direct electronic timing from comparison of the fieldmeter signal with voltage levels selected for the start and end of timing;

c) software analysis of the decay curve of the fieldmeter signal after transfer into a computer.

The response time of any signal recording or data analysis arrangement shall be less than 20 % of the minimum decay time measured or ± 5 ms whichever is the greater. The method of time measurement shall provide a resolution and accuracy of measurement within ± 5 % or ± 5 ms whichever is the greater.

7.4 Procedure

7.4.1 *Test surface preparation*

Check that the material or sample presented for test is clean and free from loose dust. Remove any loose dust by gentle brushing or blowing with clean dry air. If the surface is obviously contaminated either test an alternative area of the material or make measurements with the contamination present and report the condition of testing ‘as received’.

Handle samples only by tweezers or with gloved hands.

7.4.2 *Testing*

Rest the test aperture on the surface to be tested, set up appropriate charging conditions and make the required number of charge decay measurements.

Ensure that the test equipment remains steady and undisturbed on the surface for the duration of each measurement.

NOTE. Movement of the test apparatus relative to the surface can cause tribocharging which will affect observations.

Make measurements with both positive and negative polarities.

Make measurements on sheet and film materials both with open shielded backing and with an earthed surface backing.

Make at least three measurements for each set of test conditions with each measurement made on a new test area. If the same test area needs to be used then ensure that the time between measurements is such that the surface voltage has fallen to below 5 % of the initial voltage.

If initial measurements are needed to establish appropriate test parameters (for example the initial surface voltage) then use a fresh area of surface for the actual measurements to be reported.

7.5 Expression of results

The decay time values are the measured times for the surface voltage to fall from the selected hazard threshold voltage to 1/*e* of this voltage.

Decay time values quoted shall be the average of the values measured under the test conditions providing the longest decay times and include both positive and negative polarity values. If longer decay times are observed with initial voltages above twice the hazard threshold voltage then these values shall be averaged and reported with the test conditions used.

If it is not possible to achieve an initial voltage at least twice the risk threshold voltage with a corona voltage of at least 7 kV then it shall be recorded that the rate of charge dissipation was too rapid to allow achievement of the risk threshold voltage.

7.6 Test report

The report shall include at least the following information:

a) date and time of measurements;

b) description and/or identification of material tested;

c) charging conditions used (for example, polarity, corona voltage, charging duration, electrode dimensions, electrode capacitance to earth, electrode potential, time between tests);

d) whether the sample is supported with an open backing or resting against an insulating layer or an earthed backing surface;

e) individual values of initial surface voltage, the hazard threshold voltage from which the decay times were measured and the times for reduction of this voltage by the factor 1/*e*;

f) temperature and relative humidity at time of measurements and duration of conditioning for standard laboratory measurements;

g) identification of instrumentation used and date of most recent calibration.

8 Measurement of resistance and resistivity

8.1 Principle

The electrical resistance for liquids, solid sheets, layers or other forms of solid material, is determined by measurement of the current flowing between appropriately located electrodes at a known applied potential. The methods of measurement described are used for materials having resistance values in the range $10^6\ \Omega$ to $10^{10}\ \Omega$, this being the range for which leakage currents can significantly influence electrostatic behaviour.

Resistance measurements are used to measure electrical continuity between objects and to assess structures where static electricity is a dynamic equilibrium between contact transfer of charge and loss to earth. The general principle is to use a method that simulates the actual application as far as possible. For example, to determine the resistance of gloves hold one electrode in the gloved hand and use the other hand as the second electrode.

8.2 Test specimens and conditioning

NOTE. The electrical properties of materials vary with temperature and the absorption of moisture.

For laboratory measurements materials and samples shall be conditioned for 16 h to 24 h at (23 ± 2) °C and (50 ± 5) % r.h. and at (23 ± 2) °C and (15 ± 2) % r.h.

For measurements in practical situations the ambient temperature and relative humidity shall be recorded.

8.3 Apparatus

8.3.1 *Measurement circuit*

The basic form of circuit used to measure resistance by simultaneous measurement of voltage and current is shown in figure 6.

NOTE 1. There are special instruments available which incorporate both the voltage power supply and the current measuring ammeter and which have been set to read resistance directly.

The sensitivity and accuracy of the method depends mainly on the properties of the current measuring device, which will probably be an electrometer.

NOTE 2. Errors in current measurements may result if the input resistance of the instrument is a significant fraction of the resistance being measured.

NOTE 3. Errors caused by stray leakage currents may be minimized by the technique of 'guarding'. This involves arranging conductors to intercept all stray currents to leave the specimen resistance path as the only direct path between the measuring terminals. In some practical circumstances, such as measuring the leakage resistance from a surface to a building earth, guarding is inappropriate.

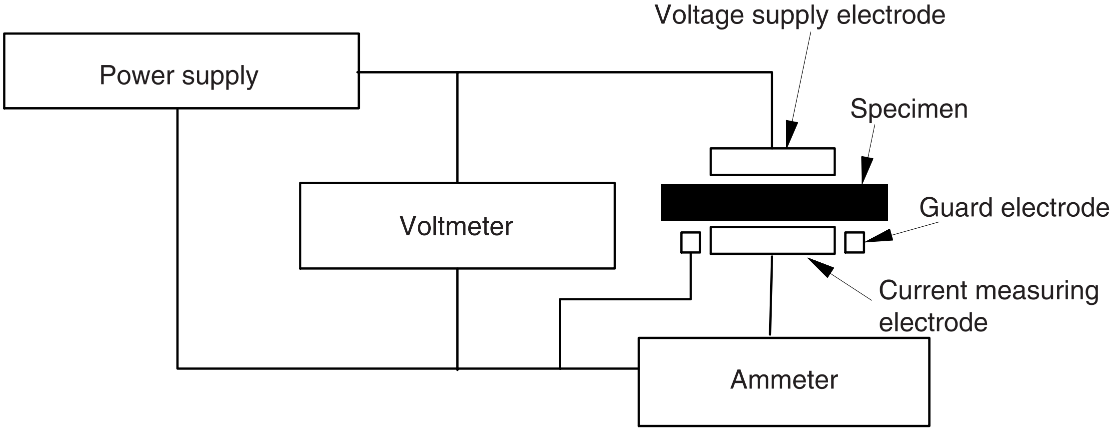


Figure 6. Test circuit for resistance measurement

8.3.2 *Electrodes*

Contact to the test sample surface shall be made with electrodes which reliably define the geometry of the area tested.

NOTE 1. Flexible conductive rubber, conductive paints or metal foils can form convenient contact electrodes. It is important, however, that these electrodes do not introduce any spurious effects by surface insulation layers, by corrosion or by physico-chemical interactions with the specimen.

The guarded electrode systems used for measurement of resistance is shown in figure 7.

It is also possible to measure the surface resistance of a sheet material using a pair of parallel, straight electrodes with a strip specimen of uniform width. If the distance between the electrodes is equal to their length and they extend the full width of the strip, the measured resistance is independent of the actual dimension and is equal to the resistivity.

NOTE 2. If the electrodes extend only partway across the surface of the material, then the calculated resistivity may be grossly underestimated (up to 70 %) because of the extended conduction paths outside the width of the electrodes.

NOTE 3. Due to the influence of current through the interior of the test specimen, the calculated value of surface resistivity may depend strongly on the specimen and electrode dimensions. For comparative determinations it is therefore recommended to use specimens of identical form with the electrode arrangement of figure 7b but using a good insulator instead of the guard electrode.

Unless otherwise specified, concentric electrodes shall be pressed into contact by a force of 25 N (i.e. a loading mass of (2.5 ± 0.5) kg).

8.4 Procedure

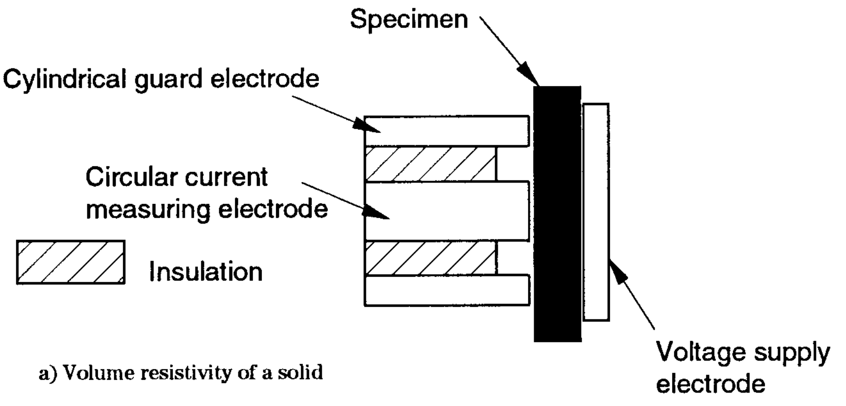
Prior to testing, connect the guard and voltage electrodes to earth and note the current (or conductance, i.e. reciprocal of resistance reading) value obtained. Connect the guard and voltage electrodes as shown in figure 6 and again note the current (or conductance).

If the former value is significant with respect to the latter the test is invalid owing to permanent polarization.

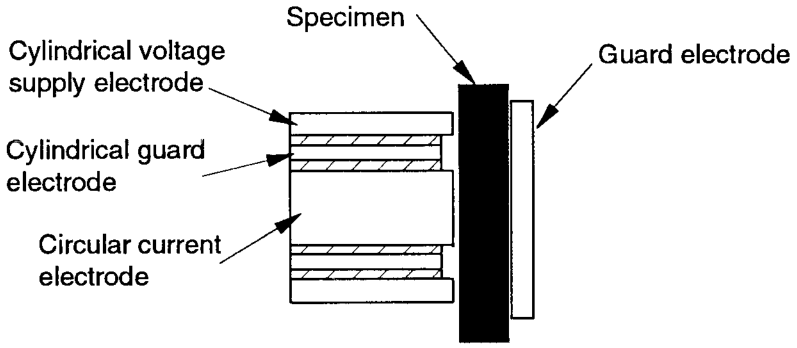
NOTE. The preferred range of voltages used for these measurements is 50 V to 2000 V, but other values may be used to simulate practical circumstance.

Use the lowest voltage to give a measurable reading, (between 10 % of full scale deflection and full scale deflection). Record the current 1 min after application of the test voltage. Repeat the measurement at twice the initial voltage and any non-linearity recorded. Repeat the set of measurements for three samples and record all data.

Measure the resistance across an industrial work surface between two circular electrodes placed an electrode diameter apart and each pressed onto the surface by a force of 25 N (a mass of (2.5 ± 0.5) kg). Measure the resistance to earth between either of these electrodes and the mains power earth contact.



a) Volume resistivity of a solid



b) Surface resistivity of a solid

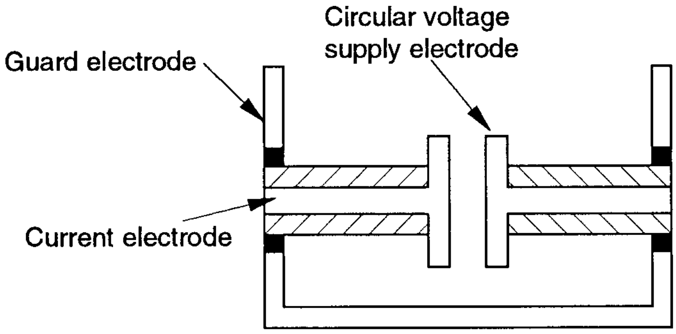


Figure 7. Guarded electrode systems

8.5 Expression of results

8.5.1 *General*

The resistance, R (in Ω), of the test piece is obtained by dividing the applied voltage by the measured current.

8.5.2 *Volume resistivity*

The volume resistivity, Γ (Ω·m), is calculated using the following formula:

$$\Gamma = RA/t$$

where

t is the thickness of the sample (in m);

A is the area of the smaller electrode (in m^2).

8.5.3 *Surface resistivity*

The surface resistivity, β (Ω), is calculated from the value of resistance, R (in Ω), obtained using the concentric electrode cell using the following formula:

$$\beta = 2\pi R/ln\ (D_2 / D_1)$$

where

D_2 is the internal diameter of the outer electrode (in mm);

D_1 is the outer diameter of the inner electrode (in mm).

Using the parallel electrodes the approximate surface resistivity is the measured resistance.

8.6 Test report

The report shall include at least the following information:

a) the number and date of this standard;

b) date and time of measurements;

c) description and/or identification of sample tested;

d) method of measurement, dimensions of sample and of contact and guard electrode;

e) cleaning, preparation and conditioning of the sample;

f) ambient temperature and relative humidity at start and end of measurements;

g) test voltages used;

h) individual values of resistance measured for each set of conditions or sample;

i) identification of instrumentation used and date of most recent calibration.

9 Measurement of chargeability

9.1 Principles

Charge is produced on each of two materials whenever they are separated after being in contact. Such contact and separation are usually achieved for measurement purposes by rubbing the materials together.

Charge may dissipate over and/or through a material during and after rubbing: it is important, therefore, that measurements are made promptly at the end of rubbing actions. Determination of the rate of charge decay after rubbing is in many cases necessary to establish whether measurements are affected by charge dissipation and provide information for compensation.

The charge produced is measured either by dropping one of the materials directly into a Faraday pail or by observing the electric field in the vicinity of one immediately the surfaces are separated.

Chargeability may be expressed either in terms of the charge generated on individual articles or in terms of charge per unit mass, area or volume.

Four standard methods of measurement are described:

a) rubbing tests;

b) charging during sliding and flowing of materials or articles;

c) charging during walking on flooring;

d) charging of sheet or web materials moving over rollers.

NOTE. Items a) and d) are more appropriate tests for obtaining basic information on materials.

The speed, pressure, distance and/or time of charging relating to the procedure are also relevant to the result and are recorded.

9.2 Environmental conditions

NOTE. The electrical properties of materials vary with temperature and the absorption of moisture.

For laboratory measurements materials and samples shall be conditioned for 16 h to 24 h at (23 ± 2) °C and (50 ± 5) % r.h. and at (23 ± 2) °C and (15 ± 2) % r.h. For measurements in practical situations the ambient temperature and relative humidity shall be recorded.

9.3 General features of test methods

9.3.1 *Apparatus*

The test methods are designed to simulate practical situations. However, they allow greater variation of the values of parameters (such as environmental conditions or the speed and pressure of sliding or flow) than is usually possible in practical situations. Variation of the materials of guiding or containing surfaces is also more easily achieved.

The net charge on individual articles or on samples of materials is measured directly using a Faraday pail. Net charge on surfaces and on bulk materials may also be obtained from fieldmeter measurements. Both methods are used in laboratory and industrial studies.

Charge separation between materials is influenced by electric fields at the point of separation from the containing or guiding surface. Measurements shall be made in an environment free from electric fields either from the surroundings, the operator or from the measurement equipment. Equipment shall be bonded to earth and there shall be no surfaces nearby (for example the operator or clothing) able to retain static charge.

9.3.2 *Procedures*

Use test materials and articles in their normal condition and do not clean. If a material or surface may be modified by the rubbing action then use a fresh area for each test.

NOTE 1. This is particularly important where surfaces may have been treated to make them astatic or static dissipative.

Avoid hand contact with the surfaces and articles. Use clean metal forceps or tools for any handling or manipulation required.

Vary the test situation and conditions to establish the values giving the highest level of charging. For example, when testing semiconductor devices sliding out of shipping tubes increase the length of travel to the longest length of tube used and vary the angle of sliding from the minimum angle of repose to vertical.

NOTE 2. It is important that immediately at the end of charging actions the material or article falls directly and without contact with any other surface into the Faraday pail or onto a suitable earthed surface for electric field measurement.

NOTE 3. In many cases, measurements are required on the rate of decay of charge of the article or material. These measurements are made after allowing the charged material or article to fall onto an earthed surface or into an earthed receiving vessel. Observations on the rate of charge decay are made by an earthed fieldmeter in a stable mechanical position to observe the electric field generated by the charge.

Measurements are made using relevant test parameters (e.g. speed, pressure, distance and/or time of charging actions) and their values reported. When the potential equivalent to the charge of an article is required, the self-capacitance of the article is needed for the calculation.

9.3.3 *Results*

Measurements of charging shall be reported as charge per article, per unit mass, area or volume. The results quoted shall be for the situation giving rise to the highest level of charging. When appropriate, the result shall include compensation for charge decay.

NOTE. In the case of the charging of individual articles a calculation may also be made of the equivalent voltage represented by the charge values measured.

9.4 Standardized rubbing tests

9.4.1 *Apparatus*

The arrangement for testing the chargeability of samples of material by rubbing under standardized conditions in an automatically working apparatus is shown in figure 8.

The sample shall be rubbed under defined conditions by each of the specified rubbing materials and the charge density generated is obtained from electric field measurements directly after cessation of rubbing. The materials are chosen as being from different positions in the triboelectric series.

For sheet materials a minimum of six (120 ± 5) mm square or (120 ± 5) mm diameter circular samples is required for each material tested. The samples shall be flat and have the same surface nature as the original product. No further treatment shall be given to the surface of the samples which shall not be deformed in any way before testing.

In the test apparatus, shown in figure 8, the sample material is mounted on an earthed metal surface which is pressed by the spring against a rubbing material with a defined force. The rubbing material is mounted on an earthed metal arm which is chamfered at (45 ± 5) °C to a depth of (5 ± 1) mm. It is moved at a specified speed for a specified time. A resilient backing support is provided for the rubbing material with a clamping mechanism for rapid fixing of the fabric without wrinkles.

At the end of the specified time of rubbing the rubbing arm is moved away so that the level of charge on the sample can be observed by the fieldmeter.

The diameter of the free area of the sample shall be (100 ± 5) mm and the total force applied by the spring (10 ± 1) N. The rubbing speed shall be (0.5 ± 0.1) ms^{-1} in the centre of the sample area. Rubbing shall be sustained for periods of (10 ± 2) s with intervals of 2 s to 4 s for field measurement.

This sequence shall be repeated for at least 5 min or until saturation of the field is observed.

The metal support for the sample shall provide uniform pressure contact with the rubbing fabric.

NOTE 1. It also provides a route to conduct charge to earth.

A rigid sample is laid over the annular support and may be held by reduced atmospheric pressure between the sample and the support. If the sample is not completely flat a ring of conductive rubber may be used between the sample and the earthed metal backing surface.

The rubbing equipment shall ensure that the whole area of the sample over which the measurement is made is uniformly charged by rubbing the material at constant speed, direction and pressure. It shall also ensure that there is no risk of damage to the rubbing fabric at any sharp edge of the sample. The rubbing fabric shall touch only the surface of the sample. The spatial arrangement of equipment shall ensure that when the rubbing material is moved away for measurement of the density of charge on the sample, the fieldmeter is electrically well shielded from the rubbing material or any stray electric fields.

The sensing aperture of the fieldmeter measuring the charge density on the rubbed surface is arranged to determine the electric field strength over an area about 70 mm diameter in the centre of the sample. The fieldmeter sensing aperture shall have rounded edges to avoid risks of discharges and shall have a surrounding guard plate to simplify interpretation of electric field readings in terms of charge density. Fieldmeter measurements shall be made with an accuracy better than 10 %.

NOTE 2. Automatic recording of data is preferred.

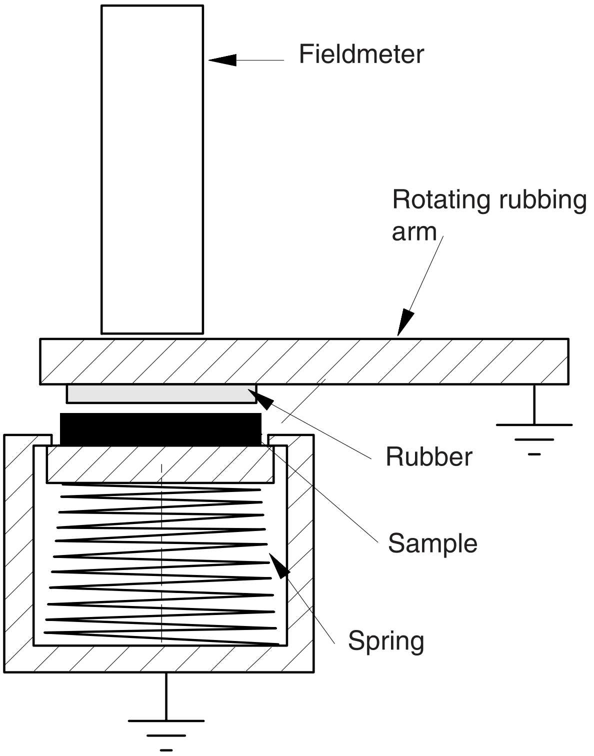


Figure 8. Rubbing apparatus

9.4.2 *Procedure*

Carry out tests with rubbing fabrics woven from staple fibre and having a mass per unit area between 80 gm^{-2} and 240 gm^{-2}. Select the rubbing fabric from the following:

— material A: fabric woven from polyamide six staple fibre;

— material B: fabric woven from acrylic staple fibre;

— material C: fabric woven from cotton staple fibre.

Before testing wash[1] the rubbing fabrics to remove all dressing and rinse in de-ionized water. Ensure that the apparent surface resistivity of the synthetic fabrics is at least 10^{13} Ω.

Condition samples before testing for 16 h to 24 h at (23 ± 2) °C and (50 ± 5) % r.h. and at (23 ± 2) °C and (15 ± 2) % r.h.

Take care to ensure that the surface is not contaminated in any way as the condition of the sample surface influences results. Only handle the test surface with tweezers, tongs or with clean protective gloves and in such a manner as to avoid charging the surface.

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[1] Details of washing procedure are material-dependent.

Test in the same atmosphere used for conditioning the samples. Fasten the sample to the apparatus and mount the selected rubbing fabric on the rubbing arm. Automatically pass the rubbing fabric over the sample surface for a number of times as required by the specification for the sample material. Measure the electric field as soon as possible after each time the rubbing fabric passes over the sample. Stop rubbing if the limiting value of the fieldmeter reading due to charging is reached or after 50 cycles. Test three samples with each type of rubbing fabric and use a new fabric for each test.

Make fieldmeter measurements of:

a) the maximum field values observed between intervals of rubbing;

b) the decay time to $1/e$ of the fieldmeter reading after cessation of rubbing and the form of the charge decay curve for 30 min.

9.4.3 *Expression of results*

For each rubbing fabric the result shall be the greatest observed value of either polarity, and the other values shall be reported.

The charge density values ($\mathrm{C \cdot m^{-2}}$) shall also be calculated from the fieldmeter readings. The charge decay behaviour shall be reported.

9.5 Sliding and flowing tests

9.5.1 *General*

This test procedure is applicable to materials or manufactured articles which may become charged in normal handling, by sliding over surfaces under gravity or in process operations. Examples are semiconductor devices sliding out of shipping tubes, circuit boards sliding out of or moving within transport packaging and articles sliding down delivery chutes. It also applies to liquids or powders flowing and being conveyed in tubes.

9.5.2 *Apparatus*

The sliding surface or structure shall be bonded to earth and, if necessary, shielded from the effects of nearby charges or fields.

Sliding tests are conducted using inclined surfaces comprising actual tubes (for instance semiconductor shipping tubes) or structures or chutes formed from materials to be investigated.

NOTE 1. An electromagnetic catch or valve will be helpful to release articles or materials down surfaces at angles steeper than the angle of repose.

Liquids or powders shall flow directly into a Faraday pail or earthed receptacle without contacting any intermediate surfaces.

NOTE 2. Where collection of the whole flow is not possible it may be acceptable to take a sample of the flow into receiving vessel, although this is not wholly satisfactory, since the sample flow may not be representative of the whole flow.

9.5.3 *Procedure*

Where pieces of material, items or articles slide over surfaces and a number of orientations are possible with different combinations of surfaces make measurements with each orientation.

Make measurements in most cases with the articles sliding down the appropriate surface for the maximum normal travel distance. Place the article at this distance and increase the inclination of the surface until the article slides down the surface and into the receptacle under gravity.

NOTE 1. It may also be necessary to measure charging when the article or material is released on surfaces at other, greater angles.

Allow a powder to slide freely into the receptacle and make a measurement of the charge associated with free sliding. If any material remains in the source vessel and/or chute tap it to encourage transfer of remaining powder and make a further measurement to determine the additional charge transferred.

NOTE 2. Where the powder or liquid is contained within a flowing system a sample may be taken either where the flow takes place over an air path and there is access for direct collection or by sampling from the flow duct or pipe. When sampling from a duct through a sampling tube a test should be made on the effect of varying the sample tube length to check whether significant errors are caused by the sampling arrangement.

With continuous manufacturing or material feed operations make observations over a sufficient time to show any significant variations with time.

NOTE 3. The values of process variables may also be required to be set to a range of values.

Record and report values of these variables.

9.5.4 *Expression of results*

The result shall be the charge per item, per unit volume, or per unit mass as required. If charge decay measurements are required, then the result shall be the value corrected for charge decay. Other parameters or measurements called for in **9.5.3** shall also be reported.

9.6 Walking tests

9.6.1 *Apparatus*[2)]

The person carrying out the walking (the 'walker') shall be connected to an electrostatic voltmeter (or a voltmeter of input impedance $\geq 10^{14}\ \Omega$) by a flexible lead from a hand held probe. The connecting lead shall hang freely and without contact to other surfaces for the duration of the test. The meter shall be bonded to earth.

NOTE 1. It may also be necessary to record the levels and variations of potential during the testing.

[2)] DD 68 : 1980 also covers the walking test

The shoes worn for testing shall be used only for this test and shall be kept in the controlled humidity environment. Two types of shoes shall be used: with leather soles and with insulating (PVC) soles. Before starting a test the shoes shall be cleaned to remove possible surface treatments from previous tests.

NOTE 2. The most satisfactory method of cleaning of the test shoes is by abrasion with a fine abrasive sheet.

9.6.2 *Procedure*

Carry out tests either on an actual floor or on samples of floor or floor covering materials. Use samples of at least 2 m × 1 m, conditioned in the test environment before testing.

Test samples both resting against a rigid earthed metal backing plate over the whole sample area and resting against a good insulator backing with an earth connection to the boundary of the sample.

At the start of a test the walker shall put on the shoes, hold the contact to the electrostatic voltmeter in the hand and step onto the sample area. The test shall consist of walking forwards and backwards at about two steps per second without scuffing or pivoting. As much of the sample as possible shall be covered. The test shall continue for at least 60 s or until the voltage generated ceases to rise. The test shall be repeated with the alternative shoes, with the alternative backing and with an alternative walker.

Record any variations of potential observed during the test.

9.6.3 *Expression of results*

For each combination of shoe/walker/test condition, the result shall be the greatest numerical value of the replicate tests. Test parameters and other values shall be reported.

9.7 Web charging

9.7.1 *Apparatus*

Automatic apparatus to test the chargeability of film or paper passing over rolls is shown in figure 9. It comprises an approximately square array of rolls. One of the rolls is driven, and three are free running. One of the rolls is mounted on a dancer arm to allow specific tension to be applied to the test loop.

NOTE. Additionally a pair of nip rolls may be provided, one of which is mounted on a dancer arm to allow adjustment of the pressure of the nip.

All roll surfaces shall have a polished hard plated finish e.g. chromium, except the nip rolls which are covered by rubber or a test material.

Two paired neutralizer bars and two fieldmeters are provided so that measurements may be made of the charge before and after a roll, free running or driven (see A and B). In addition, positions for the neutralizer bars and fieldmeters are provided relative to a pair of nip rolls (see C).

A film velocity measuring device is provided.

The apparatus is mounted inside a controlled environment chamber as specified in **9.2**.

9.7.2 *Procedure*

After cleaning the rolls by washing with a suitable solvent or by abrading, mount a loop of film over the roll system. Use double-sided adhesive tape with the adhesive tape fully covered by film in the overlapping region to close the loop. Check that film motion is satisfactory up to full test speed. Close the test chamber door and allow sufficient time for the environment and the film to reach equilibrium.

Record the initial level of fieldmeter reading and turn on the neutralizer. Raise the film speed gradually to the test value. Record the reading of the fieldmeter and the speed. With the film running at the same speed, switch off the neutralizer and record the fieldmeter readings until a maximum value is reached.

Repeat the above tests on three film loops. If required, repeat the tests with different test configurations or using nip rolls.

9.7.3 *Expression of results*

The charge density on the film ($C \cdot m^{-2}$) shall be calculated from the fieldmeter readings. The result for each configuration is numerically the greatest of the three charge density values.

The charge build up per roll contact is calculated from the increase of readings through the contact.

9.8 Test report

The report for all methods shall include at least the following information:

a) the number and date of this standard;

b) date and time of measurements;

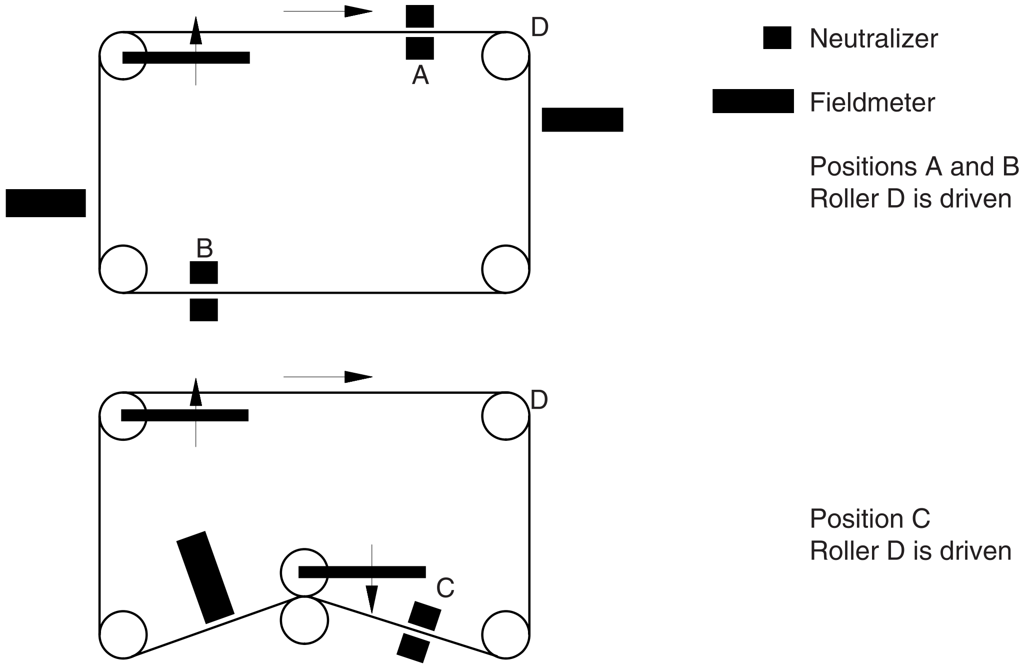
c) location, arrangement and conditions when measurements made (including the number of articles, or the quantity of material involved and information on the speed, distance and pressure of movement;

d) the charge, calculated per unit of quantity or number;

e) when required, the rate of charge decay after charging, with the article or material contacting an earthed surface;

f) ambient temperature and relative humidity;

g) identification of instrumentation used and date of most recent calibration.



NOTE. Arrangements A and B are for testing the effects of driving and idle rolls respectively, arrangement C is for testing a nip.

Figure 9. Roller systems for testing web materials (film or paper)

10 Measurement of shielding performance of materials

10.1 Principle

Mechanical dimensions have a tolerance of ± 5 %.

An electric field is applied with no net transfer of charge to the material and that the attenuation of the field is measured as a function of frequency.

Simultaneous positive and negative high electric field pulses of balanced peak amplitude and shape are used, with balanced coupling to the material. To ensure equal treatment for all materials, independent of whether shielding is provided by buried or surface or volume conductivity, the layer tested is insulated from earth.

Attenuation measurements are made as a function of frequency over the range from 10 Hz to 1 GHz and attenuation values calculated as the ratio of signals observed through the material to those observed directly at each frequency of measurement.

Since there is no net transfer of charge to the layer there is no common mode signal so that attenuated signals of either polarity can be observed on the far side of the layer of material relative to the local earth.

The shielding performance is measured under standard conditions of temperature and humidity, although for most materials the dependence is limited.

10.2 Test specimens and conditioning

The test samples shall be at least (100 × 100) mm.

Unless otherwise specified, the specimens shall be conditioned for 16 h to 24 h at (23 ± 2) °C and (50 ± 5) % r.h. and at (23 ± 2) °C and (15 ± 5) % r.h.

The temperature and relative humidity at the time of measurement shall be reported.

10.3 Apparatus

10.3.1 *Basic arrangement*

The basic design of the test system is shown in figure 10. The arrangement to provide electric field at the shielding layer uses simultaneous high voltage pulses of equal amplitude and pulse form on a pair of pulse source electrodes. These electrodes are mounted within the plane front plate of a shielding enclosure on one side of the layer under test. High voltage insulation covers the front plate of the high voltage shielding enclosure leaving the area over the pulse electrodes clear. The layer of material under test is clamped against this insulation to provide consistent and balanced coupling of the layer to the pulse source electrodes and with insulation from earth.

Sensing electrode surfaces are mounted within a plane shielding plate on the opposite side of the layer with good mechanical stability and balanced capacitive coupling to the pulse electrodes (see figure 11). Each pulse source electrode shall be coupled to two sensing electrode surfaces, one through the test layer and the other directly for reference.

NOTE. This arrangement enables information to be obtained simultaneously on the signal attenuation by the material and on the characteristics of the electric field pulse applied.

10.3.2 *Physical dimensions of electrodes*

The matching of the dimensions and spacings of the two pairs of electrodes (measurement and control), and of the pulse generating and sensing electrodes, shall in all cases be within 1 %. Within this constraint, the overall tolerances in the dimensions are given below:

The pulse source electrodes shall be (5 ± 1) mm wide by (50 ± 10) mm long. The radii of curvature of the edges shall be not less than 2 mm. The centre-lines of these electrodes shall be spaced 50 mm apart. To achieve pulse rise times below 1 ns the pulse electrodes shall be less than 75 mm from the pulse switching device. For pulse symmetry the switching device shall be equidistant from the test and reference electrodes.

The arrangement is shown in figure 11.

There shall be an air gap of 2 mm between the pulse electrodes and the test layer.

The length and spacing of the sensing electrodes shall be the same as the source pulse electrodes and mounted directly opposite. The separation distance between the pulse and sensing electrodes shall not be greater than 15 mm.

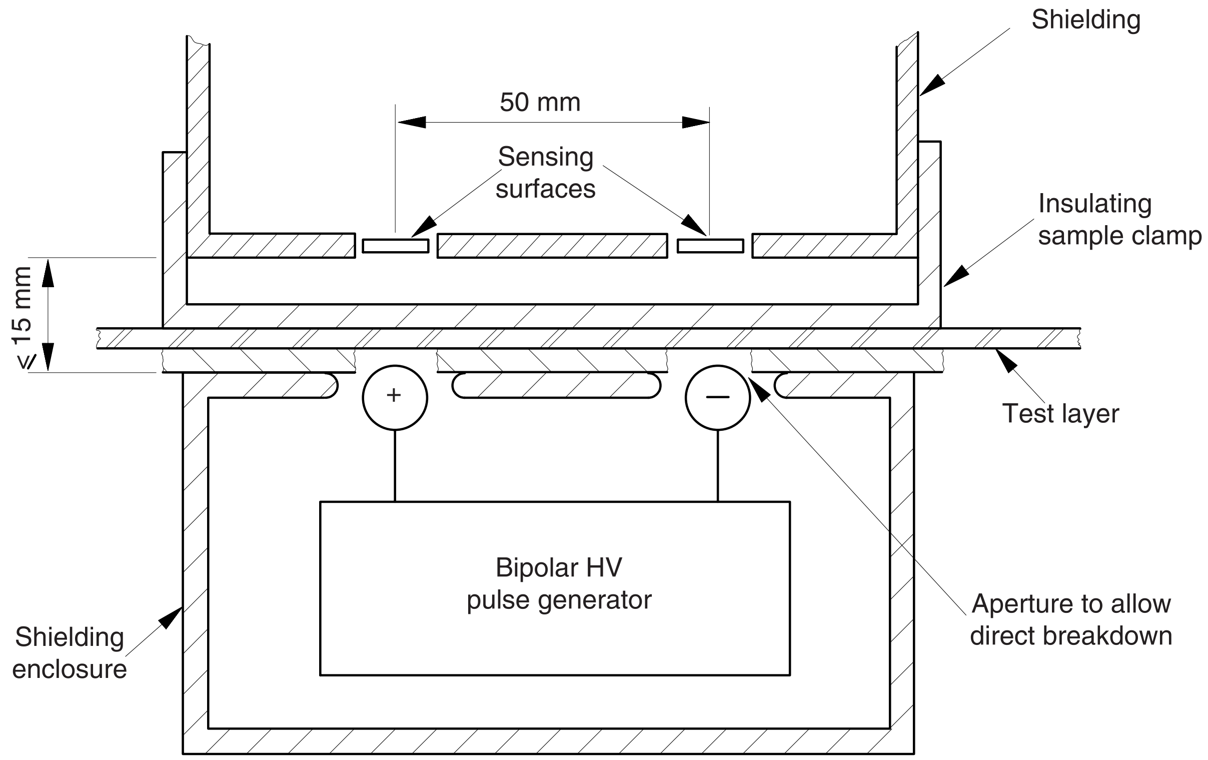


Figure 10. Apparatus for testing shielding capabilities of films and layers

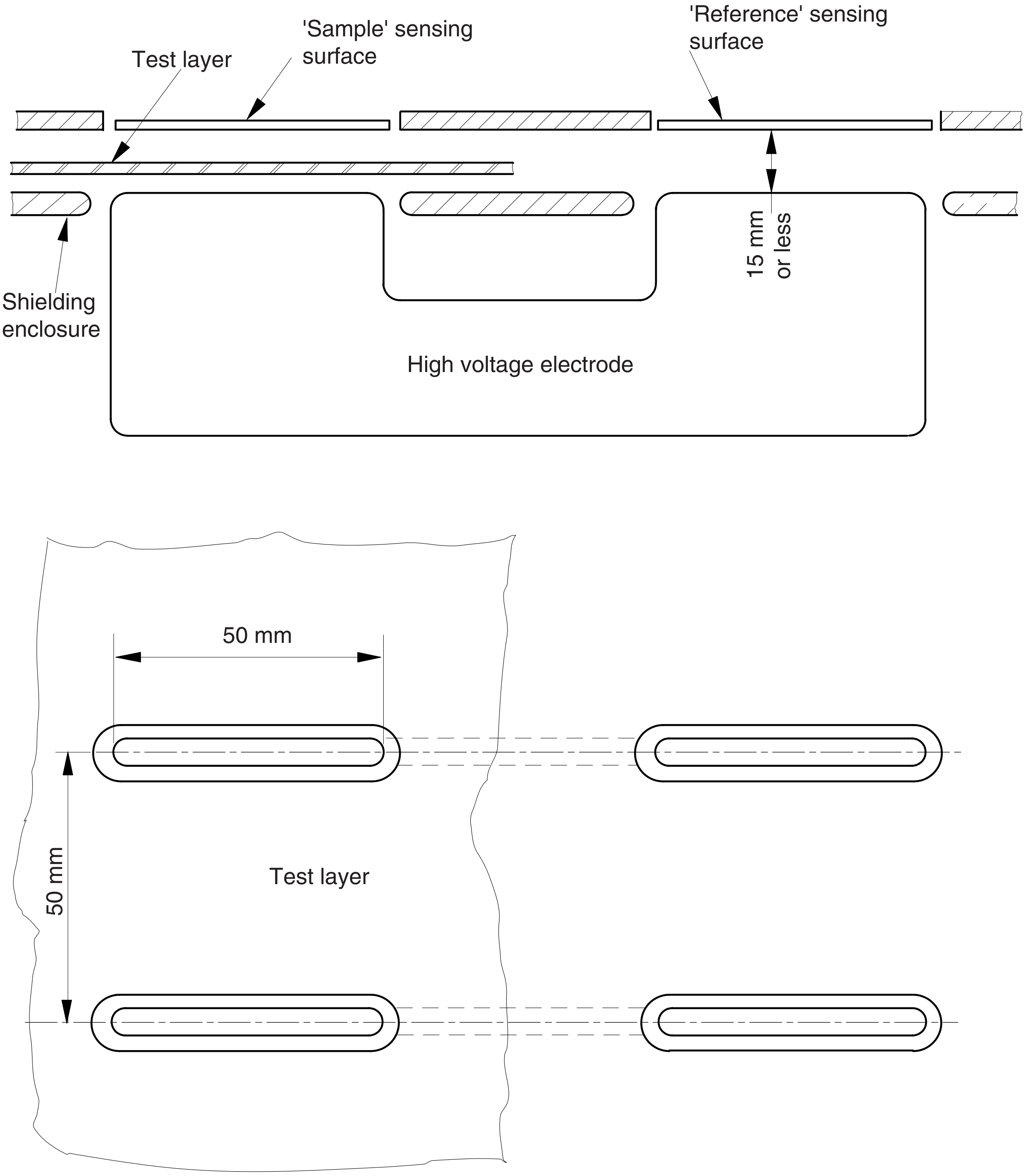


Figure 11. Plan and elevation views of shield test unit electrode system

10.3.3 *High voltage pulse source*

The capacitance of each pulse electrode providing the electric field stress shall be (150 ± 20) pF.

The high voltage pulses shall have peak amplitudes which can be set equally for both polarities in the range from 1 kV up to at least 10 kV.

The rise time, peak amplitude and fall time of the positive and negative pulses shall be matched to within 0.05 %. Pulse risetimes shall be less than 1 ns at 1 kV pulse amplitude and the pulse fall time shall be at least 0.1 s to provide an electric field test pulse with frequency components from 10 Hz to 1 GHz.

NOTE. The quality of matching of risetimes, peak amplitudes and fall times of the high voltage pulses can be tested using a high conductivity plate (for example of aluminium or copper) in the sample position.

10.3.4 *Signal measurements*

Measurement of attenuation shall be made using one or more of the following means to determine the amplitude and frequency characteristics of the signals observed on the far side of the test layer over the frequency range from 10 Hz to 1 GHz:

a) a high frequency oscilloscope of high input impedance;

b) a spectrum analyser covering frequencies from 10 Hz to 1 GHz to observe and measure the relative signal amplitude of test and reference signals as a function of frequency; or

c) multiple bandpass filter circuits with peak detection and hold circuits to observe the peak amplitudes of test and reference signals over limited frequency bandwidths centred on each decade of frequency from 10 Hz to 1 GHz.

10.4 Procedure

Position the test samples so that at least 25 mm of material extends beyond each side of each of the two pulse electrodes.

Initially, make measurements at the lowest pulse voltage (1 kV), so that breakdown to the layer does not occur. Make further measurements at pulse voltages of 5 kV, 7 kV and 10 kV and then with decreasing pulse voltages to 1 kV.

NOTE. Comparison between the initial and subsequent low voltage measurements will show if the shielding performance is affected by electric field stress and/or spark breakdown to the layer.

Repeat the measurement at least three times for each test condition and for at least three different areas of the sample of material.

Carry out additional tests on such features as seals, folds, bonds or joints present in the fabrication of practical materials or assemblies. Place the localized feature, such as a seam or join, parallel to — and half way between — the pulse electrodes. Select the plain material in the immediate vicinity of the feature as one of the sample areas (see previous paragraph).

10.5 Expression of results

Shielding performance shall be calculated and reported as the electric field attenuation ratio as a function of frequency and applied voltage.

10.6 Test report

The report shall include the following information:

a) the name and date of this standard;

b) date of measurements;

c) description and/or identification of sample tested;

d) the voltage amplitude of the source pulse for each set of measurements;

e) the signal attenuation ratios observed at each decade of frequency from 10 Hz to 1 GHz for each pulse voltage specified, with any changes in performance on repeating at lower voltages;

f) ambient temperature and relative humidity at start and end of measurements;

g) identification of instrumentation used and date of most recent calibration.

11 Measurement of d.c. breakdown voltage

11.1 Principle

The breakdown voltage of a sheet, coating layer or wrapping is sometimes required to assess the likelihood of retention of sufficient charge to cause propagating brush discharges. High accuracy is not essential but repeatability of the result is important.

Electric strength is the quotient of the breakdown voltage and the distance between the electrodes to which the voltage is applied under prescribed test conditions. It is often strongly dependent on the inter-electrode distance (i.e. the material thickness) and is not recommended for use in electrostatic work, the actual breakdown voltage being preferred.

The breakdown voltage is that voltage at which the insulating properties of an insulating medium are annihilated, at least temporarily.

NOTE. The measured values of the breakdown voltage of a material may be affected by many factors, in particular, the presence of gaseous inclusions, moisture or other contamination and also the area or volume between electrodes under maximum voltage stress.

11.2 Test specimens and conditioning

The specimens shall be conditioned for 16 h to 24 h at (23 ± 2) °C and (50 ± 5) % r.h. and at (23 ± 2) °C and (15 ± 2) % r.h. The temperature and relative humidity at which measurements are taken shall be recorded.

NOTE 1. Test specimens should be of sufficient area to prevent flashover under the conditions of test for tests made normal to the surface of the material.

NOTE 2. The electrical properties of insulating materials vary with temperature and water content.

11.3 Apparatus

11.3.1 *Electrode systems*

For plane or sheet specimens, the electrodes shall consist of two smooth, clean and defect-free, metal cylinders with rounded edges. One electrode shall be (25 ± 1) mm in diameter and approximately 25 mm high. The other electrode shall be (75 ± 1) mm in diameter and approximately 15 mm high. These electrodes are arranged coaxially as illustrated in figure 12a). Stainless steel is the preferred material to minimize electrode damage at breakdown.

The leads to the electrodes shall not tilt or otherwise move the electrodes or affect the pressure on the specimen, nor affect the electric field configuration in the neighbourhood of the specimen.

For tubing, the outer electrode shall be a band of metal foil (25 ± 1) mm wide and the inner electrode shall be a closely fitting internal conductor, e.g. rod, tube or metal foil making good contact with the inner surface. In each case, the ends of the inner electrode shall extend for at least 25 mm beyond the ends of the outer electrode. The tube shall extend beyond the outer electrode for a sufficient distance to prevent electrical leakage or flashover (see figure 12b)).

The measurement for tubes or pipes provided with buried metal wire or braid support shall be made between this and the outer, metal foil band.

11.3.2 *Test circuit*

A steadily increasing test voltage is applied such that breakdown is caused between 10 s and 20 s after the start of applying the voltage. The test voltage shall be obtained from a smoothed d.c. of ripple content less than 1 % of the output.

NOTE 1. For most materials, using electrodes as specified, an output capability of a few mA is adequate.

The voltage ramp is derived from a motor-driven power supply or a resistor-capacitor circuit. In the latter case, the voltage of the source shall be at least three times the highest expected breakdown voltage.

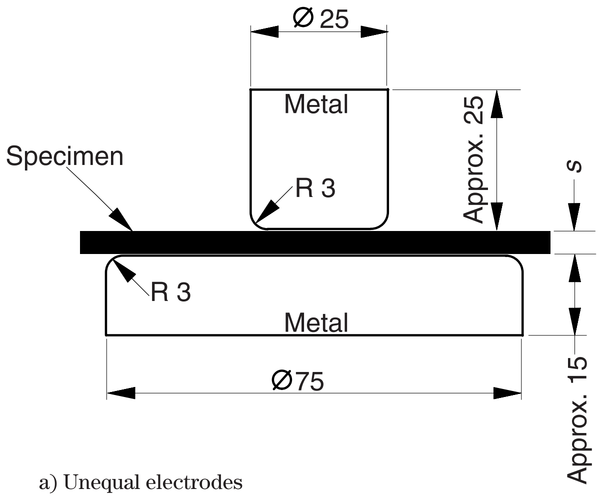
NOTE 2. An example of a suitable circuit, incorporating a current limiting resistor and resistor-capacitor generation of the voltage ramp is shown in figure 13.

The switches S_{2a} and S_{2b}, which should be able to operate satisfactorily at 20 kV, are ganged, opening the switches starting the ramp.

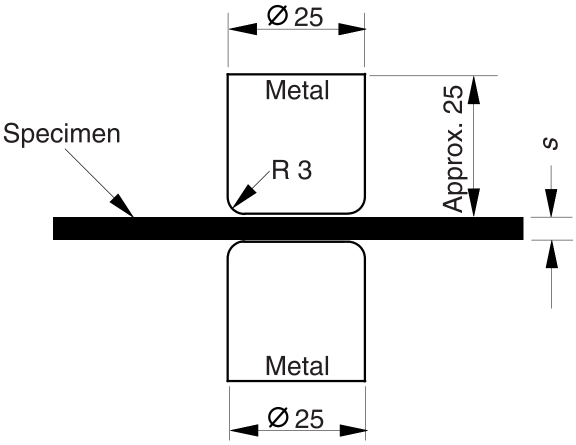
The function of switch S_1 is to disconnect the control and electrode systems for shutdown or sample changing; it is ganged to switches S_2 so that it opens when they close. Switch S_{2a} discharges the capacitor C_1 through resistor R_3 during stand-by: S_{2b} short-circuits the electrodes during stand-by and sample changing.

NOTE 3. It is desirable for the switches to be interlocked so that S_2 cannot be opened while the electrodes are exposed.

NOTE 4. Using the component values given, 4 kV is reached in about 11 s and these resistance values are suitable for samples of volume resistivity greater than 10^9 Ω·m in a thickness of 100 μm.



a) Unequal electrodes



b) Equal diameter electrodes

Dimensions in millimetres

Figure 12. Electrode arrangements for tests on boards and sheets normal to the surface

A voltmeter, connected directly to the electrodes, or via a potential divider is used to determine the breakdown voltage. The overall error of the voltage-measuring circuit shall not exceed 5 % of the measured value including the error due to the response time of the voltmeter.

NOTE 5. It is desirable for the applied voltage to be continuously recorded and the maximum value read after breakdown.

If a maximum indicating voltmeter is used, it shall not be affected by the transients which occur at breakdown.

11.4 Procedure

Apply suitable electrodes, switch on the power source and continuously record the increasing voltage. Note the maximum voltage attained.

Test five specimens.

NOTE 1. Electric breakdown is accompanied by an increase of current flowing in the circuit which usually leads to a rapid decrease of voltage across the specimen. A series resistance should be used to limit the discharge current.

NOTE 2. Where tests are made perpendicular to the surface of a material, there is usually no doubt when breakdown has occurred but subsequent visual inspection may not show the actual breakdown channel whether this is filled with carbon or not.

11.5 Results

The result is the highest value of the individual readings of breakdown voltage (in kV).

11.6 Report

The report shall include at least the following information:

a) the number and date of this standard;

b) a complete identification of the material tested;

c) the highest value of the breakdown voltage (kV) or the electric strength (kV/mm);

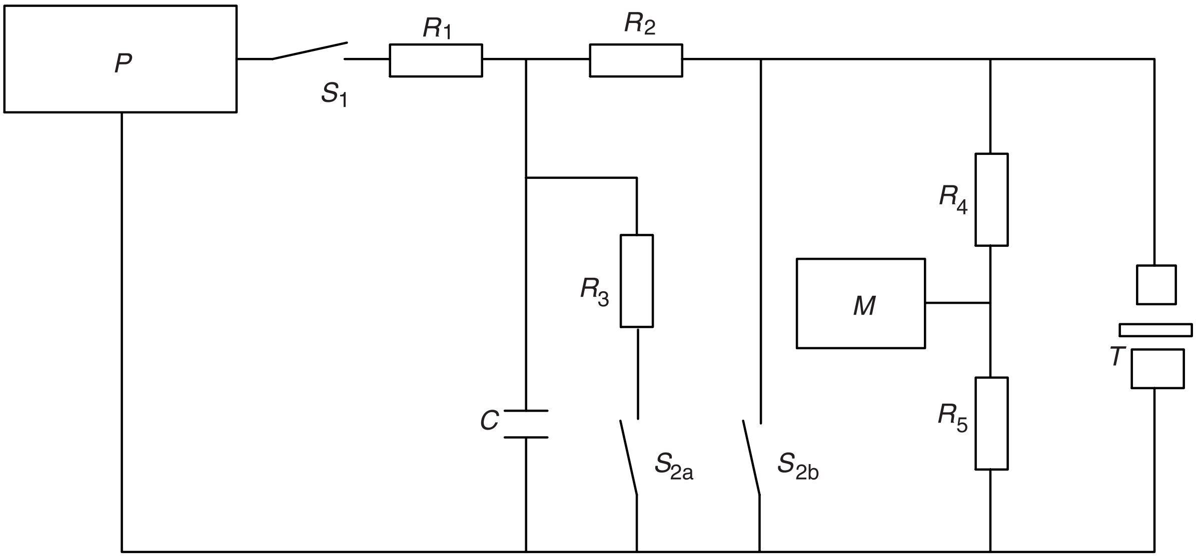
d) the thickness of each specimen;

e) the electrode system;

f) the individual values of breakdown voltage or electric strength;

g) the temperature, pressure and humidity during tests;

h) the conditioning treatment before test.



P	Power supply (20 kV, 5 mA)
R_1	Charging resistor 7 MΩ
R_2	Protective resistor 50 MΩ
R_3	Discharging resistor 100 kΩ
R_4	Potential divider 500 MΩ
R_5	Potential divider 500 Ω
M	Recorder, 10 mV
C	Timing capacitor, 7 µF
T	Test electrodes and test specimen
S	Control switch. S_1, S_{2a}, S_{2b} ganged for safety. S_1 to open when S_{2a} and S_{2b} close, and vice versa.

The switches shall be able to control potentials up to at least 20 kV at current levels of a few mA.

Figure 13. Breakdown voltage measurement circuit based on capacitor charging

Annexes

Annex A (informative)
Methods for the calibration of electrostatic instruments

A.1 General

Special instruments used for measurements in electrostatics are the fieldmeter, proximity voltmeter (fieldmeter used for surface voltage measurement at a defined distance), Faraday pail, charge decay test instrument and the shielding test instrument. Procedures for the calibration of these instruments are not available in standards literature and are presented here. Methods for the calibration of conventional voltmeters and ammeters, which may also be used to measure the electrical properties of materials, are available in the standards literature.

A.2 Electrostatic fieldmeters

A.2.1 *Apparatus*

The electric field for calibrating electrostatic fieldmeters is set up by application of a stable continuous voltage between a pair of plane and parallel metal plates. The fieldmeter is mounted with its sensing aperture mounted through a hole in the middle of one of the plates (see figure A.1). The mounting hole should fit the surface around the sensing aperture with a gap less than 0.5 % of the sensing aperture diameter and with the sensing aperture coplanar with the surrounding surface to within ± 1 % of this diameter. The calibration plates should be rigid, flat to better than ± 2 % of plate spacing, smooth and free from contamination and loose dust.

Calibrationis achieved by comparing the fieldmeter reading with the value of electric field calculated by dividing the voltage applied by the separation gap: the measurements are repeated over a range of applied voltages.

For calibration to within 1 %:

- — the spacing between the plates should be at least 1.5 times the sensing aperture diameter;
- — the radial extent of the plates should be at least 15 sensing aperture diameters.

For calibration to within 5 %:

- — the spacing between the plates should be at least 1.5 times the sensing aperture diameter;
- — the radial distance should be at least nine diameters.

The outer edges of the plates should have radii of curvature of 2 mm or more and/or be covered by a local layer of insulation to avoid corona discharges at the higher calibration voltages.

If separation of the plates is achieved by stand-off insulators between the plates these should be mounted at the outer periphery of the plates so that any charge trapped on the insulators during high voltage operation has no influence of the electric field in the central region when the plates are shorted together to check the zero setting of the fieldmeter.

A.2.2 *Voltage source*

A source of stable, low ripple voltage of both polarities should be used to provide a range of electric fields in the calibrator from less than 25 % of the most sensitive full scale range of the fieldmeter under consideration to at least 25 % of the least sensitive range.

NOTE. Typically, voltages are required from 50 V to 30 kV.

More than one power supply unit may be needed to cover the required range with adequate stability and ease of adjustment. Voltage stability shall be better than 0.2 %.

A.2.3 *Voltage measuring system*

The voltage measuring system should cover the measurement of both polarities and be separate from the voltage source so that it may be calibrated independently. Voltage measurements should be made with direct independent connection to the calibrator plates and the accuracy should be better than 0.2 % for high accuracy fieldmeters and better than 1 % for medium accuracy.

Voltages up to 1000 V may be measured using a digital multimeter. For higher voltages a high voltage resistive divider should be used to present a known fraction of the voltage to a precision digital voltmeter.

NOTE. Resistor values of 1000 MΩ and 1 MΩ are convenient for the high and low voltage arms of a divider.

Precautions should be taken to avoid corona as corona discharge currents could affect accuracy. To avoid the input impedance of the measuring voltmeter influencing accuracy, the high voltage divider should be calibrated in conjunction with its measurement voltmeter. The voltage values at which the voltage measuring instruments are calibrated should be those at which fieldmeter calibration measurements are made to avoid any linearity errors at interpolation between calibration values.

A.2.4 *Distance measurements*

The spacing between the plates adjacent to the hole for mounting the fieldmeter sensing aperture should be measured using slip gauges with the calibration system in the ‘as used’ condition. The spacing distance is taken as the arithmetic mean of measurements at four equispaced positions around the fieldmeter mounting hole with calculation of the uncertainty.

The error in matching the plane of the sensing aperture to the plane of surrounding inner surface of the mounting calibration plate is established using slip gauges to measure the thickness of the mounting plate at four equispaced points around the mounting hole and measuring the height of the spigot of each fieldmeter calibrated.

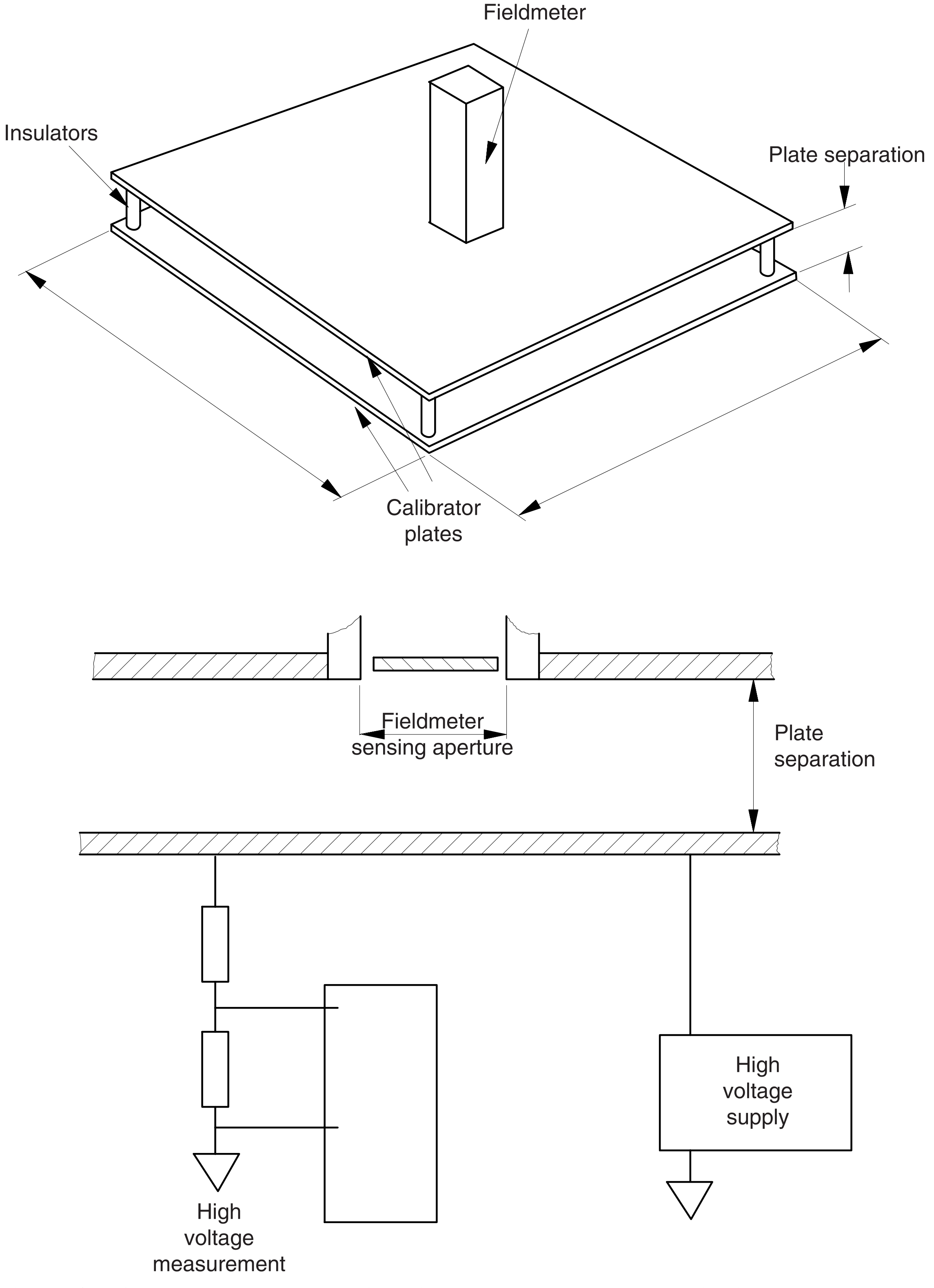


Figure A.1 General features of calibration system for electrostatic fieldmeters

A.2.5 *Procedure*

Mount the fieldmeter on the calibration unit, switch on and allow to stabilize. Read the initial (zero) value with the calibration plates shorted together.

Record the fieldmeter output for a number of applied voltages to give readings from around 25 % of the most sensitive range up to at least 25 % of the least sensitive range of the fieldmeter. For multirange instruments use voltages which give readings less than 25 % and more than 90 % of each range so there is some overlap. Use the voltage values for calibration at which the voltage measuring system has been calibrated.

Repeat the calibration measurements for both polarities.

NOTE 1. Calibration to 90 % of full scale may not be feasible where the least sensitive range is over 500 kV·m^{-1}.

After increasing the calibration voltage to maximum, check the readings as the voltage is decreased with a specific check on the zero reading.

NOTE 2. Differences between increasing and decreasing values of voltage may be due to charging of any insulation in the sensing region of the fieldmeter or to dust between the calibration plates.

A.2.6 *Results*

The results of calibration are the instrument readings which are listed directly on the calibration certificate together with the values of voltages applied and the calculated values of the field.

A.2.7 *Calibration certificate*

The calibration certificate of an instrument dispatched to a customer direct from manufacture should record the 'as dispatched' values. The calibration certificate of an instrument returned from a customer should record the 'as received' calibration. If no adjustments are needed the calibration values presented on the calibration certificate are designated 'as received and dispatched'. If changes to components or adjustments are made then the instrument is recalibrated in the sealed condition ready for dispatch and both the 'as received' and 'as dispatched' values are presented on the calibration certificate.

A.2.8 *Calibration certificate information*

The calibration certificate should include the following information:

a) the name of the organization issuing the certificate;

b) certificate number;

c) customer identity;

d) instrument type number;

e) instrument serial number;

f) date of calibration;

g) name and signature of authorized signatory;

h) method of calibration used;

i) reference number of standard;

j) overall assessed accuracy of the calibration;

k) list of applied voltages, the corresponding values of electric field and the actual instrument readings observed for both polarities (with values of upper and lower ranges where sensitivity ranges overlap);

l) reference information on the date and place of calibration of measuring instruments used and the accuracy of this calibration;

m) physical measurement information relevant to the calibration set-up (the size of the calibration plates and plate separation).

A.2.9 *Calibration of measuring instruments*

Instruments used for calibration should be calibrated with reference to national or international standards according to the procedures and requirements of BS EN 30012-1.

High voltage resistive dividers should be calibrated in conjunction with the measuring voltmeter at the voltage values used for calibration. High voltage resistive dividers, capacitors and resistors as used for the calibration of charge decay instruments should be calibrated at intervals not exceeding 12 months. Slip gauges used for distance measurement should have their calibration checked every two years.

A.3 Proximity voltmeters

A.3.1 *Apparatus*

Proximity voltmeters are calibrated by mounting the instrument with its sensing aperture at the specified 'normal' operating distance perpendicular to the middle of a large plane metal surface and recording the reading of the instrument as a function of voltage applied to the metal plate.

The calibration arrangement is shown in figure A.2. For calibration to ± 1 % accuracy, the radial extent of the calibrator plate should be at least five times the separation distance between the sensing aperture and the plate. There should be no surfaces nearer than 1 m which can retain static charge and no earthed surfaces nearer than 0.5 m. Insulators used to mount or support the calibration plate should be on the opposite side to the voltmeter.

NOTE. Many proximity voltmeters are set for an operating distance of 100 mm so a radial extent of five times the separation distance requires a calibration plate of at least 1 m square.

The calibration plate should be smooth, free from contamination and loose dust and flat to better than +2 % of the voltmeter separation distance. Plate edges should have a radius of curvature of 2 mm or more and/or be covered by a local layer of insulation to avoid corona discharges at the higher calibration voltages.

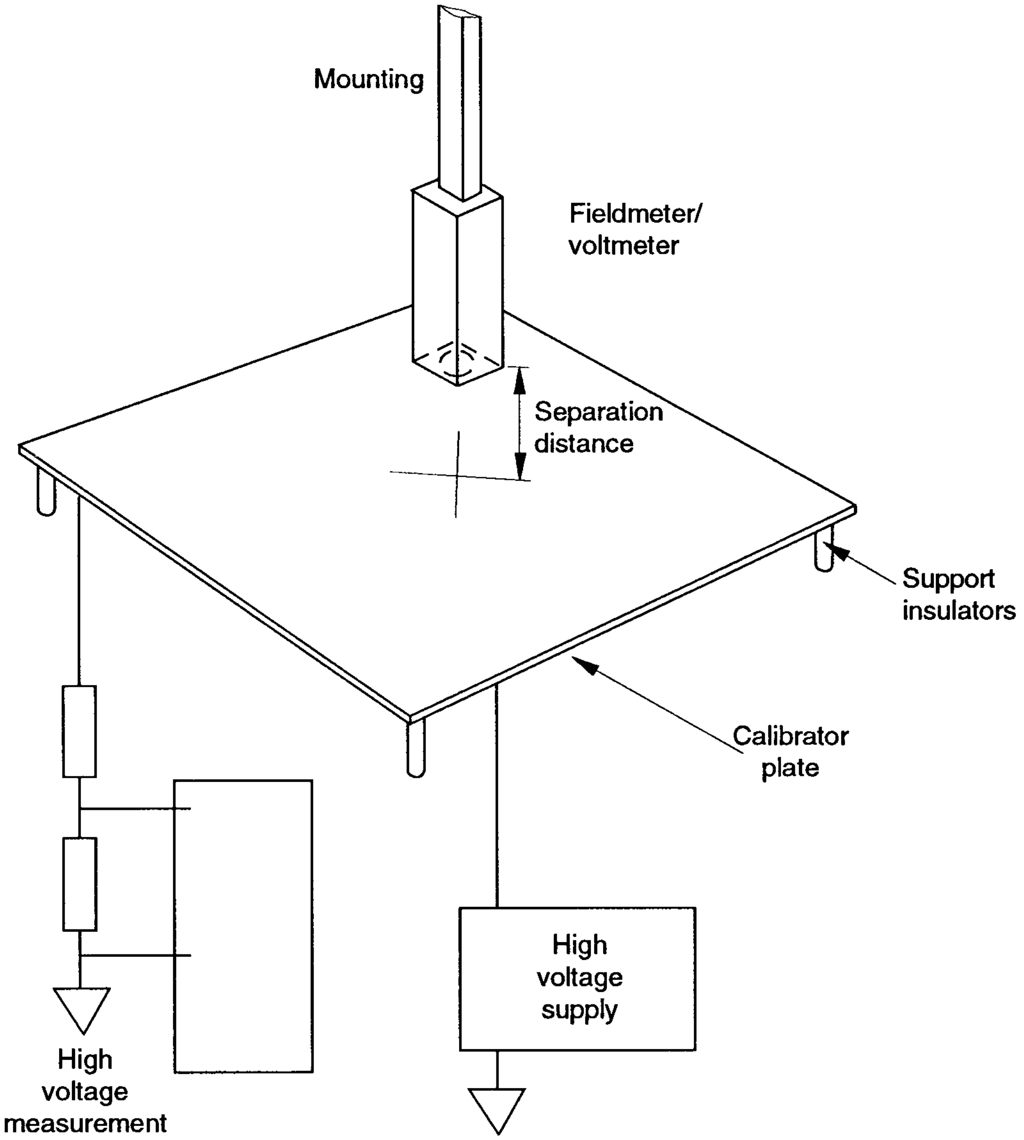


Figure A.2 General features of calibration system for proximity voltmeters

The spacing between the fieldmeter sensing aperture and the plate for earthed fieldmeter instruments should be measured using slip gauges. The distance shall be measured with an accuracy better than 0.5 % for high accuracy instrument and 2 % for medium accuracy. For voltage null instruments the separation distance is not measured so long as it is less than 10 % of the minimum radius radial distance of the surface surrounding the sensing aperture.

A.3.2 *Voltage source and measuring system*

The voltage source and voltage measurement system should fulfil the same specification requirements as for fieldmeter calibration as described in **A.2.2** and **A.2.3**.

A.3.3 *Procedure*

Mount the voltmeter at the specified measurement distance, switch on and allow to stabilize. Read the initial (zero) value with the calibration plate shorted to earth.

Apply voltages to the plate to give readings from around 25 % of the most sensitive range up to at least 25 % of the least sensitive range. For multi- range instruments use voltages which give readings from less than 25 % to more than 90 % of each range. Readings should be made on both ranges where there is overlap between ranges.

Measure the output for both increasing and decreasing voltages including zero for both polarities.

NOTE 1. Differences in readings between increasing and decreasing calibration voltage may be due to charging of insulation in the sensing region of the voltmeter, dust on the calibration plate or charge on nearby surfaces.

NOTE 2. The influence of any initial charge on nearby surfaces may be tested by checking the zero readings of the voltmeter when mounted to a clean metal 'zero check chamber' and then as mounted into the calibration position with the calibration plate connected to earth.

A.3.4 *Common aspects of calibration*

Details of calibration measurements and associated information should be recorded as given in **A.2.6** to **A.2.9**.

A.4 Faraday pail

A.4.1 *Apparatus*

The following types of calibration should be used.

a) *Calibration by capacitance and voltage sensitivity*

For a Faraday pail system in which charge measurement depends on the separate measurement of capacitance and voltage, the input capacitance is measured with the Faraday pail set up as for normal use. The voltage sensitivity is determined by applying calibrated voltages to the pail.

b) *Direct charge calibration*

Direct charge calibration of a Faraday pail for charges greater than 100 pC may be carried out using high quality calibrated capacitors charged to calibrated voltages.

Defined quantities of charge less than 100 pC shall be introduced by lowering a small sphere charged to a defined voltage into the pail. The capacitance of the sphere relates to its diameter; 0.05563 picofarads per millimetre of diameter. The sphere is suspended by a fine, highly insulating thread to avoid charge leakage. The diameter of the sphere should be measured using slip gauges. This should be measured to an accuracy better than 0.5 % for a high accuracy instrument and 2 % for medium accuracy. The sphere is charged by touching it to the tip of a long thin conductor (less than 5 % of the sphere diameter) held at the defined voltage.

No earthed or charged surfaces should be nearer than about 0.5 m. The operator should be earth bonded by a wrist strap and static dissipative clothing may be needed.

NOTE. Charge trapped on the insulating thread is minimized by leaving the sphere hung up from a loop at the end of the thread and avoiding rubbing or touching the thread in handling the sphere.

Absence of charge on nearby surfaces should be checked by observing the charge introduced when the voltage on the contact point is set to zero. A small charge will arise from electrochemical potential differences between materials. For high sensitivity measurements all surfaces should be gold plated for stability of surface potentials and the sphere is connected to earth by touching the inside bottom surface of a deep shielding chamber.

A.4.2 *Voltage source and measurement system*

The voltage source and voltage measuring system are as required for fieldmeter calibration and described in **A.2.2** and **A.2.3**.

A.4.3 *Procedure*

Switch on the voltage sensor system and allow to stabilize. Earth and then isolate the Faraday pail from earth and take readings over a time comparable to normal measurement. With zero volts applied to the charge induction point, touch the sphere and transfer the sphere to the pail. Check that the quantity of charge transferred with zero voltage is less than 1 % of the charge reading on the most sensitive scale for high accuracy instruments or 5 % for medium accuracy instruments.

Apply voltages to the induction point to give readings from around 25 % of the most sensitive range up to at least 25 % of the least sensitive range. For multi-range instruments use voltages which give readings less than 25 % and more than 90 % of each range so there is some overlap.

Make at least five measurements for each calibration condition and the results averaged with calculation of the standard deviation.

Repeat the measurements for both polarities.

A.4.4 *Results*

The average value and the standard deviation should be calculated for each set of five calibration measurements.

A.4.5 *Common aspects of calibration*

Details of calibration measurements and associated information should be recorded as given in **A.2.6** to **A.2.9**.

A.5 Charge decay apparatus

A.5.1 *Voltage sensitivity calibration*

The voltage sensitivity calibration is made in terms of a uniform potential on a conducting surface covering the whole test aperture area. The conducting surface should have a small separation below the edge of the test aperture (less than 0.5 mm) so that calibration voltages can be applied.

The voltage source and voltage measuring system are as given for fieldmeter calibration in **A.2.2** and **A.2.3**.

A.5.2 *Decay time calibration*

Calibrated resistors and capacitors are connected from the conducting calibration plate across the test aperture to earth. The resistors and capacitors should be of good quality, with a linear voltage characteristic and be capable of withstanding voltages up to at least 1 kV.

Decay time constant values from the values of calibrated resistors and capacitors should be provided for each decade of time over the main operating range of the instrument. To cover the range of interest of materials used for static control decay time constant values should be provided from 100 ms to 100 s.

Calibration of the resistors and capacitors should be carried out in the test set-up.

A.5.3 *Procedure*

Mount the charge decay unit over the voltage calibration plate, switch on, allow to stabilize. Connect the calibration plate to earth and measure the initial (zero) reading. Apply voltages to the plate to give readings from around 5 % of the most sensitive range up to at least 25 % of the least sensitive range of the surface voltage measurement and record the measured value. For multi-range instruments use voltages which give readings less than 25 % and more than 90 % of each range so there is some overlap. Repeat the measurements for increasing and decreasing voltage including zero and for both polarities.

Charge the conducting surface and measure the time for the voltage developed to fall from the voltage at which timing starts to $1/e$ of this voltage. Measure the decay time constant using both polarities for each of the combinations of resistors and capacitors providing decay time constant values.

Where calculation of decay time constant values is made using linkage of observations to a microcomputer for software analysis the values of decay time constants obtained by this method should be recorded.

A.5.4 *Results*

The average value and the standard deviation should be calculated for each set of five calibration measurements.

A.5.5 *Common aspects of calibration*

Details of calibration measurements and associated information should be recorded as given in **A.2.6** to **A.2.9**.

A.6 Shielding test apparatus

A.6.1 *Voltage calibration*

For pulse generating circuits in which the pulse amplitude equals the potential of the initial applied voltage the voltage supply sources can be calibrated as for fieldmeter calibration described in **A.2.2** and **A.2.3**.

A.6.2 *Dimensional measurements*

The length and spacing of the pulse electrodes, the separation distance between the pulse electrodes and the layer and other relevant dimensions of the test apparatus should be measured with instruments which provide traceability of measurements to national standards.

A.6.3 *Response calibration*

The response characteristics are determined by observing the test and reference signals as the source pulse voltage is varied over a wide range. High conductivity plates with uniform width apertures spanning across both source pulse electrodes are used to provide stable attenuation factors to cover operation with increased gain. The exact level of attenuation of individual plates is established by finding how much the high voltage pulse amplitude needs to be adjusted to achieve good matching of response curves for each gain setting. By using a number of such attenuator plates these comparisons shall provide absolute relationships between observed signal amplitude and attenuation for each gain setting.

The variation of observed signals with pulse amplitude shall be fairly linear for frequencies up to 10 MHz.

NOTE. The curve matching approach does not require signal response to be linear. So long as the size of the apertures in the high conductivity plates is small compared to the wavelength of the frequency involved the attenuation should be independent of frequency. This is a useful but not a critical feature.

Balance in the amplitude and pulse form of the high voltage pulses is tested using full plates of high conductivity (for example aluminium or copper) which are not bonded to earth. These are placed symmetrically into the test gaps of both the test and the reference channels. At balance no signals will be observed at any gain setting or at any frequency.

A.6.4 *Bandpass frequencies*

The bandpass characteristics of each signal channel are checked using either a swept frequency signal generator or a variable risetime single pulse source.

A.6.5 *Results*

The measured dimensions, the calibration of the pulse voltage supplies and the response characteristics of the signal observation arrangements should be recorded on the calibration certificate.

A.6.6 *Common aspects of calibration*

Details of calibration measurements and associated information should be recorded as given in **A.2.6** to **A.2.9**.

Annex B (informative)

Bibliography

NOTE. The following publications are not referred to in the text but may serve as additional information.

CHUBB J.N. and BUTTERWORTH G.J. Instrumentation and techniques for monitoring and assessing electrostatic ignition hazards, *Electrostatics: Inst. Phys. Conf. Series*, **48**, 85-95, 1979.

The following standards relate to the test methods:

BS 89 :	*Direct acting indicating analogue electrical measuring instruments and their accessories*
BS 4311 :	*Specification for gauge blocks and accessories*
BS 4311 : Part 1 : 1993	*New gauge blocks*
BS 4311 : Part 2 : 1994	*Accessories*
BS 4311 : Part 3 : 1993	*Gauge blocks in use*
BS 4372 : 1968	*Specification for engineers' steel measuring rules*
BS 5248 : 1990	*Specification for aspirated hygrometer*
BS 5737 : 1979	*Method for the measurement of relative permittivity, dielectric dissipation factor and d.c. resistivity of insulating liquids*
BS EN 100015 :	*Basic specification — Protection of electrostatic sensitive devices*
BS EN 100015-1 : 1992	*Harmonized system of quality assessment for electronic components — Basic specification: protection of electrostatic sensitive devices — General requirements*
ISO 6297 : 1983	*Petroleum products — Aviation and distillate fuels containing a static dissipator additive — Determination of electrical conductivity*

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List of references (see clause **2**)

Informative references

BSI publications

BRITISH STANDARDS INSTITUTION, London

DD 68 : 1980	*Method for determinaiton of static electrical propensity of textile floor coverings: 'walking test'*
BS EN 30012	*Quality assurance requirements for measuring equipment*
BS EN 30012-1 : 1994	*Metrological confirmation system for measuring equipment*

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