

Annex 3: METHODS FOR THE CALIBRATION OF ELECTROSTATIC MEASURING INSTRUMENTS

1. INTRODUCTION

Methods are described in the following sections for formal calibration of the main instruments for electrostatic measurements. They cover:

- electrostatic fieldmeters for measurement of electric field, surface voltage, space voltage and surface charge density
- electrostatic voltmeters for surface voltage and zero current drain voltage measurements
- Faraday Pails for measurement of charge
- charge decay test units for assessment of the suitability of materials
- air ionization test units

The methods described are based on the methods in British Standard BS 7506: Part 2: 1996 [1] but have been updated in the light of experience. No comparable alternative methods are available in standards literature. Methods for the calibration of voltage, resistance, capacitance and separation distance measurements etc are available in the standards literature.

2. COMMON FEATURES

2.1 Introduction

All instruments used in calibration work should be calibrated with reference to national or international standards according to the procedures and requirements of BS EN 30012-1. The following sections describe a number of common requirements for calibration of electrostatic instrumentation.

2.2 Voltage source

Voltages are typically required of both polarities from $\pm 50\text{V}$ up to $\pm 30\text{kV}$. The source needs to be stable and with low ripple to better than 1% and preferably to 0.2% of the voltage level applied. More than one power supply unit may be needed to cover the required range with adequate stability and ease of adjustment.

Voltage levels for calibration should be used from less than 25% of the most sensitive full scale range to at least 25% of the least sensitive range. They should cover 100% of all ranges except the least sensitive.

2.3 Voltage measurement system

The voltage measuring system should cover the full range of measurement needed for both polarities. It should preferably be separate from the voltage source so that it may be calibrated and used 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 and better than 1 % for medium accuracy instruments.

Voltages up to 1000V 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.

For voltages and voltage dividers working at over 1000V 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. Resistor values of 1000M and 1M are convenient for the high and low voltage arms of a divider.

The voltage values at which the voltage measuring instruments are calibrated should be those

at which calibration measurements are made to avoid any linearity errors at interpolation between calibration values.

High voltage resistive dividers should be calibrated in conjunction with the measuring voltmeter at the voltage values used for calibration.

2.4 Resistors and capacitors

High voltage capacitors and resistors, as used for the calibration of charge decay instruments and charge plate monitors, should be calibrated in situ in the unit or set-up used for calibration. Calibration of the values of capacitance and resistance should be made to better than 1\%.

2.5 Distance measurements

Distance measurements should be made using slip gauges. Calibration should be checked every two years.

2.6 Temperature and Humidity

Sensors used to provide supporting temperature and humidity information should be formally calibrated or, if incorporated into instrumentation, should at least be precalibrated.

2.7 Standard instrument calibration certificate information

The calibration certificate needs to 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 of person who carried out the calibration and name and signature of authorized signatory
- h) identification of method of calibration used (e.g. reference number of Standard)
- i) overall assessed accuracy of each aspect of calibration
- j) physical measurement information relevant to the calibration set-up
- k) reference information on the date and place of calibration of measuring instruments used and the accuracy of these calibrations
- l) list of applied parameters with derived values and the actual instrument readings observed with values for upper and lower ranges where sensitivity ranges overlap

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 as well as the 'as dispatched' values. If no adjustments are needed the calibration values presented on the calibration certificate are designated 'as received and dispatched'. If it has been necessary to change components or make adjustments 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.

3. ELECTROSTATIC FIELDMETERS

3.1 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 [1,2]. The fieldmeter instrument is mounted with its sensing aperture flush with the inner surface in the middle of one of the plates (see Figure 1).

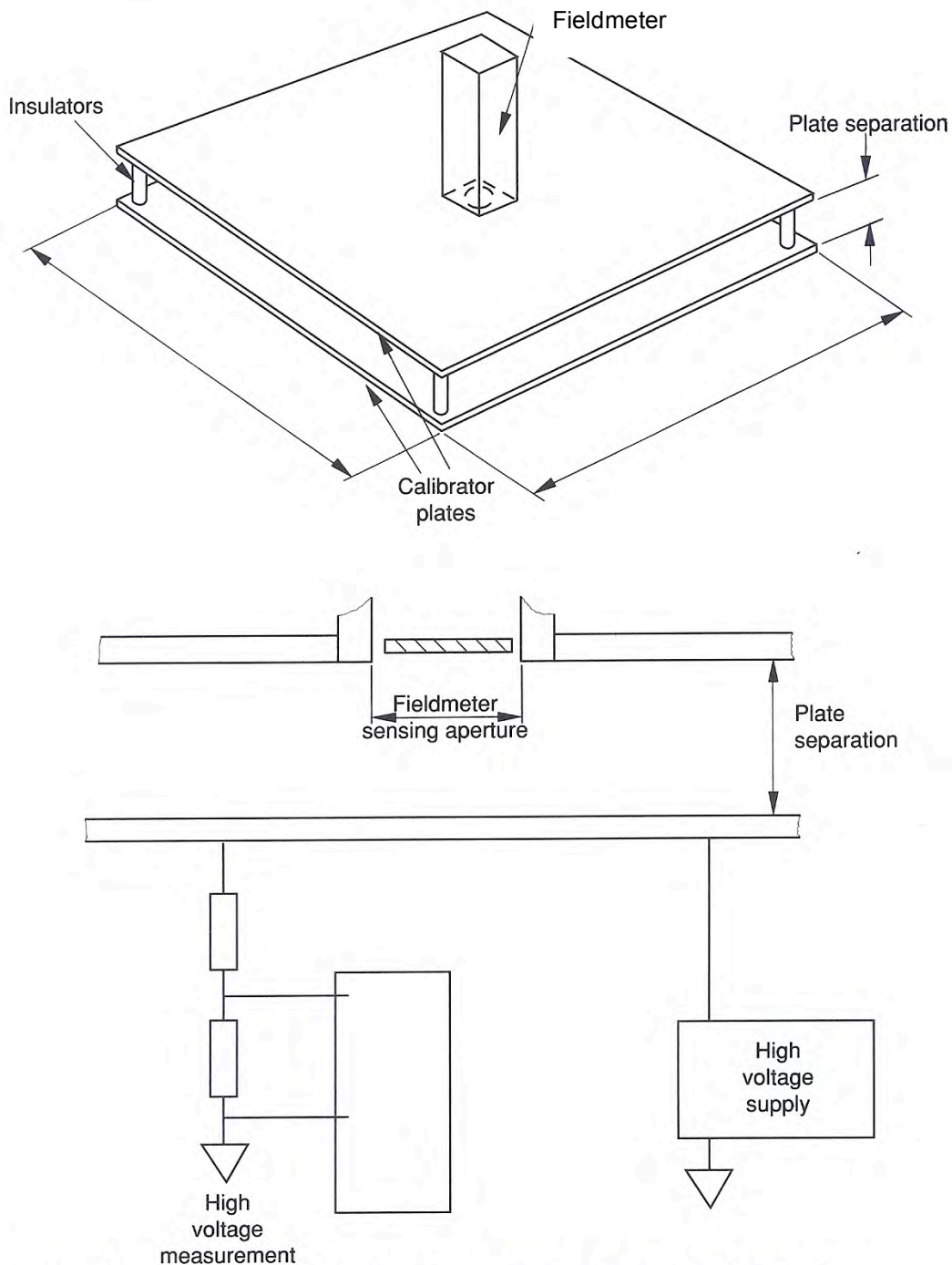


Figure 1: General arrangement for calibration of electrostatic fieldmeters

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.

Adequacy in the radial size of the calibration plates may be tested by shorting the plates together and observing any signal change on the most sensitive range when a piece of charged plastic is brought near the outside of the plate gap.

The mounting hole should be a close fit for the spigot around the sensing aperture. The fit should be better than 0.5% of the sensing aperture diameter and with the sensing aperture coplanar with the surrounding surface to within $\pm 0.1\%$ of this diameter. 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.

The calibration plates should be rigid, flat to better than 2 % of plate spacing, smooth and free from contamination and loose dust. The rigidity should be adequate to avoid any change in plate separation by the loading of the heaviest fieldmeter instruments to be calibrated.

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 (for example over 5kV).

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. This is particularly important when the plates are shorted together to check the zero setting of the fieldmeter.

With the calibration system in the 'as used' condition the spacing distance between the plates is measured using slip gauges. Measurements of separation distance are taken at four equispaced positions around the fieldmeter mounting hole. The separation spacing is taken as the arithmetic mean of measurements with calculation of the uncertainty.

3.2 Procedure

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

Mount the fieldmeter on the calibration unit with its sensing aperture flush with the inner surface of its mounting plate. Switch on the high voltage supply and allow it to stabilize.

With the calibrator plates shorted together take the initial (zero) reading of the fieldmeter display and/or output signal.

Apply voltages between the calibrator plates 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 autoranging instruments use voltages which give readings less than 25% and more than 90% of each range so there is some overlap between ranges. 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 or changes in zero reading may be due to charging of any insulation in the sensing region of the fieldmeter or to dust between the calibration plates. If

this is not it is necessary to clean both the upper and lower calibrator plates.

3.3 Results

The results of calibration are a Table of instrument readings with corresponding the values of voltages applied and calculated values of the field for both polarities.

3.4 Common aspects of calibration

Details of calibration measurements and associated information should be recorded as given in Section 2.7.

3.5 Calibration certificate information

The calibration certificate needs to include the following in addition to the standard information listed in 2.7. a Table listing values 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).

4. PROXIMITY VOLTMETERS

4.1 Apparatus

Proximity electrostatic voltmeters come in two basic forms:

4.1.1 Electrostatic fieldmeter:

The electric field observed at the sensing aperture of an earthed electrostatic fieldmeter at a defined separation distance from the surface to be measured relates directly to the voltage on the surface. Readings are not linearly dependent on gap and can be influenced by any electrostatic charges in the vicinity.

4.1.2 Voltage follower probe:

Voltage follower probes are a fieldmeter mounted close to the test surface so that their electric field readings are determined only by the nearby surface and there is no influence from any electrostatic charges in the vicinity. The voltage needed to be applied to give zero electric field is then the surface voltage

4.2 Arrangements for calibration

4.2.1 Electrostatic fieldmeter:

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 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.

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.

4.2.2 Voltage follower probe:

The probe head unit should be mounted by an insulating support with the sensing aperture separated from the clean flat calibration plate a distance similar to the sensing aperture. The mounting insulation must be suitable to withstand the highest calibration voltage to be used. It must also be well shielded to avoid any possibility that residual charge can influence observations.

All surfaces that could become charged and influence readings need to be kept well away from the sensing unit – at least $\frac{1}{2}$ m.

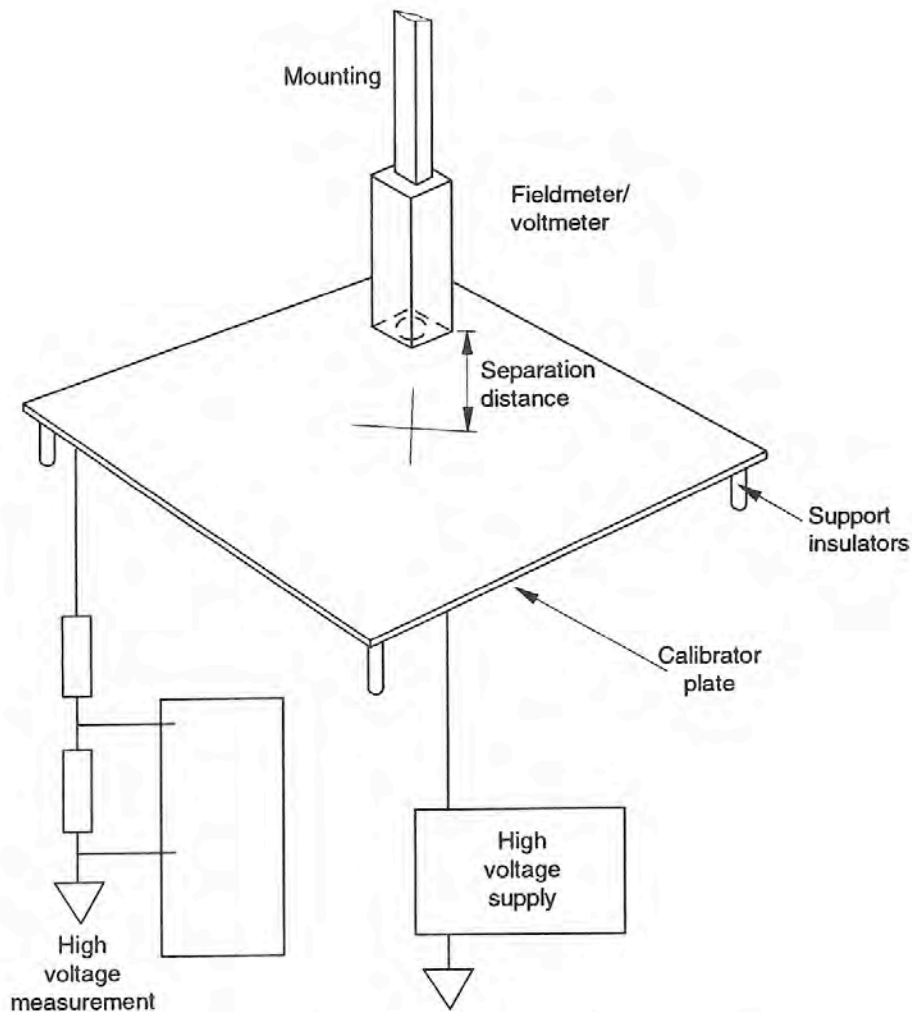


Figure 2: general arrangement for calibration of a fieldmeter proximity voltmeter

4.3 Voltage source and measuring system

The voltage source and voltage measurement system should fulfill the requirements described in Sections 2.2 and 2.3.

4.4 Procedure

Mount the voltmeter at the specified separation distance, connect it to earth, 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 multirange 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.

4.5 Common aspects of calibration

Details of calibration measurements and associated information should be recorded as given in Section 2.

4.6 Calibration certificate information

The calibration certificate needs to include the following in addition to the standard information listed in 2.7. a Table listing values 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).

5. ELECTROSTATIC VOLTMETER

5.1 Calibration method

Calibration is achieved by applying calibrated voltages to the input terminal and recording the readings against the applied voltages. may be achieved in two ways:

Where the voltage measurement unit is separable from the Electrostatic voltmeter system then this unit should be calibrated in its own right.

5.2 Voltage source and measuring system

The voltage source and voltage measurement system should fulfill the requirements described in Sections 2.2 and 2.3.

5.3 Arrangements for calibration

If the measuring region of the voltmeter is earth shielded from the surrounding environment there is no need to control charges on nearby surfaces. If the voltmeter assembly is open and readings are susceptible to charges nearby then care must be taken to earth shield the surroundings and also the operator.

5.4 Procedure

Switch on the voltmeter and allow to stabilize. Earth the input connection and record the zero reading. Apply voltages 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. Repeat the measurements for both polarities.

5.5 Results

List the values of applied calibration voltages and the corresponding readings for both polarities.

5.6 Common aspects of calibration

Details of calibration measurements and associated information should be recorded as given in Section 2.7.

5.7 Calibration certificate information

The calibration certificate needs to include the following in addition to the standard information listed in 2.7:

A Table listing the readings observed for each value of applied calibration voltage for both polarities (with values for upper and lower ranges where sensitivity ranges overlap).

6. FARADAY PAIL

6.1 Calibration method

The charge introduced into a Faraday Pail may be measured directly using a virtual earth charge measuring amplifier or from the increase in the voltage of the capacitance of the pail system. The voltage increase approach may be convenient, but because it operates by charge sharing between the item or material introduced and the capacitance of the pail there will be an associated, but perhaps small, adjustment needed. With the virtual earth measurement the pail remains at earth potential so all the charge is transferred to the measurement circuit so a more precise measurement is made.

6.1.1) Calibration of virtual earth charge measurement

The principle is to charge a calibrated capacitor to a calibrated voltage and discharge this into the input of the charge measurement circuit. The virtual earth measurement circuit ensures the input connection remains at earth potential and all the charge ($Q = CV$) is transferred from the charged capacitor to the feedback capacitor with the voltage appearing as the output voltage.

It is necessary to use a good quality capacitor to avoid any influence of charge leakage from the time of charging to the time of connection to the charge measurement circuit. The test voltage should not be less than 10V to minimise the risk of influence from contact potentials. It is wise to discharge the capacitor via a resistor to limit the maximum inrush current to within the current drive capability of the virtual earth input amplifier stage. A resistor of 10,000 ohms is likely to be suitable.

An alternative approach is to create a defined flow of current and to switch this to the charge measurement input for a defined period of time. A defined and stable flow of current can be achieved from a referenced voltage source and a defined precision resistor to earth. The flow of this current at the earth connection point is electronically switched to flow into the input of the virtual earth measurement circuit for a defined period of time. As the current flow is continuous there is no influence from any distributed capacitance in the precision resistor or its connections. The electronic switch and the layout of the circuit need to be chosen that gives negligible charge injection at operation. The period for current flow can be derived with high accuracy and stability by scaling down from a quartz crystal oscillator. Each of the 3 factors determining the quantity of charge output (voltage, resistance and time) can be formally calibrated with reference to National Standards. For circuits based on measurement of the voltage developed across an input capacitor the reference voltage needs to be suitably high.

6.1.2) Calibration by capacitance and voltage sensitivity

This applies for Faraday Pail systems in which the measurement of charge is based upon measurement of voltage change of the pail and the pail capacitance.

For visual recording of measurements it is necessary to use a calibrated electrostatic voltmeter to measure the change in pail voltage. Dynamic recording using an oscilloscope may be convenient but it is necessary to ensure the decay time of the pail capacitance and input resistance to earth give an adequate time for measurement to keep errors small. For high sensitivity Faraday Pail systems the pail capacitance needs to be small so the input impedance of normal oscilloscopes or probes may give an inconveniently short decay time.

The pail capacitance is measured on the Faraday pail system as set up for normal use using a formally calibrated capacitance meter. If an oscilloscope is used for voltage measurement the cable capacitance is included and it needs to be noted that the input impedance may affect operation of the capacitance measurement instrument. The voltage sensitivity is determined by applying calibrated voltages to the pail.

6.2 Voltage source and measuring system

The voltage source and voltage measurement system should fulfil the requirements described in Sections 2.2 and 2.3.

6.3 Capacitance

Calibration of the charged capacitor method for virtual earth measurement systems may be achieved using a formally calibrated capacitor - or a suitable capacitor may be measured using a formally calibrated capacitance meter. A formally calibrated capacitance meter is needed for direct measurement of the capacitance of a Faraday Pail.

6.4 Arrangements for calibration

Calibration must take place with the earthed shield around the pail in place. Absence of charge on nearby surfaces should be checked and precautions taken to avoid influence by choice of operator clothing and shielding surfaces nearby.

Where low voltages are used for calibration a check needs to be made for the possible influence electrochemical potential differences between materials. A simple check is to observe readings with zero voltage applied to the contact and use this as an offset for subsequent readings. For high sensitivity measurements it may be necessary to gold plated contacting surfaces to avoid electrochemical voltage effects.

6.4 Procedure

6.4.1 Method 6.1.1:

For direct charge sensitivity calibration: switch on the Faraday Pail charge measurement circuit and allow to stabilize. Zero the display or output signal reading, release and then monitor readings for zero drift over a time comparable to normal measurement time.

For charged capacitor calibration: connect one pole of the calibration capacitor to the earth connection of the Faraday Pail system. The other pole of the capacitor is then connected first to the calibration voltage source and then moved to contact the pail. Apply quantities of charge to the pail to give readings from around 10 % of the most sensitive range up to at least 25 % and preferably up to 95% of the least sensitive range. It is desirable there is some overlap across multiple ranges. Repeat the measurements for both polarities. To avoid test voltages less than 10V with multi-range instruments it may be necessary to use a number of values of capacitor. The quantity of charge transferred by a capacitor C (Farads) at a voltage V (volts) is $Q = CV$ coulombs.

For the timed current flow method of calibration: connect the calibrator to the input of the charge measurement circuit or to the Faraday Pail and allow time for any residual charge on cable connections to dissipate – checked by observing stability of zero reading. Apply quantities of charge to the pail to give readings from around 10 % of the most sensitive range up to at least 25 % and preferably up to 95% of the least sensitive range. It is desirable there is some overlap across multiple ranges. Repeat the measurements for both polarities.

6.4.2 Method 6.1.2:

Measurement of the capacitance of the pail in the Faraday Pail system requires care if the capacitance value is low – for example less than 100pF. Measurements need to take place with the shield in place around the pail. It is necessary to take account of lead capacitance and how this may vary as contact is made to the pail. The simplest approach is to have the measuring

contact supported on a rod of good insulation so the lead connecting to the capacitance meter is not close to the hand. The pail capacitance can be measured as the change in capacitance value as the measuring connection is moved from just a short distance away from contact and to touch contact with the pail.

For voltage sensitivity calibration: switch on the Faraday Pail 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 to check for zero reading drift. Apply voltages to the pail to give readings from around 10 % of the most sensitive range up to at least 25 % and preferably up to 95% of the least sensitive range. It is desirable there is some overlap across multiple ranges. Repeat the measurements for both polarities.

The charge sensitivity is calculated from the capacitance of the pail C (Farads) and the voltage sensitivity V (volts) as $Q = CV$ coulombs.

6.5 Results

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

6.6 Common aspects of calibration

Details of calibration measurements and associated information should be recorded as given in Section 2.7.

6.7 Calibration certificate information

The calibration certificate needs to include the following in addition to the standard information listed in 2.7:

A Table listing the averaged readings observed for each set of values of voltages and capacitances used for both polarities (with values for upper and lower ranges where sensitivity ranges overlap).

7. CHARGE DECAY TIME MEASURING APPARATUS

7.1 Voltage sensitivity calibration

The voltage sensitivity calibration is made in terms of a uniform potential on a conducting test plate 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 up to at least 1000V can be applied. The voltage source and voltage measuring system are as given for fieldmeter calibration in Sections 2.2 and 2.3.

7.2 Decay time calibration

Calibrated decay times are provided using calibrated resistors and capacitors in parallel to earth from the test plate across the test aperture. The resistors and capacitors must be of good quality, with a linear voltage characteristic and be able 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 – for example 0.10, 1, 10 and 100s.

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

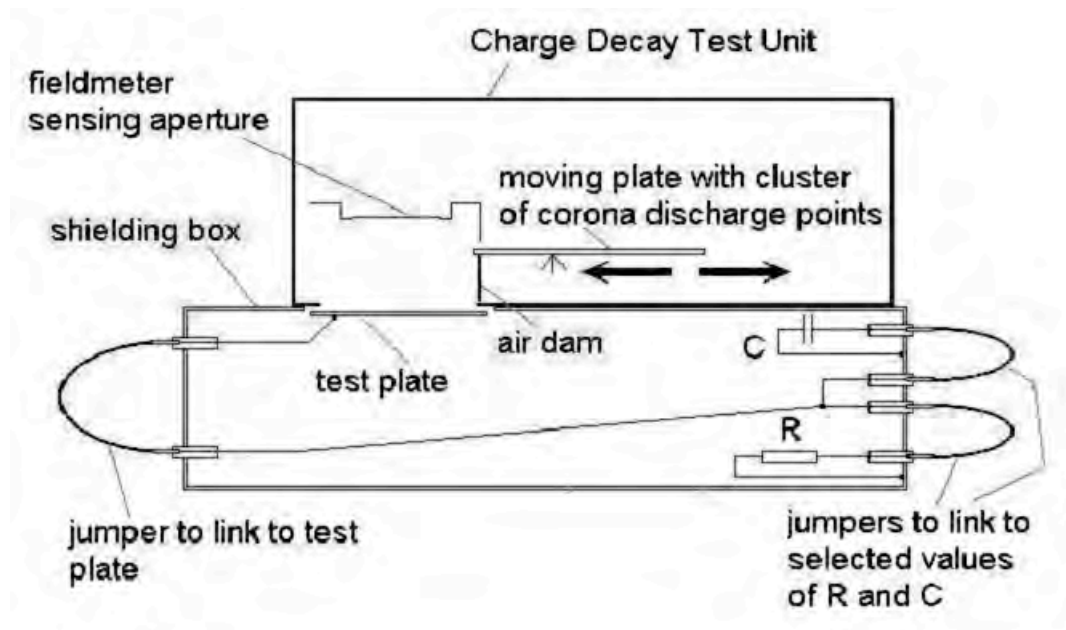


Figure 3: General arrangement for calibration of charge decay test instruments

7.3 Voltage source and measuring system

The voltage source and voltage measurement system should fulfill the requirements described in Sections 2.2 and 2.3.

7.4 Procedure

7.4.1 Voltage calibration:

Mount the charge decay unit on the calibrator unit with the test aperture over the test plate. Disconnect resistors and capacitors from the test plate to earth. Switch on the charge decay instrument and allow to stabilize. Connect the test plate to earth and measure the initial (zero)

reading. Apply calibrated 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 values. 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. Record all individual measurements.

7.4.2 Decay time calibration

Connect an initial combination of resistor and capacitor from the test plate to earth. Use the charge decay test unit to charge the test surface to a voltage between 100V and 1000V. Measure the time for the voltage developed on the test plate to fall from the voltage at which timing starts to $1/e$ of this voltage. This is the 'time constant' observed. Measure at least 3 decay time constant values for each polarity and for each combinations of resistors and capacitors providing decay time constant values. The time values observed are to be compared to decay time values calculated from $\tau = RC$ – where R is resistance in ohms, C is in Farads and τ is in seconds.

Where operation of the charge decay test unit can be linked to a computer for analysis of observations, either on-line or off-line, then the values of decay time constants obtained by this method should be measured and recorded.

At least 3 time constant measurements must be made for each polarity at each combination of resistor and capacitor.

7.5 Results

The average decay time for each combination of resistor and capacitor values and the standard deviation should be calculated with positive and negative values used together.

7.6 Common aspects of calibration

Details of calibration measurements and associated information should be recorded as given in Section 2.7.

7.7 Calibration certificate information

The calibration certificate needs to include the following in addition to the standard information listed in 2.7.

7.7.1 A Table listing values of applied voltages and the actual instrument readings observed for both polarities (with values of upper and lower ranges where sensitivity ranges overlap).

7.7.2 A Table listing the averaged values of measured charge decay time constants for each combination of resistor and capacitor value and the associated standard deviation. Each entry should be accompanied by the value of the theoretical $\tau = RC$ time constant calculated for the particular combination of resistance and capacitance values.

8. AIR IONISATION TEST UNITS

Air ionization test units are calibrated by applying defined voltages of both polarity to the test plate, measuring the voltage sensitivity and measuring the time for the plate voltage to decay from a set initial voltage to a set end point percentage of the initial voltage. For air ionization units the initial voltage is chosen as $\pm 1000\text{V}$ and the end point voltage as 10% of this – 100V.

Measuring instrument requirements and calibration procedures follow those for charge decay test units – Section 7. It needs to be noted that due allowance must be made for the capacitance of the test plate assembly to the values of formally calibrated capacitors used in conjunction with calibrated resistors to create defined decay time events.

References:

- [1] “*Methods for measurements in Electrostatics*” British Standard BS7506: Part 2: 1996
- [2] J N Chubb “*The calibration of electrostatic fieldmeters and the interpretation of their observations*” Inst Phys Conference ‘Electrostatics 1987’ Inst Phys Confr Series 85 p261