IEC 62631-3-2

Edition 2.0 2023-10
COMMENTED VERSION

INTERNATIONAL STANDARD

Dielectric and resistive properties of solid insulating materials – Part 3-2: Determination of resistive properties (DC methods) – Surface resistance and surface resistivity

IEC 62631-3-2:2023-10 CMV(en)

IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee, …). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

IEC Products & Services Portal - products.iec.ch
Discover our powerful search engine and read freely all the publications previews. With a subscription you will always have access to up to date content tailored to your needs.

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 300 terminological entries in English and French, with equivalent terms in 19 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC 62631-3-2

Edition 2.0 2023-10
COMMENTED VERSION

INTERNATIONAL STANDARD

colour inside

Dielectric and resistive properties of solid insulating materials – Part 3-2: Determination of resistive properties (DC methods) – Surface resistance and surface resistivity

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 17.220.99, 29.035.01

ISBN 978-2-8322-7699-0

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

DIELECTRIC AND RESISTIVE PROPERTIES OF SOLID INSULATING MATERIALS –

Part 3-2: Determination of resistive properties (DC methods) – Surface resistance and surface resistivity

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) IEC draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). IEC takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, IEC had not received notice of (a) patent(s), which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at https://patents.iec.ch. IEC shall not be held responsible for identifying any or all such patent rights.

This commented version (CMV) of the official standard IEC 62631-3-2:2023 edition 2.0 allows the user to identify the changes made to the previous IEC 62631-3-2:2015 edition 1.0. Furthermore, comments from IEC TC 112 experts are provided to explain the reasons of the most relevant changes, or to clarify any part of the content.

A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text. Experts' comments are identified by a blue-background number. Mouse over a number to display a pop-up note with the comment.

This publication contains the CMV and the official standard. The full list of comments is available at the end of the CMV.

IEC 62631-3-2 has been prepared by IEC technical committee 112: Evaluation and qualification of electrical insulating materials and systems. It is an International Standard.

This second edition cancels and replaces the first edition published in 2015. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) descriptions of the electrode arrangements have been clarified;
b) new descriptions of the conductive means have been added;
c) a new informative Annex B summarizing the results of the comparative verification study on surface resistivities using different electrode arrangements has been added.

The text of this International Standard is based on the following documents:

Draft	Report on voting
112/612/FDIS	112/619/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 62631 series, published under the general title *Dielectric and resistive properties of solid insulating materials*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

DIELECTRIC AND RESISTIVE PROPERTIES OF SOLID INSULATING MATERIALS –

Part 3-2: Determination of resistive properties (DC methods) – Surface resistance and surface resistivity

1 Scope

This part of IEC 62631 ~~covers~~ describes **1** methods of test for the determination of surface resistance and surface resistivity of electrical insulation materials by applying DC voltage.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60212, *Standard conditions for use prior to and during the testing of solid electrical insulating materials*

IEC 62631-3-1, *Dielectric and resistive properties of solid insulating materials – Part 3-1: Determination of resistive properties (DC methods) – Volume resistance and volume resistivity – General method*[1]

IEC 62631-3-3, *Dielectric and resistive properties of solid insulating materials – Part 3-3: Determination of resistive properties (DC methods) – Insulation resistance*[1]

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
electrode arrangement
electrical conductive bodies on the surface of a test specimen

Note 1 to entry: The arrangement of electrodes should include procedures to ascertain sufficient contact to the surface (e.g. by means of conducting paint) ~~and/~~or the use of adequate mechanical system applying the necessary contact force to the test specimen's surface or both.

~~[1] To be published.~~

3.1.1
annular electrode
central circular planar electrode with a surrounding ring electrode separated by a gap

SEE: Figure 3.

Note 1 to entry: Guarded electrode systems as described in IEC 62631-3-1 IEC 62321-3-1 are of similar shape. In the case of surface resistance, the ring electrode does not have the function of a guard; guard functionality, however, is provided by the opposite electrode.

3.1.2
line electrode
electrode arrangement provided by two parallel lines, separated by a gap, applied to the test specimen's surface using a conductive material

SEE: Figure 2.

3.1.3
spring loaded electrode
line electrode system using two parallel lines of conducting spring tongues with sharp edges, separated by a gap

SEE: Figure 1.

3.2
measured resistance
ratio of a DC voltage applied to an electrode arrangement in contact with a test specimen to the current between them measured with sufficient precision

Note 1 to entry: A three-terminal electrode arrangement may can 2 be used to exclude undesired volume currents from the determination of the measured resistance.

Note 2 to entry: A Wheatstone bridge may can 3 also be used to compare the measured resistance with a standard resistor. However, Wheatstone bridges are not commonly used anymore.

Note 3 to entry: According to IEC 60050-121: Electromagnetism, "conductivity" (IEV 121-12-03) 4 is defined as "the scalar or tensor quantity, the product of which by the electric field strength in a medium is equal to the electric current density" and "resistivity" (IEV 121-12-04) as "the inverse of the conductivity when this inverse exists". ~~Measured in this way, the surface resistivity is an average of the resistivity over possible heterogeneities in the volume incorporated in the measurement; it includes the effect of possible polarization phenomena at the electrodes.~~ Measured in this way, the surface resistivity integrates different electrical conduction pathways at the surface of the material or in its nearby volume, with the possible presence of heterogeneities; it includes the effect of possible polarization phenomena at the electrodes. Therefore, it is considered as an averaged value. 5

3.3
surface resistance
R_S
measured resistance between any electrode arrangement defined in IEC 62361-3-2

Note 1 to entry: Depending on the electrode arrangement used, it is designated as R_{SA}, R_{SB}, R_{SC}, R_{SD} or R_{SE} with surface resistance, R_S expressed in Ω.

Note 2 to entry: An indeterminable part of the resistance inside the material is also included in surface resistance during the measurement of this resistance.

3.4
R_{SC}
surface resistance between annular electrodes
measured resistance between the inner circular area of an annular electrode system and the outer circular ring electrode

3.5
R_{SD}
surface resistance between line electrodes
measured resistance between line electrodes

3.6
R_{SE}
surface resistance between line electrodes for small plates
measured resistance between line electrodes for small plates

3.7
R_{SB}
surface resistance between small line electrodes
measured resistance between small line electrodes

3.8
R_{SA}
surface resistance between spring loaded electrodes
measured resistance between spring loaded electrodes

3.9
surface resistivity
σ/square
surface resistance R_{SA}, R_{SB}, R_{SC}, R_{SD} or R_{SE} referred to a square, expressed as σ_A, σ_B, σ_C, σ_D and σ_E respectively

Note 1 to entry: Surface resistivity σ_C, σ_D and σ_E is expressed by the unit Ω.

surface resistance reduced to a square

Note 1 to entry: The numerical value of surface resistivity is independent of the size of the square.

Note 2 to entry: Surface resistance R_{SA}, R_{SB}, R_{SC}, R_{SD} and R_{SE} referred to a square, are expressed as σ_A, σ_B, σ_C, σ_D and σ_E respectively.

Note 32 to entry: Surface resistivity is often expressed by the non-standardized unit Ω per square, to show that the electrode dimension has been taken into account by calculating the specific value.

Note 43 to entry: The surface resistivity is often used to compare one kind of surface characteristic of a sample material with those of other materials. It can be compared for materials only if identical standardized dimensions of the electrodes are used. Recommended dimensions are given in 5.3. 6

4 Significance

Insulating materials are used in general to electrically isolate components of an electrical system from each other and from the earth. Solid insulating materials can also provide mechanical support. For this purpose, it is generally desirable to have the insulation resistance as high as possible, consistent with acceptable mechanical, chemical and heat resistance properties.

Surface resistance is, as volume resistance, a part of the insulating resistance.

Insulating resistance shall be determined according to IEC 62631-3-3 and volume resistance according to IEC 62631-3-1.

Surface resistance supplies information on the electrical resistances on of 7 the surface of materials and products. The surface resistance also permits monitoring of changes in the resistance by external effects. 8 Surface resistance, however, for its major part is not a materials' property. Surface resistance depends mainly on processing parameters, environmental conditions, surface ageing phenomena and pollution, etc.

NOTE Depending on the specific application, different electrode arrangements can be preferable. 9

5 Method of test

5.1 General

This general method describes common values for general measurements. If a method for a specific type of material is described in this document, the specific method shall be used.

Different types of electrodes can be used, depending on the specific measurement or product demands. For instance, on surfaces with a curved shape, a small line electrode can be advantageous. Spring loaded electrodes provide measurements with low effort on products and are optimal for materials which have to be conditioned before the test. If not already stipulated by a product standard, the choice of the electrode arrangement shall be made considering the typical application.

If test specimens are made from materials (e.g. soft rubber) ~~changing their~~ whose dimensions will change significantly ~~when applying~~ as a result of the force applied by the electrodes on them 10, these electrodes are not applicable and an alternative arrangement shall be used.

If no information about the application is available, small line electrodes (R_{SB}) are recommended.

5.2 Voltage

The measuring voltage ~~shall~~ should 11 preferably be 10 V, 100 V, 500 V, 1 000 V, 10 000 V.

~~Other voltages may be applicable.~~ If not otherwise ~~stipulated~~ specified by the relevant product standard 12, a voltage of 100 V shall be used.

Technical committees shall specify the preferred test voltage when referring to this document. 13

NOTE 1 Partial discharge can lead to erroneous measurements when a specific inception voltage is exceeded. In air, below 340 V, no partial discharges will occur.

NOTE 2 The ripple of the voltage source is important. A typical value for 100 V is < 5 × 10^{-5} peak to peak.

5.3 Equipment

5.3.1 General

Care should be taken that the surface resistance is not negatively influenced by parasitic resistances parallel to the electrode arrangement, such as the resistance of test supports or cable isolation.

To prevent measuring errors for measured resistances higher than 10^{10} Ω, shielded cables and shielded measuring cabinets shall be used.

For the determination of surface resistance and surface resistivity, different electrode arrangements can be used. The evaluation of surface resistivity is dependent on the selected electrode arrangement.

NOTE Comparison between measurement results can be done only between measurements performed using the same electrode arrangements and conductive means. 14

5.3.2 Accuracy

Any suitable equipment can be used. The measuring device shall be capable of determining the unknown resistance with an overall accuracy of at least

- ±10 % for resistances less than 10^{10} Ω;
- ±20 % for resistances between 10^{10} Ω and 10^{14} Ω; and
- ±50 % for ~~values~~ resistances higher than 10^{14} Ω. **15**

NOTE The provided accuracies have been confirmed through the round robin test results reported in Annex B. **16**

5.3.3 Voltage source

A source of ~~very~~ steady direct voltage is required. This can be provided either by batteries or by rectified and stabilized power supply. The degree of stability required is such that the change in current due to any change in voltage is negligible compared with the current to be measured.

5.3.4 Electrode arrangements **17**

5.3.4.1 General

Electrode arrangements consist of the combination of electrodes and conductive means. The conductive means shall be applied to the test specimen before performing the measurements. Electrodes are then placed in contact with the conductive means applied on the test specimen in order to perform measurements. **18**

NOTE Annex B contains the results of the comparative verification study on surface resistivities using different electrode arrangements.

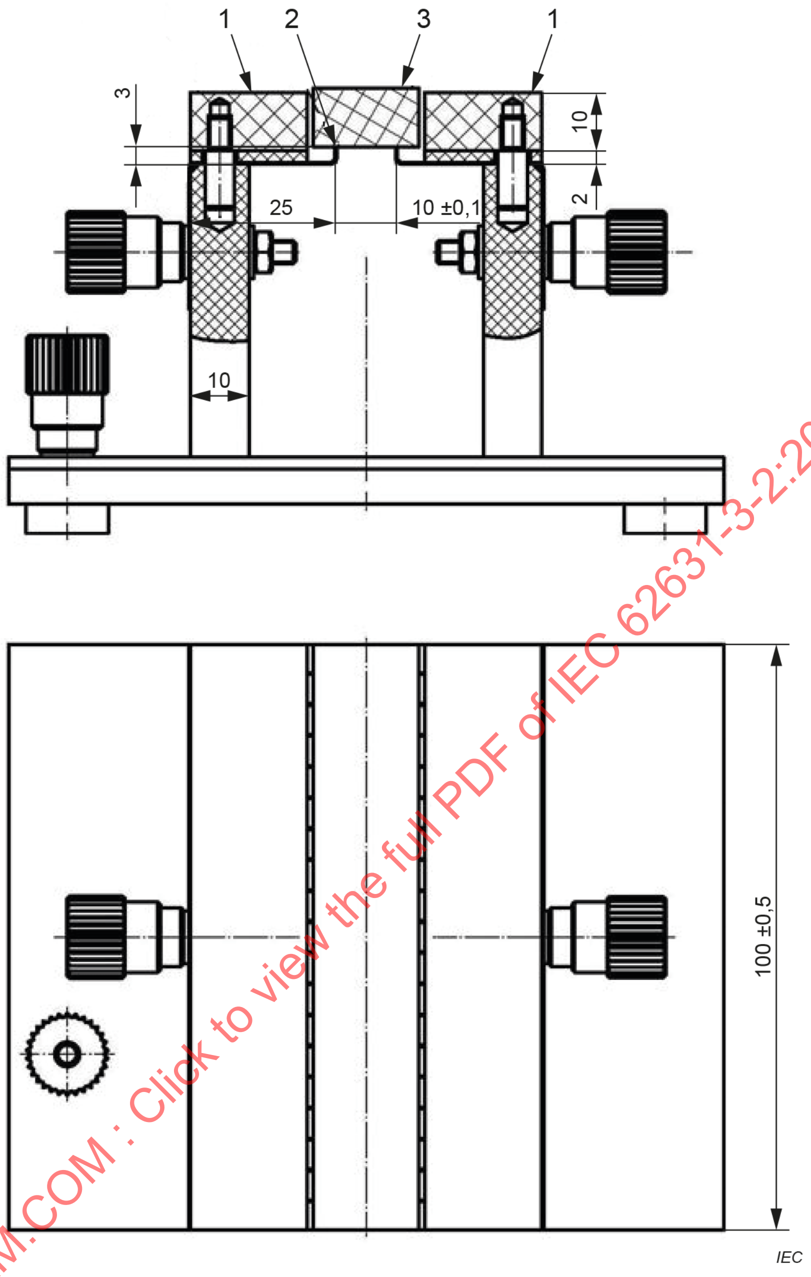
5.3.4.2 Electrode arrangement A – Spring loaded electrodes

The electrode arrangement A shall consist of two flexible metal knife-edges with a length of 100 mm and a gap distance of 10 mm as shown in Figure 1.

No guard electrode is used. The metal knife-edges shall consist of individual spring tongues arranged next to each other about 0,3 mm apart and each with a length not exceeding 5,0 mm and 0,3 mm thick. The contact force shall be high enough so that all tongues or segments rest against the surface of the test specimen, but without damaging the surface.

A piece of metal exerting the contact force ~~should~~ shall **19** be applied with high-grade insulation where in contact with the specimen.

Dimensions in millimetres



Key

1 guide bar (detachable)

2 metal knife-edges

3 specimen

Figure 1 – Electrode arrangement A (example)

5.3.4.3 Electrode arrangement B – Small line electrodes

~~Electrode arrangement B shall consist of two adhering line electrodes. No guard electrode is used. For this purpose, two 1,5 mm wide lines with a length of 25 mm and a gap distance of 2 mm apart shall be applied, e.g. with conductive silver. They shall be applied before the conditioning. The lines shall be contacted using a two terminal collector electrode arrangement with conductive blades in attach to them (see Figure 2).~~

Electrode arrangement B shall consist of a two-terminal collector with conductive blades being in contact with the conductive means on the test specimen, as shown in Figure 2. No guard electrode is used.

For the purpose of electrode arrangement B, conductive means shall be applied as two 1,5 mm wide lines with a length of 25,0 mm and a gap distance of 2,0 mm. Lines shall be applied before conditioning. 20

Types of conductive means and the related applications are described in 5.6.4. 21

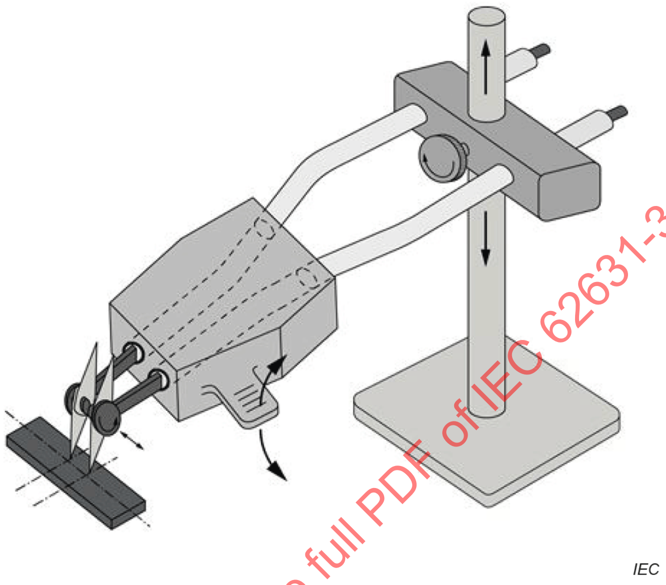
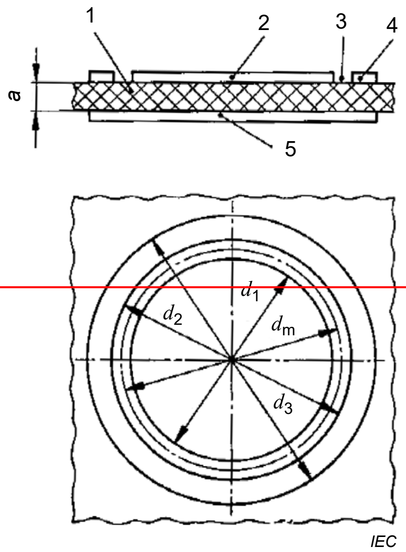


Figure 2 – ~~Collector electrode for electrode arrangement B~~ Electrode arrangement B (example)

5.3.4.4 Electrode arrangement C – Annular electrodes

Electrode arrangement C is a three-terminal electrode system, as shown in Figure 3. On one side of the test specimen, annular electrodes are applied. The opposite surface of the test specimen ~~is to~~ shall 22 be covered by a guard electrode, not smaller than the area covered by the corresponding electrodes. ~~Adhesive electrodes can be applied before the conditioning (see 5.6.3).~~



Key

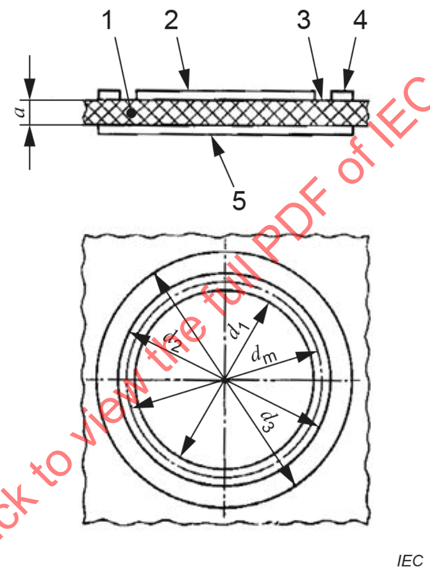
1 specimen

2 electrode 1

3 measuring area

4 electrode 2

5 electrode 3 (guard electrode)



Key 23

1 specimen

2 electrode 1

3 measuring area

4 electrode 2

5 electrode 3 (guard electrode)

a thickness of the test specimen

d_1 electrode 1 diameter

d_2 electrode 2 internal diameter

d_3 electrode 2 external diameter

d_m median diameter of measuring area

Figure 3 – Electrode arrangement C (example) 24

Any electrode dimensions can be used, unless otherwise ~~stipulated~~ specified by the relevant product standard **25**. Typical electrode dimensions are given in Table 1. For comparison tests, electrode arrangement C1 is recommended.

Table 1 – Typical electrode dimensions for electrode arrangement C

Electrode arrangement	d_1 mm	d_2 mm	d_3 mm
C1	50	60	80
C2	76	88	100
C3	25	38	50

With electrode arrangement C, the surface resistance between electrode 1 and electrode 2 shall be measured. Electrode 3 shall be earthed.

Either of the conductive means described in 5.6.4 shall be placed or painted on the surface areas where electrode 1, electrode 2 and electrode 3 are placed. The conductive means shall not be applied on the surface between electrode 1 and electrode 2. **26**

NOTE In the case of materials with limited conductivity and also occasionally films having a thickness of ≤ 10 µm, ~~it shall be noted that~~ the input resistance of the ammeter is significantly smaller than the volume resistance of the test specimen. **27**

5.3.4.5 Electrode arrangement D – Line electrodes

~~Electrode arrangement D shall consist of two adhering line electrodes. No guard electrode is used. The electrode dimensions are correspondent to electrode arrangement A with regard to the electrode length and distance between electrodes. No guard electrode is used.~~

~~For this purpose, two parallel 1,5 mm wide lines with a length of (100 ± 1) mm and a gap distance of (10 ± 0,5) mm apart shall be applied, e.g. with conductive silver. They can be applied before the treatment. The lines shall be contacted using a two terminal collector electrode arrangement with conductive blades attached to them (see Figure 2).~~

Electrode arrangement D shall consist of a two-terminal collector electrode arrangement with conductive blades being in contact with the conductive means on the test specimen, as shown in Figure 2. No guard electrode is used.

For the purpose of electrode arrangement D, the conductive means shall be applied as two parallel 1,5 mm wide lines with a length of (100,0 ± 1,0) mm and a gap distance of (10,0 ± 0,5) mm. They can be applied before the treatment.

The types of conductive means and the related applications are described in 5.6.4. **28**

5.3.4.6 Electrode arrangement E – Line electrodes for small plates

~~Electrode arrangement E is a three terminal line electrode system. For this purpose, two parallel 1 mm to 2 mm wide lines with a length of (50 ± 1) mm and a gap distance of (5 ± 0,5) mm apart shall be applied, e.g. with conductive silver.~~

~~The opposite surface of the test specimen is to be covered by a guard electrode not smaller than the area covered by the corresponding electrodes. The electrodes can be applied before conditioning of the test specimen. The lines shall be contacted using a three terminal collector electrode arrangement (see Figure 4b).~~

~~NOTE Electrode arrangement E is preferable when small plates (≥ 60 mm × ≥ 60 mm) according to ISO 10350 are in use.~~

Electrode arrangement E consists of a three-terminal collector electrode as shown in Figure 4, item B).

For the purpose of electrode arrangement E the conductive means shall be applied as two parallel 1,0 mm to 2,0 mm wide lines with a length of (50,0 ± 1,0) mm and a gap distance of (5,0 ± 0,5) mm that can be applied before conditioning of the test specimen.

The opposite surface of the test specimen shall be covered by a guard electrode not smaller than the area covered by the corresponding electrodes.

Types of conductive means and the related applications are described in 5.6.4.

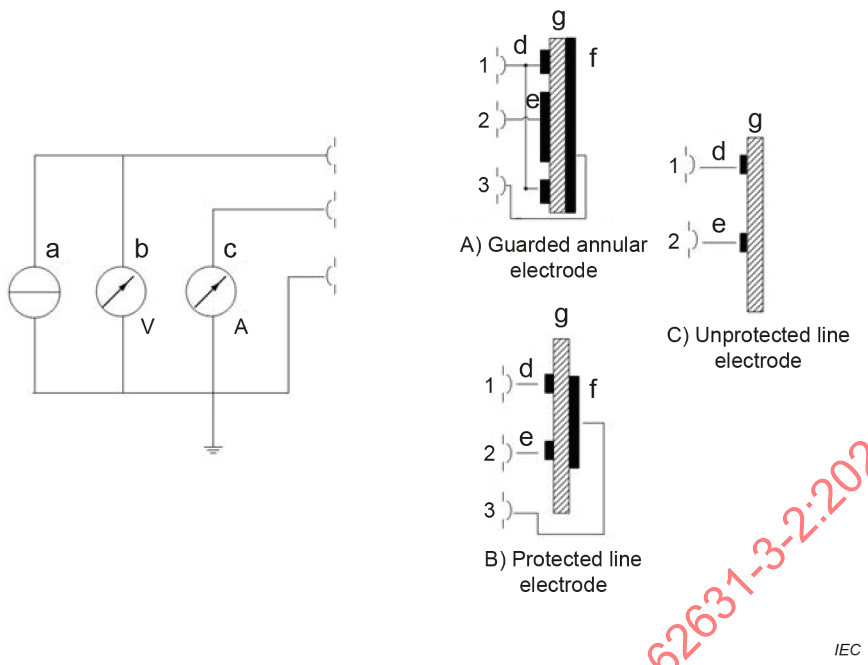
NOTE Examples of combination of electrode types and dimensions of test specimens are provided in Annex A. **29**

5.4 Test circuit

Depending on the electrode arrangement selected, two- or three-terminal measurements shall be carried out (see Figure 4).

For annular electrodes (electrode arrangement C) and line electrode arrangement E, a three-terminal test circuit is necessary as a grounded protective electrode is mandatory.

For any other line electrode arrangement (A, B and D), a two-terminal test circuit shall be used.



Key

a voltage source

b voltmeter

c ammeter

d electrode 1

e electrode 2 (shielded electrode)

f electrode 3 (protective electrode)

g specimen

Figure 4 – Connection diagram of measurement with two- and three-terminal electrode arrangements

5.5 Calibration

The equipment shall be calibrated in the magnitude of the surface resistance measured.

NOTE Calibration resistors in a range up to 100 TΩ are commercially available.

5.6 Test specimen

5.6.1 Recommended dimensions of test specimen and electrode arrangements

The specimen's dimensions ~~need~~ shall **30** be sufficient to apply the selected electrode arrangement. Recommendations for products are given in Annex A.

5.6.2 Manufacturing of test specimen

The production and shape of the test specimen shall be determined by the relevant standards for the material. During removal and production of the specimen, the condition of the material shall not be changed and the specimen removed shall not be damaged.

If the surface of the test specimen is machined at the contact areas of the electrodes, the type of machining shall be specified in the test report. The test specimen shall have a geometrically simple shape (plate with parallel measuring areas, cylinder, etc.).

NOTE Machining of the test specimen can be performed on the specimen when it is representative of the application target for the materials. 31

Specimen from products shall be prepared with the product thickness, if possible.

5.6.3 Number of test specimens

The number of test specimens to be tested shall be determined by the relevant product standards. If no such data is available, at least three specimens shall be tested.

5.6.4 Application of ~~electrodes~~ conductive means 32

5.6.4.1 General

When using adhesive ~~electrodes~~ conductive means 33 (electrode arrangements B, C, D and E)~~, care shall be taken~~, ensure 34 that a proper contact is provided over the whole area covered ~~by the electrode~~ 35. The ~~electrode material~~ conductive means 36 used shall, after an appropriate time of conditioning, not influence the measured values for surface resistance.

NOTE 1 Conductive silver paint and suspensions of graphite have been found appropriate.

NOTE 2 Annex B contains the results of the comparative verification study on surface resistivities using different electrode arrangements and conductive means. 37

5.6.4.2 Conductive silver paint

Certain types of commercially available, high-conductivity silver paints, either air-drying or low-temperature-baking varieties, are sufficiently porous to permit diffusion of moisture through them and thereby allow the test specimens to be conditioned after application of the conductive means. This is a particularly useful feature in studying resistance-humidity effect as well as changes with temperature. However, before conductive paint is used as a conductive means, it should be established that the paint solvent does not affect the electrical properties of the specimen. Reasonably smooth edges for use with guard electrodes can be obtained with a fine-bristle brush. However, for use with circular electrodes, sharper edges can be obtained by the use of a compass for drawing the outline circles of the electrodes and filling in the enclosed areas by brush. Clamp-on masks can be used if the conductive paint is sprayed on. 38

5.6.4.3 Colloidal graphite

Colloidal graphite dispersed in water or other suitable medium, can be used under the same conditions as given for conductive silver paint. 39

5.6.4.4 Conducting rubber

Conducting rubber can be used as conductive means. It has the advantage that it can be applied and removed from the specimen quickly and easily. Since the conductive means are applied only during the time of measurement, they do not interfere with the conditioning of the specimen. The resistance of the rubber electrode shall be less than 1 000 Ω.

The conducting rubber material shall be soft enough to ensure that effective contact to the specimen is obtained when a reasonable pressure, for example 2 kPa (0,2 N/cm^2), is applied. Shore A hardness according to ISO 48-4 in the range of 65 to 85 has been found suitable.

NOTE The results of resistivity measurements obtained with the application of electrodes made of conducting rubber are always higher (few tens to few hundreds per cent) in comparison to that obtained for metallic electrodes. 40

5.6.5 Conditioning and pre-treatment of test specimen

Conditioning and any other pre-treatment of the test specimen shall be carried out according to the relevant product standard.

If no product standard exists, conditioning shall be realized for at least four days at 23 °C and 50 % RH in accordance with IEC 60212 (standard climate B).

If not otherwise ~~stipulated~~ specified by the relevant product standard 41, no cleaning of the test specimen shall be done. Any additional contamination shall be avoided.

5.7 Test procedure

Unless otherwise ~~agreed~~ specified 42, the measurement shall be conducted in normal air at 23 °C and 50 % RH in accordance with IEC 60212 (standard climate B).

The specimen shall be conditioned and pre-treated in accordance with 5.6.5. Immediately after the treatment, the electrodes shall be connected with the measuring device.

Subsequently, but no more than 2 min after finishing the conditioning or pre-treatment, the surface resistance R_S shall be determined between the electrodes. If not otherwise ~~stipulated~~ specified 43, it shall be measured 1 min after voltage application.

NOTE Experience from the application of this test evidenced that, for material design and research purposes, reaching the stabilization of the current before measuring the surface resistance provides better results. 44

6 ~~Evaluation~~ Calculation of surface resistivity 45

6.1 For electrode arrangements A, B, D and E

The measured value R_S for the respective surface resistances R_{SA}, R_{SB}, R_{SD} and R_{SE} between electrodes 1 and 2 shall be specified in Ω.

For electrode arrangements A, B, D and E, surface resistivity σ can be calculated in Ω according to Equation (1) from the measured resistance R_S and electrode dimensions.

It is also possible to calculate surface resistivity even with dimensions deviating from those defined in 5.3.4, 5.3.4.3, 5.3.4.5 and 5.3.4.6.

$$\sigma_Y = \frac{l}{g} \cdot R_{SY} \qquad (1)$$

where

l is the length of the line electrodes, expressed in mm; 46

g is the distance between the lines (gap), expressed in mm; 47

Y ~~reading~~ corresponds to the electrode arrangements 48 A, B, D, or E.

As the individual surfaces ~~resistances~~ resistivities 49 are dependent on the electrode arrangement used and are therefore not comparable with each other, when reporting the measurement results, the type of electrode arrangement shall be specified together with the measured value ~~to permit a statement~~. 50

6.2 For electrode arrangement C

The surface resistance R_{SC} between electrodes 1 and 2 with earthed electrode 3 shall be specified in Ω.

The surface resistivity σ_C can be calculated in Ω according to Equation (2) from the measured resistance R_{SC} and electrode dimensions (see Figure 3).

$$\sigma_C = \frac{d_2 + d_1}{d_2 - d_1} \cdot \pi \cdot R_{SC} \qquad (2)$$

where

d_1 is the outer diameter of the inner electrode, expressed in mm; 51

d_2 is the inner diameter of the ring electrode, expressed in mm. 52

7 Test report

The report shall include the following:

- electrode arrangement and electrode dimensions;
- complete identification and description of the material tested, including the source and the manufacturer's code;
- shape and thickness of the test specimen;
- test voltage and duration of the voltage application; 53
- description of the conductive material used, test set-up and instrument used for the test; 54
- accuracy of the instrument and calibration method, depending on the measured values of resistance, if necessary;
- curing conditions of the material and any pre-treatment;
- conditioning of the samples and ~~climatic~~ ambient 55 conditions under test;
- ~~description of test set-up and instrument used for the test;~~ 56
- number of samples;
- date of test;
- each single value and the median of surface resistance and surface resistivity, respectively;
- ~~ambient conditions during testing;~~ 57
- any other important observation if applicable.

8 Repeatability and reproducibility

Measurements of surface resistance and surface resistivity are dependent on numerous aspects. Experiences have shown that the reproducibility is in the range of > 50 % (of the measured value).

The repeatability is between 20 % and 50 %.

Annex B contains the results of the comparative verification study on surface resistivities using different electrode arrangements. 58

Annex A
(informative)

Specimen dimensions and electrode arrangements

Specimen dimensions and electrode arrangements are given in Table A.1.

For materials which are not available in flat sheets, the electrode arrangement should be agreed between the supplier and customer.

Table A.1 – Recommended test specimen dimensions and electrode arrangements for specific products

Type of product	Recommended electrode arrangement	Remarks	Recommended dimensions of test specimen
Thermoplastic moulding compounds	E, C	See ISO 10350-1	≥ 60 mm × ≥ 60 mm
Thermosetting moulding compounds	A, E, C	See ISO 14526 series, ISO 14527 series, ISO 14528 series, ISO 14529 series, ISO 14530 series, ISO 15252 series	≥ 60 mm × ≥ 60 mm ≥ 100 mm × ≥ 100 mm
Long fibre, reinforced polyester resin 59 and vinyl ester resin 60 moulding compounds (SMC BMC)	A, C	See EN 14598 series, ISO 10350-2	≥ 100 mm × ≥ 100 mm
Epoxy based sheets and laminates	A, C	See IEC 60893-2	
Pipes, bars and rods	B, D	See IEC 61212-2, IEC 62011-2	
Elastomeric materials	B, C		

Annex B 61
(informative)

Comparative verification study on surface resistivities using different electrode arrangements (type C and type E)

B.1 General

An inter-laboratory trial has been performed to confirm the existing variations, for the surface resistivity test results on the same materials, in which replicated batches of two materials (hereunder referred as material A and material B) were tested at four laboratories in accordance with this part of IEC 62321.

Since this preliminary inter-laboratory trial did not fully satisfy the conditions for the international laboratory trial in ISO 5725-2 due to an insufficient number of participating laboratories, repeatability and reproducibility were not obtained in accordance with ISO 5725-2.

Nevertheless, some analysis on the test data was conducted as follows.

B.2 Inter-laboratory trial conditions

B.2.1 General

Four laboratories participated in the inter-laboratory trial.

B.2.2 Test specimens

Specimens A and B characteristics are described in Table B.1.

Table B.1 – Test specimens characteristics

	Specimen A	Specimen B
Material	Polyamide 66 (PA66)	Polybutylene terephthalate (PBT)
Filled/Unfilled	Unfilled	Unfilled
Water content (according to ISO 15512)	1,80 %	0,15 %
Dimensions	Square test plaques 100 mm × 100 mm × 2 mm	Square test plaques 100 mm × 100 mm × 2 mm
Number of specimens	10 × each test condition	10 × each test condition

B.2.3 Electrode types, conductive materials and test voltage

The following electrode types were used for the inter-laboratory trial:

- electrode arrangement C – Annular electrodes (according to 5.3.4.4);
- electrode arrangement E – Line electrodes for small plates (according to 5.3.4.6).

The conductive materials between the electrodes and the test specimen were:

- conductive silver paint (according to 5.6.4.2);
- conductive rubber (according to 5.6.4.4).

Either of the conductive materials was applied on both surfaces of the test specimens to guarded electrodes and measuring electrodes respectively.

Test voltage: 500 V DC.

B.2.4 Test conditions

The applied test conditions by the specific participants are summarized in the following Table B.2. The surface resistivity equations for the different electrodes are represented in Figure B.1.

Table B.2 – Test conditions per specific participant

Conditions		Laboratory 1	Laboratory 2	Laboratory 3	Laboratory 4
Electrode arrangement type	C		X[a]	X[a]	X[a]
	$\pi \times (d_2 + d_1)/(d_2 - d_1)$		(34,50)	(18,84)	(34,50)
	E	X[a]	X[a]		
	(l/g)	(10)	(10)		
Conductive material	Silver paint	X[a]	X[a]	X[a]	
	Rubber		X[a]		X[a]
Test voltage (V DC)	Requested 500 V	500	500	500	500

[a] Condition applied by the specific laboratory.

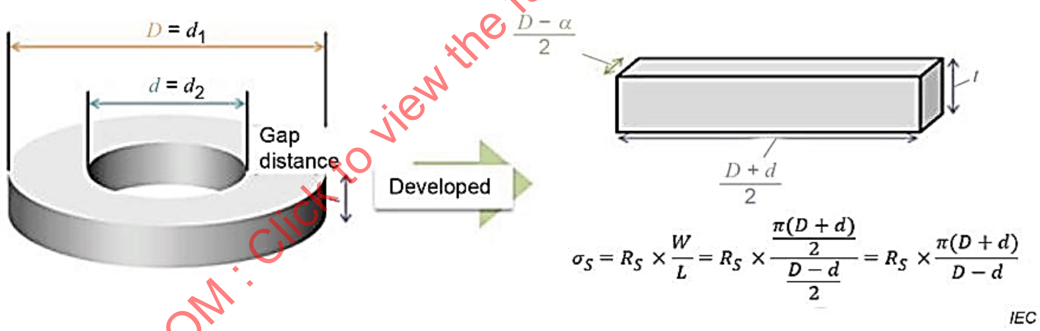


Figure B.1 – Surface resistivity equations for the used electrodes

B.3 Summary of the test results

The inter-laboratory trial results are summarized in the following Table B.3.

Table B.3 – Summary of the test results

Material	Polybutylene terephthalate (PBT)			Polyamide 66 (PA66)		
Electrode arrangement	C	C	E	C	C	E
Conductive means	Rubber	Silver	Silver	Rubber	Silver	Silver
Test voltage (V DC)	500	500	500	500	500	500
Laboratories	2, 4[a]	2, 3, 4[a]	1, 2	2, 4	2, 3, 4	1, 2
Total specimens	20	30	20	20	30	20
Grand mean (X)[b]	3,4E+16	3,5E+16	1,9E+16	1,5E+15	3,3E+14	1,4E+15
Reproducibility (S_g)[b]	1,3E+16	2,2E+16	2,0E+16	5,0E+14	6,5E+13	1,2E+15
Extended standard deviation (Std Dev r)[b]	2,1E+16	1,3E+16	1,2E+16	4,9E+14	3,7E+13	4,3E+14
Repeatability (S_r)[b]	5,8E+16	3,7E+16	3,2E+16	1,4E+15	1,0E+14	1,2E+15
Repeatability % (% S_r)	170	107	172	90	31	85

[a] Laboratory 4 reported that 7 out of 10 specimens showed results out of the measuring range (actual values were therefore higher).

[b] The reported data are provided as scientific notation. See B.5.1.

B.4 Inter-laboratory trial outcomes and suggestions for IEC 62631-3-2

The outcomes of this inter-laboratory trial provide evidence that:

a) the electrode arrangement type C (annular) variations of conductive materials (use or no use of silver paint or conductive rubber), significantly affect the repeatability and reproducibility of results;

a) the different gap distances in the electrode arrangement type C did not affect the results compared to the results of the electrode arrangement type E (the electrode arrangement type C gap distance for laboratory 3 is different from those of laboratories 2 and 4);

b) the current results show that the electrode arrangement type C in combination with silver paint has slightly better repeatability and reproducibility than the electrode arrangement type E, although more data shall be collected to confirm these results and the related precision of data.

According to the above findings, the following technical modifications have been introduced in this second edition of IEC 62631-3-2:

c) for any type of electrode arrangement, conductive material shall be applied on the specimen surface in contact with the measuring electrodes and guarding electrodes;

d) silver paint is the preferred conductive material;

e) description of the conductive rubber characteristics has been added.

In order to properly evaluate data precision and address possible results variation factors between the different electrode types, IEC TC 112 will consider the possibility to perform an additional inter-laboratory trial.

B.5 Detailed inter-laboratory results

B.5.1 General

The detailed analysis of the collected data from the inter-laboratory trial is provided in Table B.4 to Table B.13.

In Table B.4 to Table B.13 the reported data for surface resistance, surface resistivity and some statistical data are provided as scientific notation defined as per the following example:

EXAMPLE 1E+15 is equivalent to 1 · 10^{15} and to 1 000 000 000 000 000.

where

1 = coefficient

E = 10 to the power of

15 = exponent

B.5.2 Laboratories results by different groups of electrode types and conductive materials for the different test specimens

Table B.4 – Polybutylene terephthalate (PBT) test specimen results – Electrode type C with conductive rubber

Laboratory	Laboratory 2		Laboratory 4	
Test date	2020/02/18		2020/07/28	
Electrode type	Annular C1	34.56	Annular C1	34.56
Conductive means	Conductive elastomer		Conductive rubber	
Testing voltage	500 V DC		500 V DC	
Specimen PBT	Surface resistance R_{SC} Ω [b]	Surface resistivity σ Ω/square [b]	Surface resistance R_{SC} [a] Ω [b]	Surface resistivity σ [a] Ω/square [b]
1	1,30E+14	4,50E+15	1,60E+15	5,53E+16
2	1,60E+15	5,50E+16	6,30E+16	2,18E+15
3	3,10E+14	1,10E+16	5,00E+14	1,73E+16
4	1,60E+15	5,50E+16	1,60E+15	5,53E+16
5	1,60E+15	5,50E+16	1,60E+15	5,53E+16
6	6,40E+14	2,20E+16	1,60E+15	5,53E+16
7	1,70E+14	5,90E+15	1,60E+15	5,53E+16
8	2,40E+14	8,30E+15	1,60E+15	5,53E+16
9	4,80E+14	1,70E+16	6,70E+14	2,32E+16
10	5,50E+14	1,90E+16	1,60E+15	5,53E+16
Median	5,20E+14	1,80E+16	1,60E+15	5,53E+16
Standard deviation	5,90E+14	2,00E+16	5,63E+14	5,53E+16
Geometrical mean	5,10E+14	1,80E+16	9,45E+14	3,26E+16
Population	10		10	
Degree of freedom	9		9	
Confidence 95 %[b]	1,25E+16		3,43E+16	
Weighted variance[b]	1,60E+18		4,50E+18	
Extended weighted variance[b]			**Annular with conductive rubber**	6.10E+18
Total degree of freedom				18
Pooled standard deviation[b]				6,00E+08

[a] The data in red represent measurements that exceeded the instrument measuring range.

[b] The reported data are provided as scientific notation. See B.5.1.

Table B.5 – Polyamide 66 (PA66) test specimen results – Electrode type C with conductive rubber

Laboratory	Laboratory 2		Laboratory 4	
Test date	2020/02/18		2020/07/28	
Electrode type	Annular C1	34.56	Annular C1	34.56
Conductive means	Conductive elastomer		Conductive rubber	
Testing voltage	500 V DC		500 V DC	
Specimen **PA66**	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]
1	5,97E+13	2,06E+15	7,70E+13	2,66E+15
2	2,58E+13	8,92E+14	6,55E+13	2,26E+15
3	3,01E+13	1,04E+15	5,52E+13	1,91E+15
4	2,82E+13	9,75E+14	7,12E+13	2,46E+15
5	3,06E+13	1,06E+15	6,07E+13	2,10E+15
6	3,37E+13	1,16E+15	3,86E+13	1,33E+15
7	2,95E+13	1,02E+15	4,35E+13	1,50E+15
8	2,95E+13	1,02E+15	2,91E+13	1,01E+15
9	3,12E+13	1,08E+15	6,84E+13	2,36E+15
10	3,61E+13	1,25E+15	3,01E+13	1,04E+15
Median	3,00E+13	1,10E+15	5,80E+13	2,00E+15
Standard deviation	9,20E+12	3,20E+14	1,66E+13	2,00E+15
Geometrical mean	3,30E+13	1,10E+15	5,11E+13	1,77E+15
Population	10		10	
Degree of freedom	9		9	
Confidence 95 %[a]	1,95E+14		1,24E+15	
Weighted variance[a]	2,60E+16		1,60E+17	
Extended weighted variance[a]			**Annular with conductive rubber**	1,90E+17
Total degree of freedom				18
Pooled standard deviation[a]				1,00E+08

[a] The reported data are provided as scientific notation. See B.5.1.

Table B.6 – Polybutylene terephthalate (PBT) test specimen results – Electrode type C with conductive silver paint

Laboratory	Laboratory 2		Laboratory 4		Laboratory 3	
Test date	2020/02/18		2020/07/28		2020/02/26	
Electrode type	Annular C1	34.56	Annular C1	34.56	Annular	18.84
Conductive means	Conductive silver paint		Conductive silver paint		Conductive silver paint	
Testing voltage	500 V DC		500 V DC		500 V DC	
Specimen **PBT**	Surface resistance R_{SC} Ω [b]	Surface resistivity σ Ω/square [b]	Surface resistance R_{SC} [a] Ω [b]	Surface resistivity σ [a] Ω/square [b]	Surface resistance R_{SC} Ω [b]	Surface resistivity σ Ω/square [b]
1	1,60E+15	5,50E+16	4,70E+14	1,62E+16	4,66E+14	8,78E+15
2	1,60E+15	5,50E+16	1,52E+15	5,25E+16	4,95E+14	9,33E+15
3	1,60E+15	5,50E+16	1,60E+15	5,53E+16	4,90E+14	9,23E+15
4	6,10E+14	2,10E+16	1,54E+15	5,32E+16	4,76E+14	8,97E+15
5	1,60E+15	5,50E+16	1,60E+15	5,53E+16	4,85E+14	9,14E+15
6	1,60E+15	5,50E+16	1,60E+15	5,53E+16	4,46E+14	8,40E+15
7	1,60E+15	5,50E+16	1,60E+15	5,53E+16	4,95E+14	9,33E+15
8	1,60E+15	5,50E+16	1,60E+15	5,53E+16	4,81E+14	9,06E+15
9	1,60E+15	5,50E+16	1,60E+15	5,53E+16	5,00E+14	9,42E+15
10	1,10E+15	3,60E+16	1,60E+15	5,53E+16	5,00E+14	9,42E+15
Median	1,60E+15	5,50E+16	1,60E+15	5,53E+16	4,88E+14	9,19E+15
Standard deviation	3,20E+14	1,10E+16	5,49E+14	1,90E+16	1,62E+13	3,06E+14
Geometrical mean	1,40E+15	4,80E+16	7,03E+14	2,43E+16	4,83E+14	9,10E+15
Population	10		10		10	
Degree of freedom	9		9		9	
Confidence 95 % [b]	6,89E+15		1,18E+16		1,90E+14	
Weighted variance [b]	9,00E+17		1,50E+18		2,50E+16	
Extended weighted variance [b]					**Annular with conductive silver paint**	2,50E+18
Total degree of freedom						27
Pooled standard deviation [b]						3,00E+08

[a] The data in red represent measurements that exceeded the instrument measuring range.

[b] The reported data are provided as scientific notation. See B.5.1.

Table B.7 – Polyamide 66 (PA66) test specimen results – Electrode type C with conductive silver paint

Laboratory	Laboratory 2		Laboratory 4		Laboratory 3	
Test date	2020/02/18		2020/07/28		2020/02/26	
Electrode type	Annular C1	34.56	Annular C1	34.56	Annular	18.84
Conductive means	Conductive silver paint		Conductive silver paint		Conductive silver paint	
Testing voltage	500 V DC		500 V DC		500 V DC	
Specimen PA66	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]
1	1,04E+13	3,59E+14	7,69E+12	2,66E+14	1,59E+13	2,99E+14
2	1,10E+13	3,80E+14	1,02E+13	3,51E+14	1,68E+13	3,16E+14
3	9,64E+12	3,33E+14	5,31E+12	1,84E+14	1,76E+13	3,32E+14
4	1,19E+13	4,11E+14	6,83E+12	2,36E+14	1,91E+13	3,59E+14
5	1,09E+13	3,77E+14	5,71E+12	1,97E+14	1,86E+13	3,51E+14
6	1,13E+13	3,91E+14	6,52E+12	2,25E+14	2,01E+13	3,78E+14
7	1,05E+13	3,63E+14	8,10E+12	2,80E+14	1,91E+13	3,59E+14
8	1,07E+13	3,70E+14	7,18E+12	2,48E+14	2,16E+13	4,07E+14
9	9,86E+12	3,41E+14	8,01E+12	2,7E+14	2,13E+13	4,01E+14
10	1,17E+13	4,04E+14	7,93E+12	2,74E+14	1,91E+13	3,60E+14
Median	1,10E+13	3,70E+14	7,43E+12	2,57E+14	1,91E+13	3,59E+14
Standard deviation	6,90E+11	2,40E+13	1,31E+13	4,53E+13	1,73E+12	3,25E+13
Geometrical mean	1,10E+13	3,70E+14	2,50E+14	2,50E+14	1,88E+13	3,55E+14
Population	10		10		10	
Degree of freedom	9		9		9	
Confidence 95 %[a]	1,48E+13		2,81E+13		2,02E+13	
Weighted variance[a]	1,90E+15		3,70E+15		2,60E+15	
Extended weighted variance[a]					**Annular with conductive silver paint**	8,24E+15
Total degree of freedom						27
Pooled standard deviation[a]						2,00E+07

[a] The reported data are provided as scientific notation. See B.5.1.

Table B.8 – Polybutylene terephthalate (PBT results) test specimen results – Electrode type E with conductive silver paint

Laboratory	Laboratory 2		Laboratory 1	
Test date	2020/02/18		2020/06/12	
Electrode type	Lines E	10	Lines E	10
Conductive means	Conductive silver paint		Conductive silver paint	
Testing voltage	500 V DC		500 V DC	
Specimen **PBT**	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]
1	3,10E+14	3,10E+15	1,30E+15	1,30E+16
2	2,80E+14	2,80E+15	4,00E+15	4,00E+16
3	4,70E+14	4,70E+15	1,90E+15	1,90E+16
4	3,10E+14	3,10E+15	4,70E+15	4,70E+16
5	5,30E+14	5,30E+15	2,10E+15	2,10E+16
6	5,10E+14	5,10E+15	3,30E+15	3,30E+16
7	4,90E+14	4,90E+15	5,00E+15	5,00E+16
8	5,20E+14	5,20E+15	3,60E+15	3,60E+16
9	4,60E+14	4,60E+15	6,10E+15	6,10E+16
10	4,50E+14	4,50E+15	1,30E+15	1,30E+16
Median	4,70E+14	4,70E+15	3,40E+15	3,40E+16
Standard deviation	9,10E+13	9,10E+14	1,60E+15	1,60E+16
Geometrical mean	4,20E+14	4,20E+15	2,90E+15	2,90E+16
Population	10		10	
Degree of freedom	9		9	
Confidence 95 %[a]	5,62E+14		9,68E+15	
Weighted variance[a]	7,30E+16		1,30E+18	
Extended weighted variance[a]			**Lines with conductive silver paint**	1,3E+18
Total degree of freedom				18
Pooled standard deviation[a]				3,00E+08

[a] The reported data are provided as scientific notation. See B.5.1.

Table B.9 – Polyamide 66 (PA66) test specimen results – Electrode type E with conductive silver paint

Laboratory	Laboratory 2		Laboratory 1	
Test date	2020/02/18		2020/06/12	
Electrode type	Lines E	10	Lines E	10
Conductive means	Conductive silver paint		Conductive silver paint	
Testing voltage	500 V DC		500 V DC	
Specimen PA66	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]
1	5,20E+13	5,21E+14	2,49E+14	2,49E+15
2	5,58E+13	5,58E+14	2,48E+14	2,48E+15
3	6,09E+13	6,09E+14	1,45E+14	1,45E+15
4	5,63E+13	5,63E+14	2,78E+14	2,78E+15
5	5,96E+13	5,96E+14	3,18E+14	3,18E+15
6	7,16E+13	7,16E+14	1,39E+14	1,39E+15
7	9,09E+13	9,09E+14	1,92E+14	1,92E+15
8	4,89E+13	4,89E+14	2,06E+14	2,06E+15
9	4,09E+13	4,09E+14	1,96E+14	1,96E+15
10	4,66E+13	4,66E+14	2,82E+14	2,82E+15
Median	5,60E+13	5,60E+14	2,30E+14	2,30E+15
Standard deviation	1,40E+13	1,40E+14	5,70E+13	5,70E+14
Geometrical mean	5,70E+13	5,70E+14	2,20E+14	2,20E+15
Population	10		10	
Degree of freedom	9		9	
Confidence 95 %[a]	8,37E+13		3,50E+14	
Weighted variance[a]	1,10E+16		4,60E+16	
Extended weighted variance[a]			**Lines with conductive silver paint**	5,70E+16
Total degree of freedom				18
Pooled standard deviation[a]				6,00E+07

[a] The reported data are provided as scientific notation. See B.5.1.

B.5.3 Laboratory 2 results comparing different electrode types and conductive materials

Table B.10 – Laboratory 2 results – Polybutylene terephthalate (PBT) – Different electrodes and conductive materials

Laboratory	Laboratory 2		Laboratory 2		Laboratory 2	
Test date	2020/02/18		2020/02/18		2020/02/18	
Electrode type	Annular C1	34.56	Annular C1	34.56	Lines E	10
Conductive means	Conductive elastomer		Conductive silver paint		Conductive silver paint	
Testing voltage	500 V DC		500 V DC		500 V DC	
Specimen PBT	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]
1	1,30E+14	4,50E+15	1,60E+15	5,50E+16	3,10E+14	3,10E+15
2	1,60E+15	5,50E+16	1,60E+15	5,50E+16	2,80E+14	2,80E+15
3	3,10E+14	1,10E+16	1,60E+16	5,50E+16	4,70E+14	4,70E+15
4	1,60E+15	5,50E+16	6,10E+14	2,10E+16	3,10E+14	3,10E+15
5	1,60E+15	5,50E+16	1,60E+15	5,50E+16	5,30E+14	5,30E+15
6	6,40E+14	2,20E+16	1,60E+15	5,50E+16	5,10E+14	5,10E+15
7	1,70E+14	5,90E+15	1,60E+15	5,50E+16	4,90E+14	4,90E+15
8	2,40E+14	8,30E+15	1,60E+15	5,50E+16	5,20E+14	5,20E+15
9	4,80E+14	1,70E+16	1,60E+15	5,50E+16	4,60E+14	4,60E+15
10	5,50E+14	1,90E+16	1,10E+15	3,60E+16	4,50E+14	4,50E+15
Median	5,20E+14	1,80E+16	1,60E+15	5,50E+16	4,70E+14	4,70E+15
Standard deviation	9,20E+14	2,00E+16	3,20E+14	1,10E+16	9,10E+13	9,10E+14
Geometrical mean	5,10E+14	1,80E+16	1,40E+15	4,80E+16	4,20E+14	4,20E+15
Population	10		10		10	
Degree of freedom	9		9		9	
Confidence 95 %[a]	1,25E+16		6,89E+15		5,62E+14	
Weighted variance[a]	1,60E+18		9,00E+17		7,30E+16	

[a] The reported data are provided as scientific notation. See B.5.1.

Table B.11 – Laboratory 2 results – Polyamide 66 (PA66) – Different electrodes and conductive materials

Laboratory	Laboratory 2		Laboratory 2		Laboratory 2	
Test date	2020/02/18		2020/02/18		2020/02/18	
Electrode type	Annular C1	34.56	Annular C1	34.56	Lines E	10
Conductive means	Conductive elastomer		Conductive silver paint		Conductive silver paint	
Testing voltage	500 V DC		500 V DC		500 V DC	
Specimen PA66	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]
1	5,97E+13	2,06E+15	1,04E+13	3,59E+14	5,21E+13	5,21E+14
2	2,58E+13	8,92E+14	1,10E+13	3,80E+14	5,58E+13	5,58E+14
3	3,01E+13	1,04E+15	9,64E+12	3,33E+14	6,09E+13	6,09E+14
4	2,82E+13	9,75E+14	1,19E+13	4,11E+14	5,63E+13	5,63E+14
5	3,06E+13	1,06E+15	1,09E+13	3,77E+15	5,96E+13	5,96E+14
6	3,37E+13	1,16E+15	1,13E+13	3,91E+14	7,16E+13	7,16E+14
7	2,95E+13	1,02E+15	1,05E+13	3,63E+14	9,09E+13	9,09E+14
8	2,95E+13	1,02E+15	1,07E+13	3,70E+14	4,89E+13	4,89E+14
9	3,12E+13	1,08E+15	9,86E+12	3,41E+14	4,09E+13	4,09E+14
10	3,61E+13	1,25E+15	1,17E+13	4,04E+14	4,66E+13	4,66E+14
Median	3,00E+13	1,10E+15	1,10E+13	3,70E+14	5,60E+13	5,60E+14
Standard deviation	9,20E+12	3,20E+14	6,90E+11	2,40E+13	1,40E+13	1,40E+14
Geometrical mean	3,30E+13	1,10E+15	1,10E+13	3,70E+14	5,70E+13	5,70E+14
Population	10		10		10	
Degree of freedom	9		9		9	
Confidence 95 %[a]	1,95E+14		1,48E+13		8,37E+13	
Weighted variance[a]	2,60E+16		1,90E+15		1,10E+16	

[a] The reported data are provided as scientific notation. See B.5.1.

B.5.4 Laboratory 3 results – Electrode type C with and without use of conductive silver paint

Table B.12 – Laboratory 3 results – Polybutylene terephthalate (PBT) – Electrode type C with and without conductive silver paint

Laboratory	Laboratory 3		Laboratory 3	
Test date	2020/02/12		2020/02/26	
Electrode type	Annular	18.84	Annular	18.84
Conductive means	No conductive means		Conductive silver paint	
Testing voltage	500 V DC		500 V DC	
Specimen **PBT**	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]
1	3,10E+15	5,84E+16	4,66E+14	8,78E+15
2	6,60E+14	1,24E+16	4,95E+14	9,3E+15
3	1,10E+15	2,07E+16	4,90E+14	9,24E+15
4	7,90E+14	1,49E+16	4,76E+14	8,97E+15
5	5,00E+15	9,42E+16	4,85E+14	9,14E+15
6	1,50E+14	2,83E+15	4,46E+14	8,41E+15
7	3,47E+14	6,54E+15	4,95E+14	9,33E+15
8	1,40E+15	2,64E+16	4,81E+14	9,07E+15
9	1,10E+15	2,07E+16	5,00E+14	9,42E+15
10	2,64E+14	4,98E+15	5,00E+14	9,42E+15
11	4,00E+14	7,54E+15	4,81E+14	9,07E+15
12	4,10E+14	7,67E+15	4,24E+14	7,99E+15
13	1,70E+15	3,20E+16	4,87E+14	9,18E+15
14	2,00E+15	3,77E+16	4,85E+14	9,14E+15
15	2,50E+14	4,69E+15	4,59E+14	8,65E+15
16	3,30E+15	6,22E+16	5,40E+14	1,02E+16
17	1,40E+15	2,64E+16	4,95E+14	9,33E+15
18	9,60E+14	1,81E+16	4,85E+14	9,14E+15
19	3,90E+14	7,26E+15	4,72E+14	8,90E+15
20	1,5E+14	2,79E+15	3,97E+14	7,48E+15
Median	8,80E+14	1,60E+16	4,90E+14	9,10E+15
Standard deviation[a]	1,20E+15	2,30E+16	4,90E+13	5,50E+14
Geometrical mean[a]	7,80E+14	1,50E+16	4,77E+14	8,99E+15

[a] The reported data are provided as scientific notation. See B.5.1.

Table B.13 – Laboratory 3 results – Polyamide 66 (PA66) – Electrode type C with and without conductive silver paint

Laboratory	Laboratory 3		Laboratory 3	
Test date	2020/02/12		2020/02/26	
Electrode type	Annular	18.84	Annular	18.84
Conductive means	No conductive means		Conductive silver paint	
Testing voltage	500 V DC		500 V DC	
Specimen PA66	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]
1	3,91E+14	7,37E+15	1,59E+13	2,99E+14
2	3,94E+14	7,43E+15	1,68E+13	3,16E+14
3	6,50E+14	1,23E+16	1,76E+13	3,32E+14
4	1,60E+15	3,02E+16	1,91E+13	3,59E+14
5	5,70E+14	1,07E+16	1,86E+13	3,51E+14
6	4,51E+14	8,50E+15	2,01E+13	3,78E+16
7	2,20E+15	4,15E+16	1,91E+13	3,59E+14
8	4,50E+15	8,48E+16	2,16E+13	4,07E+14
9	4,90E+14	9,24E+15	2,13E+13	4,01E+14
10	3,85E+14	7,26E+15	1,91E+13	3,60E+14
11	7,20E+14	1,36E+16	1,66E+13	3,12E+14
12	6,10E+14	1,15E+16	1,78E+13	3,36E+14
13	1,30E+15	2,45E+16	1,81E+13	3,41E+14
14	6,00E+15	1,13E+17	1,52E+13	2,87E+14
15	1,90E+15	3,58E+16	1,69E+13	3,19E+14
16	9,60E+14	1,81E+16	1,71E+13	3,23E+14
17	8,30E+14	1,56E+16	1,88E+13	3,54E+14
18	8,60E+14	1,62E+16	1,89E+13	3,56E+14
19	7,60E+14	1,43E+16	1,88E+13	3,54E+14
20	1,09E+14	2,05E+15	1,87E+13	3,35E+14
Median	7,40E+14	1,40E+16	1,80E+13	3,50E+14
Standard deviation[a]	1,40E+15	2,70E+16	1,60E+12	3,00E+13
Geometrical mean[a]	8,40E+14	1,60E+16	1,62E+13	3,43E+14

[a] The reported data are provided as scientific notation. See B.5.1.

Bibliography

IEC 60050-121, *International Electrotechnical Vocabulary (IEV) – Part 121: Electromagnetism,* available at http://www.electropedia.org

IEC 60893-2, *Industrial rigid laminated sheets based on thermosetting resins for electrical purposes – Part 2: Methods of test*

IEC 61212-2, *Insulating materials – Industrial rigid round laminated tubes and rods based on thermosetting resins for electrical purposes – Part 2: Methods of test*

IEC 62011-2, *Insulating materials – Industrial, rigid, moulded, laminated tubes and rods of rectangular and hexagonal cross-section, based on thermosetting resins for electrical purposes – Part 2: Methods of test*

ISO 48-4, *Rubber, vulcanized or thermoplastics – Determination of hardness – Part 4: Indentation hardness by durometer method (Shore hardness)* **62**

ISO 5725-2, *Accuracy (trueness and precision) of measurement methods and results – Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method* **63**

ISO 10350 (all parts), *Plastics – Acquisition and presentation of comparable single-point data*

ISO 10350-1, *Plastics – Acquisition and presentation of comparable single-point data – Part 1: Moulding materials*

ISO 10350-2, *Plastics – Acquisition and presentation of comparable single-point data – Part 2: Long-fibre-reinforced plastics*

ISO 14526 (all parts), *Plastics – Phenolic powder moulding compounds (PF-PMCs)*

ISO 14527 (all parts), *Plastics – Urea-formaldehyde and urea/melamine-formaldehyde powder moulding compounds (UF- and UF/MF-PMCs)*

ISO 14528 (all parts), *Plastics – Melamine-formaldehyde powder moulding compounds (MF-PMCs)*

ISO 14529 (all parts), *Plastics – Melamine/phenolic powder moulding compounds (MP-PMCs)*

ISO 14530 (all parts), *Plastics – Unsaturated-polyester powder moulding compounds (UP-PMCs)*

ISO 15252 (all parts), *Plastics – Epoxy powder moulding compounds (EP-PMCs)*

ISO 15512, *Plastics – Determination of water content* **64**

EN 14598 (all parts), *Reinforced thermosetting moulding compounds – Specification for Sheet Moulding Compound (SMC) and Bulk Moulding Compound (BMC)*

List of comments

1 Editorial clarification.

2 Editorial clarification.

3 Editorial clarification.

4 Reference source is added for the defined term.

5 It is clarified that the surface resistivity value may include the presence of heterogeneities as well as the possible effects of polarization phenomena.

6 The definition is aligned to the definition in IEC 60050 reference 212-11-13.

7 Editorial clarification.

8 Sentence is deleted to avoid possible misinterpretations that monitoring the surface resistance may allow the evaluation of the overall resistance variation due to external effects, which is not the intention of test method.

9 Sentence is moved to a note since no requirements are provided.

10 Sentence is editorially improved for easier understanding.

11 It is clarified that the provided voltage values are suggested, and are not a requirement. Different voltage values can be used by the Technical Committees referring to this test method.

12 It is clarified that voltage values specified by the relevant product standards have priority over the recommended 100 V by this clause.

13 It is clarified that product committees referring to the test method described in this Standard have the responsibility to specify which test voltage values shall be used to test the materials used in the products under their responsibility.

14 Considering the results of the comparative verification study described in Annex B, it is clarified that comparison of test results can be done only between measurements performed by the same type of electrode arrangements and conductive means.

15 The text of third bullet item is aligned with the text of first and second bullet items.

16 Note is added to inform about the results of the round robin test that are provided in new Annex B.

17 The electrode arrangements are grouped into a subclause for easier understanding of the test method.

18 It is clarified that “electrode arrangements” is composed by the type of the electrode used and the type of conductive means used. A general description of the testing process is also added comprising two main steps: 1) the application of the conductive means to the test specimen, and 2) the execution of the measurements after having brought the electrode in contact with the conductive means applied to the test specimen.

19 To avoid possible different interpretation and therefore ensure consistency of results between different tests, it is clarified that the sentence is a requirement.

20 For better understanding, the description of the electrode arrangement is separated from the description of the conductive means dimensions and application.

21 For a better understanding of the document, the description of different types of conductive means and the related suggested application processes are moved to a new clause.

22 Editorial clarification.

23 Figure key is revised to correctly report all the abbreviations keys.

24 It is clarified that the provided electrode arrangement is an example.

25 Editorial clarification.

26 The new paragraph clarifies the conductive means application procedure.

27 Sentence is moved to a note since no requirements are provided.

28 The clause is simplified by separating the description of the electrode arrangement and the description of the conductive means application method.

29 The clause is simplified by separating the description of the electrode arrangement and the description of the conductive means application method.

30 Editorial clarification.

31 It is clarified that the machining of test specimen is possible. As per other specimen preparation conditions, it is important to ensure that the specimen to be tested is representative of the material to be used on final application.

32 The clause is changed to differentiate between the electro arrangements (described in Subclause 5.3.4) and the application methodologies for the different conductive means (described in this subclause).

33 Editorial clarification.

34 Editorial clarification.

35 Editorial clarification.

36 Editorial clarification.

37 Added reference to the new Annex B that contains the results of the round robin test.

38 New subclause describing the characteristics and application methodology of the silver paint.

39 New subclause describing the characteristics and application methodology for colloidal graphite. This conductive means works similarly to the silver paint.

40 New subclause describing the characteristics and application methodology for conducting rubber.

41 Editorial clarification.

42 Editorial clarification.

43 Editorial clarification.

44 Although reaching stabilization of the current can in certain cases provide more accurate measurement results, it requires more than 2 minutes to be achieved. Since this time exceeds the provided time requirement of 2 minutes, for measuring the surface resistance, to avoid possible variation of test results due to environment influence on conditioned or pre-treated specimen, it is decided to include this information into a note.

45 Clause title is changed to clarify that it described the calculation methodologies for the surface resistance measured by the different electrode arrangements.

46 Editorial clarification.

47 Editorial clarification.

48 Editorial clarification.

49 The reference is corrected from “surface resistance” to “surface resistivity”.

50 Editorial clarifications.

51 Editorial clarification.

52 Editorial clarification.

53 For comparison purposes between tests on different samples of the same type of test specimen, it is requested to report also the duration of the voltage application.

54 For comparison purposes between tests on different samples of the same type of test specimen, it is requested to report also the type of conductive means that has been used for test.

55 Editorial clarification.

56 This bullet item is replaced by new fifth bullet item.

57 This bullet item is deleted since it is a duplication of the eight bullet item.

58 It is clarified that Annex B contain the results of the round robin test results.

59 Editorial clarification.

60 Editorial clarification.

61 The new Annex B includes the results of round robin test and the related analysis.

62 Missing bibliographic reference is added.

63 Missing bibliographic reference is added.

64 Missing bibliographic reference is added.

IEC 62631-3-2

Edition 2.0 2023-10

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

**Dielectric and resistive properties of solid insulating materials –
Part 3-2: Determination of resistive properties (DC methods) – Surface resistance and surface resistivity**

**Propriétés diélectriques et résistives des matériaux isolants solides –
Partie 3-2: Détermination des propriétés résistives (méthodes en courant continu) – Résistance superficielle et résistivité superficielle**

IEC 62631-3-2:2023-10(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

DIELECTRIC AND RESISTIVE PROPERTIES OF SOLID INSULATING MATERIALS –

Part 3-2: Determination of resistive properties (DC methods) – Surface resistance and surface resistivity

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) IEC draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). IEC takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, IEC had not received notice of (a) patent(s), which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at https://patents.iec.ch. IEC shall not be held responsible for identifying any or all such patent rights.

IEC 62631-3-2 has been prepared by IEC technical committee 112: Evaluation and qualification of electrical insulating materials and systems. It is an International Standard.

This second edition cancels and replaces the first edition published in 2015. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) descriptions of the electrode arrangements have been clarified;
b) new descriptions of the conductive means have been added;

c) a new informative Annex B summarizing the results of the comparative verification study on surface resistivities using different electrode arrangements has been added.

The text of this International Standard is based on the following documents:

Draft	Report on voting
112/612/FDIS	112/619/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 62631 series, published under the general title *Dielectric and resistive properties of solid insulating materials*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

DIELECTRIC AND RESISTIVE PROPERTIES OF SOLID INSULATING MATERIALS –

Part 3-2: Determination of resistive properties (DC methods) – Surface resistance and surface resistivity

1 Scope

This part of IEC 62631 describes methods of test for the determination of surface resistance and surface resistivity of electrical insulation materials by applying DC voltage.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60212, *Standard conditions for use prior to and during the testing of solid electrical insulating materials*

IEC 62631-3-1, *Dielectric and resistive properties of solid insulating materials – Part 3-1: Determination of resistive properties (DC methods) – Volume resistance and volume resistivity – General method*

IEC 62631-3-3, *Dielectric and resistive properties of solid insulating materials – Part 3-3: Determination of resistive properties (DC methods) – Insulation resistance*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
electrode arrangement
electrical conductive bodies on the surface of a test specimen

Note 1 to entry: The arrangement of electrodes should include procedures to ascertain sufficient contact to the surface (e.g. by means of conducting paint) or the use of adequate mechanical system applying the necessary contact force to the test specimen's surface or both.

3.1.1
annular electrode
central circular planar electrode with a surrounding ring electrode separated by a gap

SEE: Figure 3.

Note 1 to entry: Guard electrode systems as described in IEC 62321-3-1 are of similar shape. In the case of surface resistance, the ring electrode does not have the function of a guard; guard functionality, however, is provided by the opposite electrode.

3.1.2
line electrode
electrode arrangement provided by two parallel lines, separated by a gap, applied to the test specimen's surface using a conductive material

SEE: Figure 2.

3.1.3
spring loaded electrode
line electrode system using two parallel lines of conducting spring tongues with sharp edges, separated by a gap

SEE: Figure 1.

3.2
measured resistance
ratio of a DC voltage applied to an electrode arrangement in contact with a test specimen to the current between them measured with sufficient precision

Note 1 to entry: A three-terminal electrode arrangement can be used to exclude undesired volume currents from the determination of the measured resistance.

Note 2 to entry: A Wheatstone bridge can also be used to compare the measured resistance with a standard resistor. However, Wheatstone bridges are not commonly used anymore.

Note 3 to entry: According to IEC 60050-121: Electromagnetism, "conductivity" (IEV 121-12-03) is defined as "the scalar or tensor quantity, the product of which by the electric field strength in a medium is equal to the electric current density" and "resistivity" (IEV 121-12-04) as "the inverse of the conductivity when this inverse exists". Measured in this way, the surface resistivity integrates different electrical conduction pathways at the surface of the material or in its nearby volume, with the possible presence of heterogeneities; it includes the effect of possible polarization phenomena at the electrodes. Therefore, it is considered as an averaged value.

3.3
surface resistance
R_S
measured resistance between any electrode arrangement defined in IEC 62361-3-2

Note 1 to entry: Depending on the electrode arrangement used, it is designated as R_{SA}, R_{SB}, R_{SC}, R_{SD} or R_{SE} with surface resistance, R_S expressed in Ω.

Note 2 to entry: An indeterminable part of the resistance inside the material is also included in surface resistance during the measurement of this resistance.

3.4
R_{SC}
surface resistance between annular electrodes
measured resistance between the inner circular area of an annular electrode system and the outer circular ring electrode

3.5
R_{SD}
surface resistance between line electrodes
measured resistance between line electrodes

3.6
R_{SE}
surface resistance between line electrodes for small plates
measured resistance between line electrodes for small plates

3.7
R_{SB}
surface resistance between small line electrodes
measured resistance between small line electrodes

3.8
R_{SA}
surface resistance between spring load electrodes
measured resistance between spring loaded electrodes

3.9
surface resistivity
σ/square
surface resistance reduced to a square

Note 1 to entry: The numerical value of surface resistivity is independent of the size of the square.

Note 2 to entry: Surface resistance R_{SA}, R_{SB}, R_{SC}, R_{SD} and R_{SE} referred to a square, are expressed as σ_A, σ_B, σ_C, σ_D and σ_E respectively.

Note 3 to entry: Surface resistivity is often expressed by the non-standardized unit Ω per square, to show that the electrode dimension has been taken into account by calculating the specific value.

Note 4 to entry: The surface resistivity is often used to compare one kind of surface characteristic of a sample material with those of other materials. It can be compared for materials only if identical standardized dimensions of the electrodes are used. Recommended dimensions are given in 5.3.

4 Significance

Insulating materials are used in general to electrically isolate components of an electrical system from each other and from the earth. Solid insulating materials can also provide mechanical support. For this purpose, it is generally desirable to have the insulation resistance as high as possible, consistent with acceptable mechanical, chemical and heat resistance properties.

Surface resistance is, as volume resistance, a part of the insulating resistance.

Insulating resistance shall be determined according to IEC 62631-3-3 and volume resistance according to IEC 62631-3-1.

Surface resistance supplies information on the electrical resistances of the surface of materials and products. Surface resistance, however, for its major part is not a materials' property. Surface resistance depends mainly on processing parameters, environmental conditions, surface ageing phenomena and pollution, etc.

NOTE Depending on the specific application, different electrode arrangements can be preferable.

5 Method of test

5.1 General

This general method describes common values for general measurements. If a method for a specific type of material is described in this document, the specific method shall be used.

Different types of electrodes can be used, depending on the specific measurement or product demands. For instance, on surfaces with a curved shape, a small line electrode can be advantageous. Spring loaded electrodes provide measurements with low effort on products and are optimal for materials which have to be conditioned before the test. If not already stipulated by a product standard, the choice of the electrode arrangement shall be made considering the typical application.

If test specimens are made from materials (e.g. soft rubber) whose dimensions will change significantly as a result of the force applied by the electrodes on them, these electrodes are not applicable and an alternative arrangement shall be used.

If no information about the application is available, small line electrodes (R_{SB}) are recommended.

5.2 Voltage

The measuring voltage should preferably be 10 V, 100 V, 500 V, 1 000 V, 10 000 V.

If not otherwise specified by the relevant product standard, a voltage of 100 V shall be used.

Technical committees shall specify the preferred test voltage when referring to this document.

NOTE 1 Partial discharge can lead to erroneous measurements when a specific inception voltage is exceeded. In air, below 340 V, no partial discharges will occur.

NOTE 2 The ripple of the voltage source is important. A typical value for 100 V is < 5×10^{-5} peak to peak.

5.3 Equipment

5.3.1 General

Care should be taken that the surface resistance is not negatively influenced by parasitic resistances parallel to the electrode arrangement, such as the resistance of test supports or cable isolation.

To prevent measuring errors for measured resistances higher than 10^{10} Ω, shielded cables and shielded measuring cabinets shall be used.

For the determination of surface resistance and surface resistivity, different electrode arrangements can be used. The evaluation of surface resistivity is dependent on the selected electrode arrangement.

NOTE Comparison between measurement results can be done only between measurements performed using the same electrode arrangements and conductive means.

5.3.2 Accuracy

Any suitable equipment can be used. The measuring device shall be capable of determining the unknown resistance with an overall accuracy of at least

- ±10 % for resistances less than 10^{10} Ω;
- ±20 % for resistances between 10^{10} Ω and 10^{14} Ω; and
- ±50 % for resistances higher than 10^{14} Ω.

NOTE The provided accuracies have been confirmed through the round robin test results reported in Annex B.

5.3.3 Voltage source

A source of steady direct voltage is required. This can be provided either by batteries or by rectified and stabilized power supply. The degree of stability required is such that the change in current due to any change in voltage is negligible compared with the current to be measured.

5.3.4 Electrode arrangements

5.3.4.1 General

Electrode arrangements consist of the combination of electrodes and conductive means. The conductive means shall be applied to the test specimen before performing the measurements. Electrodes are then placed in contact with the conductive means applied on the test specimen in order to perform measurements.

NOTE Annex B contains the results of the comparative verification study on surface resistivities using different electrode arrangements.

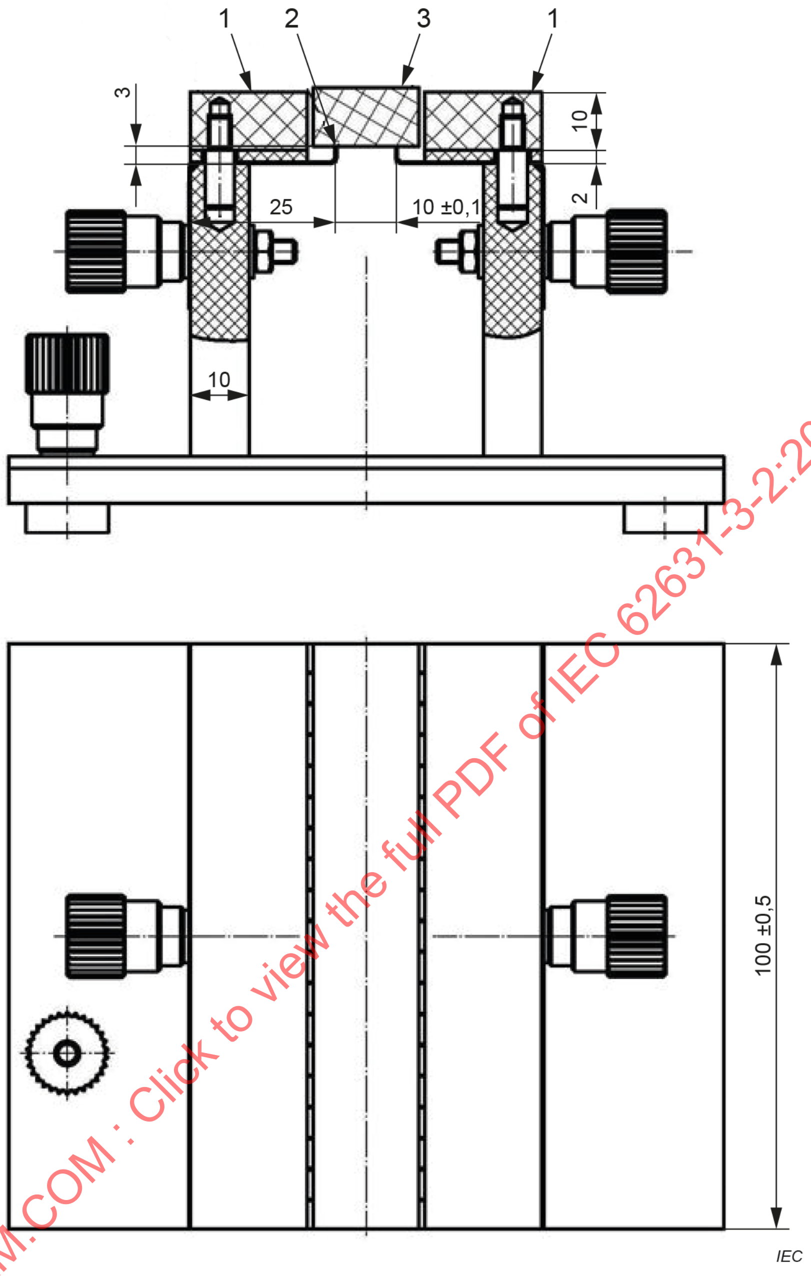
5.3.4.2 Electrode arrangement A – Spring loaded electrodes

The electrode arrangement A shall consist of two flexible metal knife-edges with a length of 100 mm and a gap distance of 10 mm as shown in Figure 1.

No guard electrode is used. The metal knife-edges shall consist of individual spring tongues arranged next to each other about 0,3 mm apart and each with a length not exceeding 5,0 mm and 0,3 mm thick. The contact force shall be high enough so that all tongues or segments rest against the surface of the test specimen, but without damaging the surface.

A piece of metal exerting the contact force shall be applied with high-grade insulation where in contact with the specimen.

Dimensions in millimetres



Key

1 guide bar (detachable)

2 metal knife-edges

3 specimen

Figure 1 – Electrode arrangement A (example)

5.3.4.3 Electrode arrangement B – Small line electrodes

Electrode arrangement B shall consist of a two-terminal collector with conductive blades being in contact with the conductive means on the test specimen, as shown in Figure 2. No guard electrode is used.

For the purpose of electrode arrangement B, conductive means shall be applied as two 1,5 mm wide lines with a length of 25,0 mm and a gap distance of 2,0 mm. Lines shall be applied before conditioning.

Types of conductive means and the related applications are described in 5.6.4.

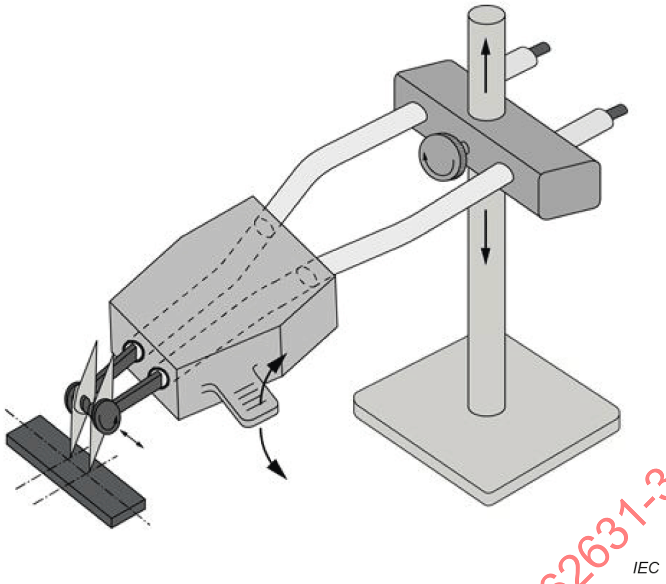
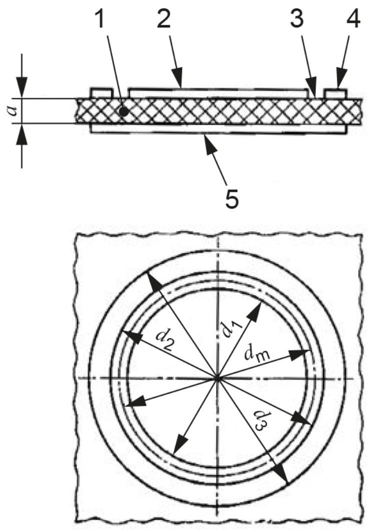


Figure 2 – Electrode arrangement B (example)

5.3.4.4 Electrode arrangement C – Annular electrodes

Electrode arrangement C is a three-terminal electrode system, as shown in Figure 3. On one side of the test specimen, annular electrodes are applied. The opposite surface of the test specimen shall be covered by a guard electrode, not smaller than the area covered by the corresponding electrodes.



Key

1 specimen

2 electrode 1

3 measuring area

4 electrode 2

5 electrode 3 (guard electrode)

a thickness of the test specimen

d_1 electrode 1 diameter

d_2 electrode 2 internal diameter

d_3 electrode 2 external diameter

d_m median diameter of measuring area

Figure 3 – Electrode arrangement C (example)

Any electrode dimensions can be used, unless otherwise specified by the relevant product standard. Typical electrode dimensions are given in Table 1. For comparison tests, electrode arrangement C1 is recommended.

Table 1 – Typical electrode dimensions for electrode arrangement C

Electrode arrangement	d_1 mm	d_2 mm	d_3 mm
C1	50	60	80
C2	76	88	100
C3	25	38	50

With electrode arrangement C, the surface resistance between electrode 1 and electrode 2 shall be measured. Electrode 3 shall be earthed.

Either of the conductive means described in 5.6.4 shall be placed or painted on the surface areas where electrode 1, electrode 2 and electrode 3 are placed. The conductive means shall not be applied on the surface between electrode 1 and electrode 2.

NOTE In the case of materials with limited conductivity and also occasionally films having a thickness of ≤ 10 µm, the input resistance of the ammeter is significantly smaller than the volume resistance of the test specimen.

5.3.4.5 Electrode arrangement D – Line electrodes

Electrode arrangement D shall consist of a two-terminal collector electrode arrangement with conductive blades being in contact with the conductive means on the test specimen, as shown in Figure 2. No guard electrode is used.

For the purpose of electrode arrangement D, the conductive means shall be applied as two parallel 1,5 mm wide lines with a length of (100,0 ± 1,0) mm and a gap distance of (10,0 ± 0,5) mm. They can be applied before the treatment.

The types of conductive means and the related applications are described in 5.6.4.

5.3.4.6 Electrode arrangement E – Line electrodes for small plates

Electrode arrangement E consists of a three-terminal collector electrode as shown in Figure 4, item B).

For the purpose of electrode arrangement E the conductive means shall be applied as two parallel 1,0 mm to 2,0 mm wide lines with a length of (50,0 ± 1,0) mm and a gap distance of (5,0 ± 0,5) mm that can be applied before conditioning of the test specimen.

The opposite surface of the test specimen shall be covered by a guard electrode not smaller than the area covered by the corresponding electrodes.

Types of conductive means and the related applications are described in 5.6.4.

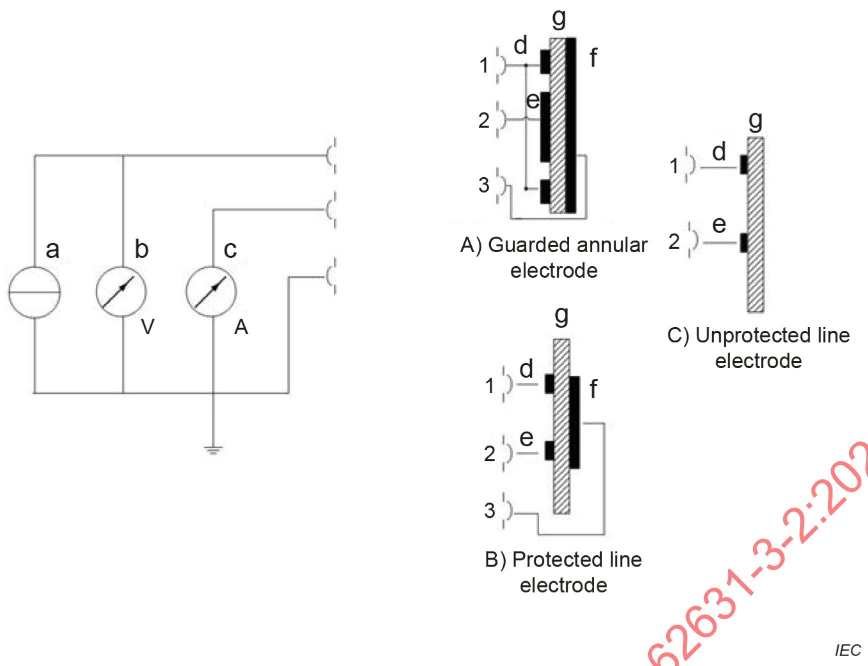
NOTE Examples of combination of electrode types and dimensions of test specimens are provided in Annex A.

5.4 Test circuit

Depending on the electrode arrangement selected, two- or three-terminal measurements shall be carried out (see Figure 4).

For annular electrodes (electrode arrangement C) and line electrode arrangement E, a three-terminal test circuit is necessary as a grounded protective electrode is mandatory.

For any other line electrode arrangement (A, B and D), a two-terminal test circuit shall be used.



Key

a voltage source

b voltmeter

c ammeter

d electrode 1

e electrode 2 (shielded electrode)

f electrode 3 (protective electrode)

g specimen

Figure 4 – Connection diagram of measurement with two- and three-terminal electrode arrangements

5.5 Calibration

The equipment shall be calibrated in the magnitude of the surface resistance measured.

NOTE Calibration resistors in a range up to 100 TΩ are commercially available.

5.6 Test specimen

5.6.1 Recommended dimensions of test specimen and electrode arrangements

The specimen's dimensions shall be sufficient to apply the selected electrode arrangement. Recommendations for products are given in Annex A.

5.6.2 Manufacturing of test specimen

The production and shape of the test specimen shall be determined by the relevant standards for the material. During removal and production of the specimen, the condition of the material shall not be changed and the specimen removed shall not be damaged.

If the surface of the test specimen is machined at the contact areas of the electrodes, the type of machining shall be specified in the test report. The test specimen shall have a geometrically simple shape (plate with parallel measuring areas, cylinder, etc.).

NOTE Machining of the test specimen can be performed on the specimen when it is representative of the application target for the materials.

Specimen from products shall be prepared with the product thickness, if possible.

5.6.3 Number of test specimens

The number of test specimens to be tested shall be determined by the relevant product standards. If no such data is available, at least three specimens shall be tested.

5.6.4 Application of conductive means

5.6.4.1 General

When using adhesive conductive means (electrode arrangements B, C, D and E), ensure that a proper contact is provided over the whole area covered. The conductive means used shall, after an appropriate time of conditioning, not influence the measured values for surface resistance.

NOTE 1 Conductive silver paint and suspensions of graphite have been found appropriate.

NOTE 2 Annex B contains the results of the comparative verification study on surface resistivities using different electrode arrangements and conductive means.

5.6.4.2 Conductive silver paint

Certain types of commercially available, high-conductivity silver paints, either air-drying or low-temperature-baking varieties, are sufficiently porous to permit diffusion of moisture through them and thereby allow the test specimens to be conditioned after application of the conductive means. This is a particularly useful feature in studying resistance-humidity effect as well as changes with temperature. However, before conductive paint is used as a conductive means, it should be established that the paint solvent does not affect the electrical properties of the specimen. Reasonably smooth edges for use with guard electrodes can be obtained with a fine-bristle brush. However, for use with circular electrodes, sharper edges can be obtained by the use of a compass for drawing the outline circles of the electrodes and filling in the enclosed areas by brush. Clamp-on masks can be used if the conductive paint is sprayed on.

5.6.4.3 Colloidal graphite

Colloidal graphite dispersed in water or other suitable medium, can be used under the same conditions as given for conductive silver paint.

5.6.4.4 Conducting rubber

Conducting rubber can be used as conductive means. It has the advantage that it can be applied and removed from the specimen quickly and easily. Since the conductive means are applied only during the time of measurement, they do not interfere with the conditioning of the specimen. The resistance of the rubber electrode shall be less than 1 000 Ω.

The conducting rubber material shall be soft enough to ensure that effective contact to the specimen is obtained when a reasonable pressure, for example 2 kPa (0,2 N/cm^2), is applied. Shore A hardness according to ISO 48-4 in the range of 65 to 85 has been found suitable.

NOTE The results of resistivity measurements obtained with the application of electrodes made of conducting rubber are always higher (few tens to few hundreds per cent) in comparison to that obtained for metallic electrodes.

5.6.5 Conditioning and pre-treatment of test specimen

Conditioning and any other pre-treatment of the test specimen shall be carried out according to the relevant product standard.

If no product standard exists, conditioning shall be realized for at least four days at 23 °C and 50 % RH in accordance with IEC 60212 (standard climate B).

If not otherwise specified by the relevant product standard, no cleaning of the test specimen shall be done. Any additional contamination shall be avoided.

5.7 Test procedure

Unless otherwise specified, the measurement shall be conducted in normal air at 23 °C and 50 % RH in accordance with IEC 60212 (standard climate B).

The specimen shall be conditioned and pre-treated in accordance with 5.6.5. Immediately after the treatment, the electrodes shall be connected with the measuring device.

Subsequently, but no more than 2 min after finishing the conditioning or pre-treatment, the surface resistance R_S shall be determined between the electrodes. If not otherwise specified, it shall be measured 1 min after voltage application.

NOTE Experience from the application of this test evidenced that, for material design and research purposes, reaching the stabilization of the current before measuring the surface resistance provides better results.

6 Calculation of surface resistivity

6.1 For electrode arrangements A, B, D and E

The measured value R_S for the respective surface resistances R_{SA}, R_{SB}, R_{SD} and R_{SE} between electrodes 1 and 2 shall be specified in Ω.

For electrode arrangements A, B, D and E, surface resistivity σ can be calculated in Ω according to Equation (1) from the measured resistance R_S and electrode dimensions.

It is also possible to calculate surface resistivity even with dimensions deviating from those defined in 5.3.4, 5.3.4.3, 5.3.4.5 and 5.3.4.6.

$$\sigma_Y = \frac{l}{g} \cdot R_{SY} \quad (1)$$

where

l is the length of the line electrodes, expressed in mm;

g is the distance between the lines (gap), expressed in mm;

Y corresponds to the electrode arrangements A, B, D, or E.

As the individual surfaces resistivities are dependent on the electrode arrangement used and are therefore not comparable with each other, when reporting the measurement results, the type of electrode arrangement shall be specified together with the measured value.

6.2 For electrode arrangement C

The surface resistance R_{SC} between electrodes 1 and 2 with earthed electrode 3 shall be specified in Ω.

The surface resistivity σ_C can be calculated in Ω according to Equation (2) from the measured resistance R_{SC} and electrode dimensions (see Figure 3).

$$\sigma_C = \frac{d_2 + d_1}{d_2 - d_1} \cdot \pi \cdot R_{SC} \quad (2)$$

where

d_1 is the outer diameter of the inner electrode, expressed in mm;

d_2 is the inner diameter of the ring electrode, expressed in mm.

7 Test report

The report shall include the following:

- electrode arrangement and electrode dimensions;
- complete identification and description of the material tested, including the source and the manufacturer's code;
- shape and thickness of the test specimen;
- test voltage and duration of the voltage application;
- description of the conductive material used, test set-up and instrument used for the test;
- accuracy of the instrument and calibration method, depending on the measured values of resistance, if necessary;
- curing conditions of the material and any pre-treatment;
- conditioning of the samples and ambient conditions under test;
- number of samples;
- date of test;
- each single value and the median of surface resistance and surface resistivity, respectively;
- any other important observation if applicable.

8 Repeatability and reproducibility

Measurements of surface resistance and surface resistivity are dependent on numerous aspects. Experiences have shown that the reproducibility is in the range of > 50 % (of the measured value).

The repeatability is between 20 % and 50 %.

Annex B contains the results of the comparative verification study on surface resistivities using different electrode arrangements.

Annex A
(informative)

Specimen dimensions and electrode arrangements

Specimen dimensions and electrode arrangements are given in Table A.1.

For materials which are not available in flat sheets, the electrode arrangement should be agreed between the supplier and customer.

Table A.1 – Recommended test specimen dimensions and electrode arrangements for specific products

Type of product	Recommended electrode arrangement	Remarks	Recommended dimensions of test specimen
Thermoplastic moulding compounds	E, C	See ISO 10350-1	≥ 60 mm × ≥ 60 mm
Thermosetting moulding compounds	A, E, C	See ISO 14526 series, ISO 14527 series, ISO 14528 series, ISO 14529 series, ISO 14530 series, ISO 15252 series	≥ 60 mm × ≥ 60 mm ≥ 100 mm × ≥ 100 mm
Long fibre, reinforced polyester resin and vinyl ester resin moulding compounds (SMC BMC)	A, C	See EN 14598 series, ISO 10350-2	≥ 100 mm × ≥ 100 mm
Epoxy based sheets and laminates	A, C	See IEC 60893-2	
Pipes, bars and rods	B, D	See IEC 61212-2, IEC 62011-2	
Elastomeric materials	B, C		

Annex B
(informative)

Comparative verification study on surface resistivities using different electrode arrangements (type C and type E)

B.1 General

An inter-laboratory trial has been performed to confirm the existing variations, for the surface resistivity test results on the same materials, in which replicated batches of two materials (hereunder referred as material A and material B) were tested at four laboratories in accordance with this part of IEC 62321.

Since this preliminary inter-laboratory trial did not fully satisfy the conditions for the international laboratory trial in ISO 5725-2 due to an insufficient number of participating laboratories, repeatability and reproducibility were not obtained in accordance with ISO 5725-2.

Nevertheless, some analysis on the test data was conducted as follows.

B.2 Inter-laboratory trial conditions

B.2.1 General

Four laboratories participated in the inter-laboratory trial.

B.2.2 Test specimens

Specimens A and B characteristics are described in Table B.1.

Table B.1 – Test specimens characteristics

	Specimen A	Specimen B
Material	Polyamide 66 (PA66)	Polybutylene terephthalate (PBT)
Filled/Unfilled	Unfilled	Unfilled
Water content (according to ISO 15512)	1,80 %	0,15 %
Dimensions	Square test plaques 100 mm × 100 mm × 2 mm	Square test plaques 100 mm × 100 mm × 2 mm
Number of specimens	10 × each test condition	10 × each test condition

B.2.3 Electrode types, conductive materials and test voltage

The following electrode types were used for the inter-laboratory trial:

- electrode arrangement C – Annular electrodes (according to 5.3.4.4);
- electrode arrangement E – Line electrodes for small plates (according to 5.3.4.6).

The conductive materials between the electrodes and the test specimen were:

- conductive silver paint (according to 5.6.4.2);
- conductive rubber (according to 5.6.4.4).

Either of the conductive materials was applied on both surfaces of the test specimens to guarded electrodes and measuring electrodes respectively.

Test voltage: 500 V DC.

B.2.4 Test conditions

The applied test conditions by the specific participants are summarized in the following Table B.2. The surface resistivity equations for the different electrodes are represented in Figure B.1.

Table B.2 – Test conditions per specific participant

Conditions		Laboratory 1	Laboratory 2	Laboratory 3	Laboratory 4
Electrode arrangement type	C		X[a]	X[a]	X[a]
	$\pi \times (d_2 + d_1)/(d_2 - d_1)$		(34,50)	(18,84)	(34,50)
	E	X[a]	X[a]		
	(l/g)	(10)	(10)		
Conductive material	Silver paint	X[a]	X[a]	X[a]	
	Rubber		X[a]		X[a]
Test voltage (V DC)	Requested 500 V	500	500	500	500

[a] Condition applied by the specific laboratory.

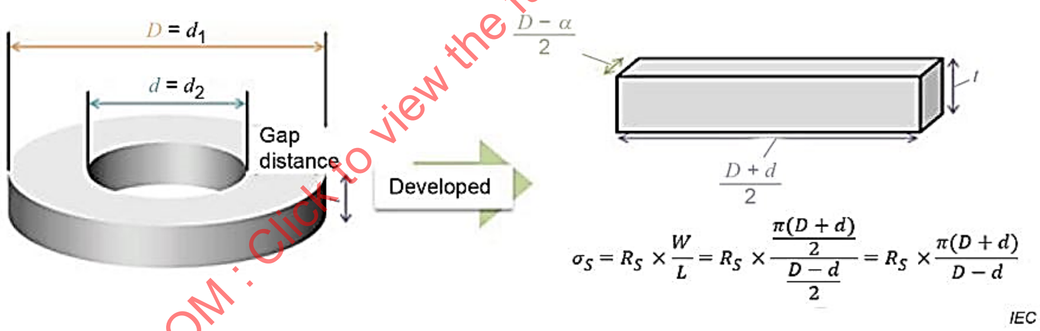


Figure B.1 – Surface resistivity equations for the used electrodes

B.3 Summary of the test results

The inter-laboratory trial results are summarized in the following Table B.3.

Table B.3 – Summary of the test results

Material	Polybutylene terephthalate (PBT)			Polyamide 66 (PA66)		
Electrode arrangement	C	C	E	C	C	E
Conductive means	Rubber	Silver	Silver	Rubber	Silver	Silver
Test voltage (V DC)	500	500	500	500	500	500
Laboratories	2, 4[a]	2, 3, 4[a]	1, 2	2, 4	2, 3, 4	1, 2
Total specimens	20	30	20	20	30	20
Grand mean (X)[b]	3,4E+16	3,5E+16	1,9E+16	1,5E+15	3,3E+14	1,4E+15
Reproducibility (S_g)[b]	1,3E+16	2,2E+16	2,0E+16	5,0E+14	6,5E+13	1,2E+15
Extended standard deviation (Std Dev r)[b]	2,1E+16	1,3E+16	1,2E+16	4,9E+14	3,7E+13	4,3E+14
Repeatability (S_r)[b]	5,8E+16	3,7E+16	3,2E+16	1,4E+15	1,0E+14	1,2E+15
Repeatability % (% S_r)	170	107	172	90	31	85

[a] Laboratory 4 reported that 7 out of 10 specimens showed results out of the measuring range (actual values were therefore higher).

[b] The reported data are provided as scientific notation. See B.5.1.

B.4 Inter-laboratory trial outcomes and suggestions for IEC 62631-3-2

The outcomes of this inter-laboratory trial provide evidence that:

a) the electrode arrangement type C (annular) variations of conductive materials (use or no use of silver paint or conductive rubber), significantly affect the repeatability and reproducibility of results;

b) the different gap distances in the electrode arrangement type C did not affect the results compared to the results of the electrode arrangement type E (the electrode arrangement type C gap distance for laboratory 3 is different from those of laboratories 2 and 4);

c) the current results show that the electrode arrangement type C in combination with silver paint has slightly better repeatability and reproducibility than the electrode arrangement type E, although more data shall be collected to confirm these results and the related precision of data.

According to the above findings, the following technical modifications have been introduced in this second edition of IEC 62631-3-2:

d) for any type of electrode arrangement, conductive material shall be applied on the specimen surface in contact with the measuring electrodes and guarding electrodes;

e) silver paint is the preferred conductive material;

f) description of the conductive rubber characteristics has been added.

In order to properly evaluate data precision and address possible results variation factors between the different electrode types, IEC TC 112 will consider the possibility to perform an additional inter-laboratory trial.

B.5 Detailed inter-laboratory results

B.5.1 General

The detailed analysis of the collected data from the inter-laboratory trial is provided in Table B.4 to Table B.13.

In Table B.4 to Table B.13 the reported data for surface resistance, surface resistivity and some statistical data are provided as scientific notation defined as per the following example:

EXAMPLE 1E+15 is equivalent to $1 \cdot 10^{15}$ and to 1 000 000 000 000 000.

where

1 = coefficient

E = 10 to the power of

15 = exponent

B.5.2 Laboratories results by different groups of electrode types and conductive materials for the different test specimens

Table B.4 – Polybutylene terephthalate (PBT) test specimen results – Electrode type C with conductive rubber

Laboratory	Laboratory 2		Laboratory 4	
Test date	2020/02/18		2020/07/28	
Electrode type	Annular C1	34.56	Annular C1	34.56
Conductive means	Conductive elastomer		Conductive rubber	
Testing voltage	500 V DC		500 V DC	
Specimen **PBT**	Surface resistance R_{SC} Ω [b]	Surface resistivity σ Ω/square [b]	Surface resistance R_{SC} [a] Ω [b]	Surface resistivity σ [a] Ω/square [b]
1	1,30E+14	4,50E+15	1,60E+15	5,53E+16
2	1,60E+15	5,50E+16	6,30E+16	2,18E+15
3	3,10E+14	1,10E+16	5,00E+14	1,73E+16
4	1,60E+15	5,50E+16	1,60E+15	5,53E+16
5	1,60E+15	5,50E+16	1,60E+15	5,53E+16
6	6,40E+14	2,20E+16	1,60E+15	5,53E+16
7	1,70E+14	5,90E+15	1,60E+15	5,53E+16
8	2,40E+14	8,30E+15	1,60E+15	5,53E+16
9	4,80E+14	1,70E+16	6,70E+14	2,32E+16
10	5,50E+14	1,90E+16	1,60E+15	5,53E+16
Median	5,20E+14	1,80E+16	1,60E+15	5,53E+16
Standard deviation	5,90E+14	2,00E+16	5,63E+14	5,53E+16
Geometrical mean	5,10E+14	1,80E+16	9,45E+14	3,26E+16
Population	10		10	
Degree of freedom	9		9	
Confidence 95 %[b]	1,25E+16		3,43E+16	
Weighted variance[b]	1,60E+18		4,50E+18	
Extended weighted variance[b]			**Annular with conductive rubber**	6.10E+18
Total degree of freedom				18
Pooled standard deviation[b]				6,00E+08

[a] The data in red represent measurements that exceeded the instrument measuring range.

[b] The reported data are provided as scientific notation. See B.5.1.

Table B.5 – Polyamide 66 (PA66) test specimen results – Electrode type C with conductive rubber

Laboratory	Laboratory 2		Laboratory 4	
Test date	2020/02/18		2020/07/28	
Electrode type	Annular C1	34.56	Annular C1	34.56
Conductive means	Conductive elastomer		Conductive rubber	
Testing voltage	500 V DC		500 V DC	
Specimen PA66	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]
1	5,97E+13	2,06E+15	7,70E+13	2,66E+15
2	2,58E+13	8,92E+14	6,55E+13	2,26E+15
3	3,01E+13	1,04E+15	5,52E+13	1,91E+15
4	2,82E+13	9,75E+14	7,12E+13	2,46E+15
5	3,06E+13	1,06E+15	6,07E+13	2,10E+15
6	3,37E+13	1,16E+15	3,86E+13	1,33E+15
7	2,95E+13	1,02E+15	4,35E+13	1,50E+15
8	2,95E+13	1,02E+15	2,91E+13	1,01E+15
9	3,12E+13	1,08E+15	6,84E+13	2,36E+15
10	3,61E+13	1,25E+15	3,01E+13	1,04E+15
Median	3,00E+13	1,10E+15	5,80E+13	2,00E+15
Standard deviation	9,20E+12	3,20E+14	1,66E+13	2,00E+15
Geometrical mean	3,30E+13	1,10E+15	5,11E+13	1,77E+15
Population	10		10	
Degree of freedom	9		9	
Confidence 95 %[a]	1,95E+14		1,24E+15	
Weighted variance[a]	2,60E+16		1,60E+17	
Extended weighted variance[a]			Annular with conductive rubber	1,90E+17
Total degree of freedom				18
Pooled standard deviation[a]				1,00E+08

[a] The reported data are provided as scientific notation. See B.5.1.

Table B.6 – Polybutylene terephthalate (PBT) test specimen results – Electrode type C with conductive silver paint

Laboratory	Laboratory 2		Laboratory 4		Laboratory 3	
Test date	2020/02/18		2020/07/28		2020/02/26	
Electrode type	Annular C1	34.56	Annular C1	34.56	Annular	18.84
Conductive means	Conductive silver paint		Conductive silver paint		Conductive silver paint	
Testing voltage	500 V DC		500 V DC		500 V DC	
Specimen PBT	Surface resistance R_{SC} Ω [b]	Surface resistivity σ Ω/square [b]	Surface resistance R_{SC} [a] Ω [b]	Surface resistivity σ [a] Ω/square [b]	Surface resistance R_{SC} Ω [b]	Surface resistivity σ Ω/square [b]
1	1,60E+15	5,50E+16	4,70E+14	1,62E+16	4,66E+14	8,78E+15
2	1,60E+15	5,50E+16	1,52E+15	5,25E+16	4,95E+14	9,33E+15
3	1,60E+15	5,50E+16	1,60E+15	5,53E+16	4,90E+14	9,23E+15
4	6,10E+14	2,10E+16	1,54E+15	5,32E+16	4,76E+14	8,97E+15
5	1,60E+15	5,50E+16	1,60E+15	5,53E+16	4,85E+14	9,14E+15
6	1,60E+15	5,50E+16	1,60E+15	5,53E+16	4,46E+14	8,40E+15
7	1,60E+15	5,50E+16	1,60E+15	5,53E+16	4,95E+14	9,33E+15
8	1,60E+15	5,50E+16	1,60E+15	5,53E+16	4,81E+14	9,06E+15
9	1,60E+15	5,50E+16	1,60E+15	5,53E+16	5,00E+14	9,42E+15
10	1,10E+15	3,60E+16	1,60E+15	5,53E+16	5,00E+14	9,42E+15
Median	1,60E+15	5,50E+16	1,60E+15	5,53E+16	4,88E+14	9,19E+15
Standard deviation	3,20E+14	1,10E+16	5,49E+14	1,90E+16	1,62E+13	3,06E+14
Geometrical mean	1,40E+15	4,80E+16	7,03E+14	2,43E+16	4,83E+14	9,10E+15
Population	10		10		10	
Degree of freedom	9		9		9	
Confidence 95 %[b]	6,89E+15		1,18E+16		1,90E+14	
Weighted variance[b]	9,00E+17		1,50E+18		2,50E+16	
Extended weighted variance[b]					**Annular with conductive silver paint**	2,50E+18
Total degree of freedom						27
Pooled standard deviation[b]						3,00E+08

[a] The data in red represent measurements that exceeded the instrument measuring range.

[b] The reported data are provided as scientific notation. See B.5.1.

Table B.7 – Polyamide 66 (PA66) test specimen results – Electrode type C with conductive silver paint

Laboratory	Laboratory 2		Laboratory 4		Laboratory 3	
Test date	2020/02/18		2020/07/28		2020/02/26	
Electrode type	Annular C1	34.56	Annular C1	34.56	Annular	18.84
Conductive means	Conductive silver paint		Conductive silver paint		Conductive silver paint	
Testing voltage	500 V DC		500 V DC		500 V DC	
Specimen PA66	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]
1	1,04E+13	3,59E+14	7,69E+12	2,66E+14	1,59E+13	2,99E+14
2	1,10E+13	3,80E+14	1,02E+13	3,51E+14	1,68E+13	3,16E+14
3	9,64E+12	3,33E+14	5,31E+12	1,84E+14	1,76E+13	3,32E+14
4	1,19E+13	4,11E+14	6,83E+12	2,36E+14	1,91E+13	3,59E+14
5	1,09E+13	3,77E+14	5,71E+12	1,97E+14	1,86E+13	3,51E+14
6	1,13E+13	3,91E+14	6,52E+12	2,25E+14	2,01E+13	3,78E+14
7	1,05E+13	3,63E+14	8,10E+12	2,80E+14	1,91E+13	3,59E+14
8	1,07E+13	3,70E+14	7,18E+12	2,48E+14	2,16E+13	4,07E+14
9	9,86E+12	3,41E+14	8,01E+12	2,7E+14	2,13E+13	4,01E+14
10	1,17E+13	4,04E+14	7,93E+12	2,74E+14	1,91E+13	3,60E+14
Median	1,10E+13	3,70E+14	7,43E+12	2,57E+14	1,91E+13	3,59E+14
Standard deviation	6,90E+11	2,40E+13	1,31E+13	4,53E+13	1,73E+12	3,25E+13
Geometrical mean	1,10E+13	3,70E+14	2,50E+14	2,50E+14	1,88E+13	3,55E+14
Population	10		10		10	
Degree of freedom	9		9		9	
Confidence 95 %[a]	1,48E+13		2,81E+13		2,02E+13	
Weighted variance[a]	1,90E+15		3,70E+15		2,60E+15	
Extended weighted variance[a]					**Annular with conductive silver paint**	8,24E+15
Total degree of freedom						27
Pooled standard deviation[a]						2,00E+07

[a] The reported data are provided as scientific notation. See B.5.1.

Table B.8 – Polybutylene terephthalate (PBT results) test specimen results – Electrode type E with conductive silver paint

Laboratory	Laboratory 2		Laboratory 1	
Test date	2020/02/18		2020/06/12	
Electrode type	Lines E	10	Lines E	10
Conductive means	Conductive silver paint		Conductive silver paint	
Testing voltage	500 V DC		500 V DC	
Specimen **PBT**	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]
1	3,10E+14	3,10E+15	1,30E+15	1,30E+16
2	2,80E+14	2,80E+15	4,00E+15	4,00E+16
3	4,70E+14	4,70E+15	1,90E+15	1,90E+16
4	3,10E+14	3,10E+15	4,70E+15	4,70E+16
5	5,30E+14	5,30E+15	2,10E+15	2,10E+16
6	5,10E+14	5,10E+15	3,30E+15	3,30E+16
7	4,90E+14	4,90E+15	5,00E+15	5,00E+16
8	5,20E+14	5,20E+15	3,60E+15	3,60E+16
9	4,60E+14	4,60E+15	6,10E+15	6,10E+16
10	4,50E+14	4,50E+15	1,30E+15	1,30E+16
Median	4,70E+14	4,70E+15	3,40E+15	3,40E+16
Standard deviation	9,10E+13	9,10E+14	1,60E+15	1,60E+16
Geometrical mean	4,20E+14	4,20E+15	2,90E+15	2,90E+16
Population	10		10	
Degree of freedom	9		9	
Confidence 95 %[a]	5,62E+14		9,68E+15	
Weighted variance[a]	7,30E+16		1,30E+18	
Extended weighted variance[a]			**Lines with conductive silver paint**	1,3E+18
Total degree of freedom				18
Pooled standard deviation[a]				3,00E+08

[a] The reported data are provided as scientific notation. See B.5.1.

**Table B.9 – Polyamide 66 (PA66) test specimen results –
Electrode type E with conductive silver paint**

Laboratory	Laboratory 2		Laboratory 1	
Test date	2020/02/18		2020/06/12	
Electrode type	Lines E	10	Lines E	10
Conductive means	Conductive silver paint		Conductive silver paint	
Testing voltage	500 V DC		500 V DC	
Specimen **PA66**	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]
1	5,20E+13	5,21E+14	2,49E+14	2,49E+15
2	5,58E+13	5,58E+14	2,48E+14	2,48E+15
3	6,09E+13	6,09E+14	1,45E+14	1,45E+15
4	5,63E+13	5,63E+14	2,78E+14	2,78E+15
5	5,96E+13	5,96E+14	3,18E+14	3,18E+15
6	7,16E+13	7,16E+14	1,39E+14	1,39E+15
7	9,09E+13	9,09E+14	1,92E+14	1,92E+15
8	4,89E+13	4,89E+14	2,06E+14	2,06E+15
9	4,09E+13	4,09E+14	1,96E+14	1,96E+15
10	4,66E+13	4,66E+14	2,82E+14	2,82E+15
Median	5,60E+13	5,60E+14	2,30E+14	2,30E+15
Standard deviation	1,40E+13	1,40E+14	5,70E+13	5,70E+14
Geometrical mean	5,70E+13	5,70E+14	2,20E+14	2,20E+15
Population	10		10	
Degree of freedom	9		9	
Confidence 95 %[a]	8,37E+13		3,50E+14	
Weighted variance[a]	1,10E+16		4,60E+16	
Extended weighted variance[a]			**Lines with conductive silver paint**	5,70E+16
Total degree of freedom				18
Pooled standard deviation[a]				6,00E+07

[a] The reported data are provided as scientific notation. See B.5.1.

B.5.3 Laboratory 2 results comparing different electrode types and conductive materials

Table B.10 – Laboratory 2 results – Polybutylene terephthalate (PBT) – Different electrodes and conductive materials

Laboratory	Laboratory 2		Laboratory 2		Laboratory 2	
Test date	2020/02/18		2020/02/18		2020/02/18	
Electrode type	Annular C1	34.56	Annular C1	34.56	Lines E	10
Conductive means	Conductive elastomer		Conductive silver paint		Conductive silver paint	
Testing voltage	500 V DC		500 V DC		500 V DC	
Specimen PBT	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]
1	1,30E+14	4,50E+15	1,60E+15	5,50E+16	3,10E+14	3,10E+15
2	1,60E+15	5,50E+16	1,60E+15	5,50E+16	2,80E+14	2,80E+15
3	3,10E+14	1,10E+16	1,60E+16	5,50E+16	4,70E+14	4,70E+15
4	1,60E+15	5,50E+16	6,10E+14	2,10E+16	3,10E+14	3,10E+15
5	1,60E+15	5,50E+16	1,60E+15	5,50E+16	5,30E+14	5,30E+15
6	6,40E+14	2,20E+16	1,60E+15	5,50E+16	5,10E+14	5,10E+15
7	1,70E+14	5,90E+15	1,60E+15	5,50E+16	4,90E+14	4,90E+15
8	2,40E+14	8,30E+15	1,60E+15	5,50E+16	5,20E+14	5,20E+15
9	4,80E+14	1,70E+16	1,60E+15	5,50E+16	4,60E+14	4,60E+15
10	5,50E+14	1,90E+16	1,10E+15	3,60E+16	4,50E+14	4,50E+15
Median	5,20E+14	1,80E+16	1,60E+15	5,50E+16	4,70E+14	4,70E+15
Standard deviation	9,20E+14	2,00E+16	3,20E+14	1,10E+16	9,10E+13	9,10E+14
Geometrical mean	5,10E+14	1,80E+16	1,40E+15	4,80E+16	4,20E+14	4,20E+15
Population	10		10		10	
Degree of freedom	9		9		9	
Confidence 95 %[a]	1,25E+16		6,89E+15		5,62E+14	
Weighted variance[a]	1,60E+18		9,00E+17		7,30E+16	

[a] The reported data are provided as scientific notation. See B.5.1.

Table B.11 – Laboratory 2 results – Polyamide 66 (PA66) – Different electrodes and conductive materials

Laboratory	Laboratory 2		Laboratory 2		Laboratory 2	
Test date	2020/02/18		2020/02/18		2020/02/18	
Electrode type	Annular C1	34.56	Annular C1	34.56	Lines E	10
Conductive means	Conductive elastomer		Conductive silver paint		Conductive silver paint	
Testing voltage	500 V DC		500 V DC		500 V DC	
Specimen PA66	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]
1	5,97E+13	2,06E+15	1,04E+13	3,59E+14	5,21E+13	5,21E+14
2	2,58E+13	8,92E+14	1,10E+13	3,80E+14	5,58E+13	5,58E+14
3	3,01E+13	1,04E+15	9,64E+12	3,33E+14	6,09E+13	6,09E+14
4	2,82E+13	9,75E+14	1,19E+13	4,11E+14	5,63E+13	5,63E+14
5	3,06E+13	1,06E+15	1,09E+13	3,77E+15	5,96E+13	5,96E+14
6	3,37E+13	1,16E+15	1,13E+13	3,91E+14	7,16E+13	7,16E+14
7	2,95E+13	1,02E+15	1,05E+13	3,63E+14	9,09E+13	9,09E+14
8	2,95E+13	1,02E+15	1,07E+13	3,70E+14	4,89E+13	4,89E+14
9	3,12E+13	1,08E+15	9,86E+12	3,41E+14	4,09E+13	4,09E+14
10	3,61E+13	1,25E+15	1,17E+13	4,04E+14	4,66E+13	4,66E+14
Median	3,00E+13	1,10E+15	1,10E+13	3,70E+14	5,60E+13	5,60E+14
Standard deviation	9,20E+12	3,20E+14	6,90E+11	2,40E+13	1,40E+13	1,40E+14
Geometrical mean	3,30E+13	1,10E+15	1,10E+13	3,70E+14	5,70E+13	5,70E+14
Population	10		10		10	
Degree of freedom	9		9		9	
Confidence 95 %[a]	1,95E+14		1,48E+13		8,37E+13	
Weighted variance[a]	2,60E+16		1,90E+15		1,10E+16	

[a] The reported data are provided as scientific notation. See B.5.1.

B.5.4 Laboratory 3 results – Electrode type C with and without use of conductive silver paint

Table B.12 – Laboratory 3 results – Polybutylene terephthalate (PBT) – Electrode type C with and without conductive silver paint

Laboratory	Laboratory 3		Laboratory 3	
Test date	2020/02/12		2020/02/26	
Electrode type	Annular	18.84	Annular	18.84
Conductive means	No conductive means		Conductive silver paint	
Testing voltage	500 V DC		500 V DC	
Specimen **PBT**	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]
1	3,10E+15	5,84E+16	4,66E+14	8,78E+15
2	6,60E+14	1,24E+16	4,95E+14	9,3E+15
3	1,10E+15	2,07E+16	4,90E+14	9,24E+15
4	7,90E+14	1,49E+16	4,76E+14	8,97E+15
5	5,00E+15	9,42E+16	4,85E+14	9,14E+15
6	1,50E+14	2,83E+15	4,46E+14	8,41E+15
7	3,47E+14	6,54E+15	4,95E+14	9,33E+15
8	1,40E+15	2,64E+16	4,81E+14	9,07E+15
9	1,10E+15	2,07E+16	5,00E+14	9,42E+15
10	2,64E+14	4,98E+15	5,00E+14	9,42E+15
11	4,00E+14	7,54E+15	4,81E+14	9,07E+15
12	4,10E+14	7,67E+15	4,24E+14	7,99E+15
13	1,70E+15	3,20E+16	4,87E+14	9,18E+15
14	2,00E+15	3,77E+16	4,85E+14	9,14E+15
15	2,50E+14	4,69E+15	4,59E+14	8,65E+15
16	3,30E+15	6,22E+16	5,40E+14	1,02E+16
17	1,40E+15	2,64E+16	4,95E+14	9,33E+15
18	9,60E+14	1,81E+16	4,85E+14	9,14E+15
19	3,90E+14	7,26E+15	4,72E+14	8,90E+15
20	1,5E+14	2,79E+15	3,97E+14	7,48E+15
Median	8,80E+14	1,60E+16	4,90E+14	9,10E+15
Standard deviation[a]	1,20E+15	2,30E+16	4,90E+13	5,50E+14
Geometrical mean[a]	7,80E+14	1,50E+16	4,77E+14	8,99E+15

[a] The reported data are provided as scientific notation. See B.5.1.

Table B.13 – Laboratory 3 results – Polyamide 66 (PA66) – Electrode type C with and without conductive silver paint

Laboratory	Laboratory 3		Laboratory 3	
Test date	2020/02/12		2020/02/26	
Electrode type	Annular	18.84	Annular	18.84
Conductive means	No conductive means		Conductive silver paint	
Testing voltage	500 V DC		500 V DC	
Specimen PA66	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]	Surface resistance R_{SC} Ω [a]	Surface resistivity σ Ω/square [a]
1	3,91E+14	7,37E+15	1,59E+13	2,99E+14
2	3,94E+14	7,43E+15	1,68E+13	3,16E+14
3	6,50E+14	1,23E+16	1,76E+13	3,32E+14
4	1,60E+15	3,02E+16	1,91E+13	3,59E+14
5	5,70E+14	1,07E+16	1,86E+13	3,51E+14
6	4,51E+14	8,50E+15	2,01E+13	3,78E+16
7	2,20E+15	4,15E+16	1,91E+13	3,59E+14
8	4,50E+15	8,48E+16	2,16E+13	4,07E+14
9	4,90E+14	9,24E+15	2,13E+13	4,01E+14
10	3,85E+14	7,26E+15	1,91E+13	3,60E+14
11	7,20E+14	1,36E+16	1,66E+13	3,12E+14
12	6,10E+14	1,15E+16	1,78E+13	3,36E+14
13	1,30E+15	2,45E+16	1,81E+13	3,41E+14
14	6,00E+15	1,13E+17	1,52E+13	2,87E+14
15	1,90E+15	3,58E+16	1,69E+13	3,19E+14
16	9,60E+14	1,81E+16	1,71E+13	3,23E+14
17	8,30E+14	1,56E+16	1,88E+13	3,54E+14
18	8,60E+14	1,62E+16	1,89E+13	3,56E+14
19	7,60E+14	1,43E+16	1,88E+13	3,54E+14
20	1,09E+14	2,05E+15	1,87E+13	3,35E+14
Median	7,40E+14	1,40E+16	1,80E+13	3,50E+14
Standard deviation[a]	1,40E+15	2,70E+16	1,60E+12	3,00E+13
Geometrical mean[a]	8,40E+14	1,60E+16	1,62E+13	3,43E+14

[a] The reported data are provided as scientific notation. See B.5.1.

Bibliography

IEC 60050-121, *International Electrotechnical Vocabulary (IEV) – Part 121: Electromagnetism*, available at http://www.electropedia.org

IEC 60893-2, *Industrial rigid laminated sheets based on thermosetting resins for electrical purposes – Part 2: Methods of test*

IEC 61212-2, *Insulating materials – Industrial rigid round laminated tubes and rods based on thermosetting resins for electrical purposes – Part 2: Methods of test*

IEC 62011-2, *Insulating materials – Industrial, rigid, moulded, laminated tubes and rods of rectangular and hexagonal cross-section, based on thermosetting resins for electrical purposes – Part 2: Methods of test*

ISO 48-4, *Rubber, vulcanized or thermoplastics – Determination of hardness – Part 4: Indentation hardness by durometer method (Shore hardness)*

ISO 5725-2, *Accuracy (trueness and precision) of measurement methods and results – Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method*

ISO 10350 (all parts), *Plastics – Acquisition and presentation of comparable single-point data*

ISO 10350-1, *Plastics – Acquisition and presentation of comparable single-point data – Part 1: Moulding materials*

ISO 10350-2, *Plastics – Acquisition and presentation of comparable single-point data – Part 2: Long-fibre-reinforced plastics*

ISO 14526 (all parts), *Plastics – Phenolic powder moulding compounds (PF-PMCs)*

ISO 14527 (all parts), *Plastics – Urea-formaldehyde and urea/melamine-formaldehyde powder moulding compounds (UF- and UF/MF-PMCs)*

ISO 14528 (all parts), *Plastics – Melamine-formaldehyde powder moulding compounds (MF-PMCs)*

ISO 14529 (all parts), *Plastics – Melamine/phenolic powder moulding compounds (MP-PMCs)*

ISO 14530 (all parts), *Plastics – Unsaturated-polyester powder moulding compounds (UP-PMCs)*

ISO 15252 (all parts), *Plastics – Epoxy powder moulding compounds (EP-PMCs)*

ISO 15512, *Plastics – Determination of water content*

EN 14598 (all parts), *Reinforced thermosetting moulding compounds – Specification for Sheet Moulding Compound (SMC) and Bulk Moulding Compound (BMC)*

SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

____

PROPRIÉTÉS DIÉLECTRIQUES ET RÉSISTIVES DES MATÉRIAUX ISOLANTS SOLIDES –

Partie 3-2: Détermination des propriétés résistives (méthodes en courant continu) – Résistance superficielle et résistivité superficielle

AVANT-PROPOS

1) La Commission Électrotechnique Internationale (IEC) est une organisation mondiale de normalisation composée de l'ensemble des comités électrotechniques nationaux (Comités nationaux de l'IEC). L'IEC a pour objet de favoriser la coopération internationale pour toutes les questions de normalisation dans les domaines de l'électricité et de l'électronique. À cet effet, l'IEC – entre autres activités – publie des Normes internationales, des Spécifications techniques, des Rapports techniques, des Spécifications accessibles au public (PAS) et des Guides (ci-après dénommés "Publication(s) de l'IEC"). Leur élaboration est confiée à des comités d'études, aux travaux desquels tout Comité national intéressé par le sujet traité peut participer. Les organisations internationales, gouvernementales et non gouvernementales, en liaison avec l'IEC, participent également aux travaux. L'IEC collabore étroitement avec l'Organisation Internationale de Normalisation (ISO), selon des conditions fixées par accord entre les deux organisations.
2) Les décisions ou accords officiels de l'IEC concernant les questions techniques représentent, dans la mesure du possible, un accord international sur les sujets étudiés, étant donné que les Comités nationaux de l'IEC intéressés sont représentés dans chaque comité d'études.
3) Les Publications de l'IEC se présentent sous la forme de recommandations internationales et sont agréées comme telles par les Comités nationaux de l'IEC. Tous les efforts raisonnables sont entrepris afin que l'IEC s'assure de l'exactitude du contenu technique de ses publications, l'IEC ne peut pas être tenue responsable de l'éventuelle mauvaise utilisation ou interprétation qui en est faite par un quelconque utilisateur final.
4) Dans le but d'encourager l'uniformité internationale, les Comités nationaux de l'IEC s'engagent, dans toute la mesure possible, à appliquer de façon transparente les Publications de l'IEC dans leurs publications nationales et régionales. Toutes divergences entre toutes Publications de l'IEC et toutes publications nationales ou régionales correspondantes doivent être indiquées en termes clairs dans ces dernières.
5) L'IEC elle-même ne fournit aucune attestation de conformité. Des organismes de certification indépendants fournissent des services d'évaluation de conformité et, dans certains secteurs, accèdent aux marques de conformité de l'IEC. L'IEC n'est responsable d'aucun des services effectués par les organismes de certification indépendants.
6) Tous les utilisateurs doivent s'assurer qu'ils sont en possession de la dernière édition de cette publication.
7) Aucune responsabilité ne doit être imputée à l'IEC, à ses administrateurs, employés, auxiliaires ou mandataires, y compris ses experts particuliers et les membres de ses comités d'études et des Comités nationaux de l'IEC, pour tout préjudice causé en cas de dommages corporels et matériels, ou de tout autre dommage de quelque nature que ce soit, directe ou indirecte, ou pour supporter les coûts (y compris les frais de justice) et les dépenses découlant de la publication ou de l'utilisation de cette Publication de l'IEC ou de toute autre Publication de l'IEC, ou au crédit qui lui est accordé.
8) L'attention est attirée sur les références normatives citées dans cette publication. L'utilisation de publications référencées est obligatoire pour une application correcte de la présente publication.
9) L'IEC attire l'attention sur le fait que la mise en application du présent document peut entraîner l'utilisation d'un ou de plusieurs brevets. L'IEC ne prend pas position quant à la preuve, à la validité et à l'applicabilité de tout droit de brevet revendiqué à cet égard. À la date de publication du présent document, l'IEC n'avait pas reçu notification qu'un ou plusieurs brevets pouvaient être nécessaires à sa mise en application. Toutefois, il y a lieu d'avertir les responsables de la mise en application du présent document que des informations plus récentes sont susceptibles de figurer dans la base de données de brevets, disponible à l'adresse https://patents.iec.ch. L'IEC ne saurait être tenue pour responsable de ne pas avoir identifié de tels droits de brevets.

L'IEC 62631-3-2 a été établie par le comité d'études 112 de l'IEC: Évaluation et qualification des systèmes et matériaux d'isolement électrique. Il s'agit d'une Norme internationale.

Cette deuxième édition annule et remplace la première édition parue en 2015. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

a) les descriptions relatives aux montages d'électrodes ont été clarifiées;
b) de nouvelles descriptions ont été ajoutées pour les matériaux conducteurs;
c) une nouvelle Annexe B informative a été ajoutée; elle récapitule les résultats de l'étude de vérification comparative sur les résistivités superficielles effectuée avec différents montages d'électrodes.

Le texte de cette Norme internationale est issu des documents suivants:

Projet	Rapport de vote
112/612/FDIS	112/619/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à son approbation.

La langue employée pour l'élaboration de cette Norme internationale est l'anglais.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2, il a été développé selon les Directives ISO/IEC, Partie 1 et les Directives ISO/IEC, Supplément IEC, disponibles sous www.iec.ch/members_experts/refdocs. Les principaux types de documents développés par l'IEC sont décrits plus en détail sous www.iec.ch/publications.

Une liste de toutes les parties de la série IEC 62631, publiées sous le titre général *Propriétés diélectriques et résistives des matériaux isolants solides*, se trouve sur le site web de l'IEC.

Le comité a décidé que le contenu de ce document ne sera pas modifié avant la date de stabilité indiquée sur le site web de l'IEC sous webstore.iec.ch dans les données relatives au document recherché. À cette date, le document sera

- reconduit,
- supprimé, ou
- révisé.

IMPORTANT – Le logo "colour inside" qui se trouve sur la page de couverture de ce document indique qu'il contient des couleurs qui sont considérées comme utiles à une bonne compréhension de son contenu. Les utilisateurs devraient, par conséquent, imprimer ce document en utilisant une imprimante couleur.

PROPRIÉTÉS DIÉLECTRIQUES ET RÉSISTIVES DES MATÉRIAUX ISOLANTS SOLIDES –

Partie 3-2: Détermination des propriétés résistives (méthodes en courant continu) – Résistance superficielle et résistivité superficielle

1 Domaine d'application

La présente partie de l'IEC 62631 décrit les méthodes d'essai pour déterminer la résistance superficielle et la résistivité superficielle de matériaux isolants électriques par application d'une tension continue.

2 Références normatives

Les documents suivants sont cités dans le texte de sorte qu'ils constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60212, *Conditions normales à observer avant et pendant les essais de matériaux isolants électriques solides*

IEC 62631-3-1, *Propriétés diélectriques et résistives des matériaux isolants solides – Partie 3-1: Détermination des propriétés résistives (méthodes en courant continu) – Résistance volumique et résistivité volumique – Méthode générale*

IEC 62631-3-3, *Propriétés diélectriques et résistives des matériaux isolants solides – Partie 3-3: Détermination des propriétés résistives (méthodes en courant continu) – Résistance d'isolement*

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions suivants s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse https://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse https://www.iso.org/obp

3.1
montage d'électrodes
corps électriquement conducteurs placés sur la surface d'une éprouvette

Note 1 à l'article: Il convient que le montage d'électrodes comporte des procédures afin d'assurer un contact suffisant avec la surface (au moyen d'une peinture conductrice, par exemple) ou l'utilisation d'un système mécanique approprié qui applique la force de contact nécessaire sur la surface de l'éprouvette, ou les deux.

3.1.1
électrode annulaire
électrode plane circulaire centrale entourée d'une électrode en anneau, espacées l'une de l'autre

VOIR: Figure 3.

Note 1 à l'article: Les systèmes d'électrodes de garde décrits dans l'IEC 62321-3-1 ont une forme similaire. Dans le cas de la résistance superficielle, l'électrode en anneau n'assure pas la fonction de garde. Toutefois, la fonctionnalité de garde est assurée par l'électrode opposée.

3.1.2
électrode en forme de lignes
montage d'électrodes constitué de deux lignes parallèles, espacées et appliquées sur la surface de l'éprouvette à l'aide d'un matériau conducteur

VOIR: Figure 2.

3.1.3
électrode à lame souple
système d'électrodes en forme de lignes constitué de deux lignes parallèles de lames conductrices souples à bords nets et espacées

VOIR: Figure 1.

3.2
résistance mesurée
rapport entre une tension continue appliquée à un montage d'électrodes en contact avec une éprouvette et le courant qui traverse les électrodes mesuré avec une précision suffisante

Note 1 à l'article: Un montage d'électrodes à trois bornes peut être utilisé pour exclure les courants indésirables qui traversent le volume à partir de la détermination de la résistance mesurée.

Note 2 à l'article: Un pont de Wheatstone peut également être utilisé pour comparer la résistance mesurée à une résistance normalisée. Toutefois, les ponts de Wheatstone ne sont plus couramment utilisés.

Note 3 à l'article: Conformément à l'IEC 60050-121: Électromagnétisme, la "conductivité" (IEV 121-12-03) est définie comme "la grandeur scalaire ou tensorielle dont le produit par le champ électrique dans un milieu est égal à la densité de courant électrique" et la "résistivité" (IEV 121-12-04) est définie comme "l'inverse de la conductivité lorsque cet inverse existe". Mesurée ainsi, la résistivité superficielle intègre différents chemins de conduction électrique à la surface du matériau ou dans son volume proche, avec la présence éventuelle d'hétérogénéités; elle comprend l'effet d'éventuels phénomènes de polarisation au niveau des électrodes. Par conséquent, elle est considérée comme une valeur moyenne.

3.3
résistance superficielle
R_S
résistance mesurée entre n'importe quel montage d'électrodes défini dans l'IEC 62361-3-2

Note 1 à l'article: Selon le montage d'électrodes utilisé, elle s'appelle R_{SA}, R_{SB}, R_{SC}, R_{SD} ou R_{SE}, où la résistance superficielle R_S est exprimée en Ω.

Note 2 à l'article: Une partie indéterminable de la résistance à l'intérieur du matériau est également incluse dans la résistance superficielle pendant les mesurages de cette résistance.

3.4
R_{SC}
résistance superficielle entre des électrodes annulaires
résistance mesurée entre la surface circulaire intérieure d'un système d'électrodes annulaires et l'électrode circulaire en anneau extérieure

3.5
R_{SD}
résistance superficielle entre des électrodes en forme de lignes
résistance mesurée entre des électrodes en forme de lignes

3.6
R_{SE}
résistance superficielle entre des électrodes en forme de lignes pour petites plaques
résistance mesurée entre des électrodes en forme de lignes pour petites plaques

3.7
R_{SB}
résistance superficielle entre des électrodes en forme de petites lignes
résistance mesurée entre des électrodes en forme de petites lignes

3.8
R_{SA}
résistance superficielle entre des électrodes à lame souple
résistance mesurée entre des électrodes à lame souple

3.9
résistivité superficielle
σ/carré
résistance superficielle ramenée à un carré

Note 1 à l'article: La valeur numérique de la résistivité superficielle est indépendante de la taille du carré.

Note 2 à l'article: Les résistances superficielles R_{SA}, R_{SB}, R_{SC}, R_{SD} et R_{SE} rapportées par carré sont exprimées respectivement par σ_A, σ_B, σ_C, σ_D et σ_E.

Note 3 à l'article: La résistivité superficielle est souvent exprimée en Ω par carré, unité non normalisée, pour indiquer que les dimensions de l'électrode ont été prises en compte en calculant la valeur spécifique.

Note 4 à l'article: La résistivité superficielle est souvent utilisée pour comparer un type de surface caractéristique d'un matériau échantillon à ceux d'autres matériaux. Elle peut être comparée pour des matériaux uniquement si des électrodes de dimensions normalisées identiques sont utilisées. Les dimensions recommandées sont données au 5.3.

4 Signification

Des matériaux isolants sont en général utilisés pour isoler électriquement les composants d'un système électrique les uns par rapport aux autres et par rapport à la terre. Des matériaux isolants solides peuvent également servir de support mécanique. Pour cette utilisation, il est généralement souhaitable que la résistance d'isolement soit aussi élevée que possible et qu'elle présente des propriétés mécaniques, chimiques et de résistance à la chaleur acceptables.

Comme la résistance volumique, la résistance superficielle fait partie de la résistance d'isolement.

La résistance d'isolement doit être déterminée conformément à l'IEC 62631-3-3 et la résistance volumique conformément à l'IEC 62631-3-1.

La résistance superficielle fournit des informations sur les résistances électriques de la surface des matériaux et des produits. Toutefois, la résistance superficielle, pour sa majeure partie, ne constitue pas une propriété des matériaux. La résistance superficielle dépend principalement des paramètres de fabrication, des conditions d'environnement, des phénomènes de vieillissement de la surface, de la pollution, etc.

NOTE En fonction de l'application spécifique, différents montages d'électrodes peuvent être privilégiés.

5 Méthode d'essai

5.1 Généralités

Cette méthode générale décrit des valeurs courantes pour les mesurages d'ordre général. Si le présent document décrit une méthode pour un type de matériau spécifique, la méthode spécifique doit alors être utilisée.

Différents types d'électrodes peuvent être utilisés en fonction des mesurages spécifiques ou des besoins du produit. Par exemple, une électrode en forme de petites lignes peut être avantageuse sur des surfaces incurvées. Les électrodes à lame souple permettent de réaliser des mesurages en appliquant moins de contraintes sur les produits et conviennent mieux aux matériaux conditionnés avant l'essai. Sauf indication contraire dans une norme de produit, le montage d'électrodes doit être choisi en fonction de l'application type.

Si des éprouvettes sont constituées de matériaux (caoutchouc tendre, par exemple) dont les dimensions varient de manière significative sous l'effet de la force appliquée par les électrodes, ces électrodes ne sont pas appropriées et un autre montage doit être utilisé.

En l'absence d'informations sur l'application, il est recommandé d'utiliser des électrodes en forme de petites lignes (R_{SB}).

5.2 Tension

Il convient que la tension de mesure soit préférentiellement de 10 V, 100 V, 500 V, 1 000 V, 10 000 V.

Sauf spécification contraire dans la norme de produit applicable, une tension de 100 V doit être utilisée.

Les comités d'études doivent spécifier la tension d'essai préférentielle lorsqu'ils font référence au présent document.

NOTE 1 Les décharges partielles peuvent fausser les mesures lorsqu'une tension de seuil spécifique est dépassée. Dans l'air, aucune décharge partielle ne se produit au-dessous de 340 V.

NOTE 2 L'ondulation de la source de tension est importante. Une valeur type pour 100 V est $< 5 \times 10^{-5}$ crête à crête.

5.3 Matériel

5.3.1 Généralités

Il convient de veiller à ce que la résistance superficielle ne soit pas perturbée par des résistances parasites parallèles au montage d'électrodes, par exemple la résistance des supports d'essai ou de l'isolation des câbles.

Pour éviter les erreurs de mesure sur des résistances mesurées supérieures à 10^{10} Ω, des câbles blindés et des armoires de mesure blindées doivent être utilisés.

Différents montages d'électrodes peuvent être utilisés pour déterminer la résistance superficielle et la résistivité superficielle. L'évaluation de la résistivité superficielle dépend du montage d'électrodes choisi.

NOTE La comparaison des résultats mesurés ne peut être effectuée qu'entre des mesures obtenues à l'aide des mêmes montages d'électrodes et matériaux conducteurs.

5.3.2 Exactitude

Tout matériel approprié peut être utilisé. Le dispositif de mesure doit être capable de déterminer la résistance inconnue avec une exactitude d'au moins:

- ±10 % pour des résistances inférieures à 10^{10} Ω;
- ±20 % pour des résistances comprises entre 10^{10} Ω et 10^{14} Ω; et
- ±50 % pour des résistances supérieures à 10^{14} Ω.

NOTE Les exactitudes indiquées ont été confirmées par les résultats d'essai interlaboratoires donnés à l'Annexe B.

5.3.3 Source de tension

Une source de tension continue stable est exigée. Cette condition peut être réalisée par l'emploi de piles ou d'une alimentation redressée et stabilisée. Le degré de stabilité exigé est tel que la variation de courant liée aux variations de tension reste négligeable par rapport au courant à mesurer.

5.3.4 Montages d'électrodes

5.3.4.1 Généralités

Les montages d'électrodes sont constitués d'une combinaison d'électrodes et de matériaux conducteurs. Les matériaux conducteurs doivent être appliqués sur l'éprouvette avant d'effectuer les mesurages. Pour les besoins des mesurages, les électrodes sont ensuite placées en contact avec les matériaux conducteurs appliqués sur l'éprouvette.

NOTE L'Annexe B contient les résultats de l'étude de vérification comparative sur les résistivités superficielles effectuée avec différents montages d'électrodes.

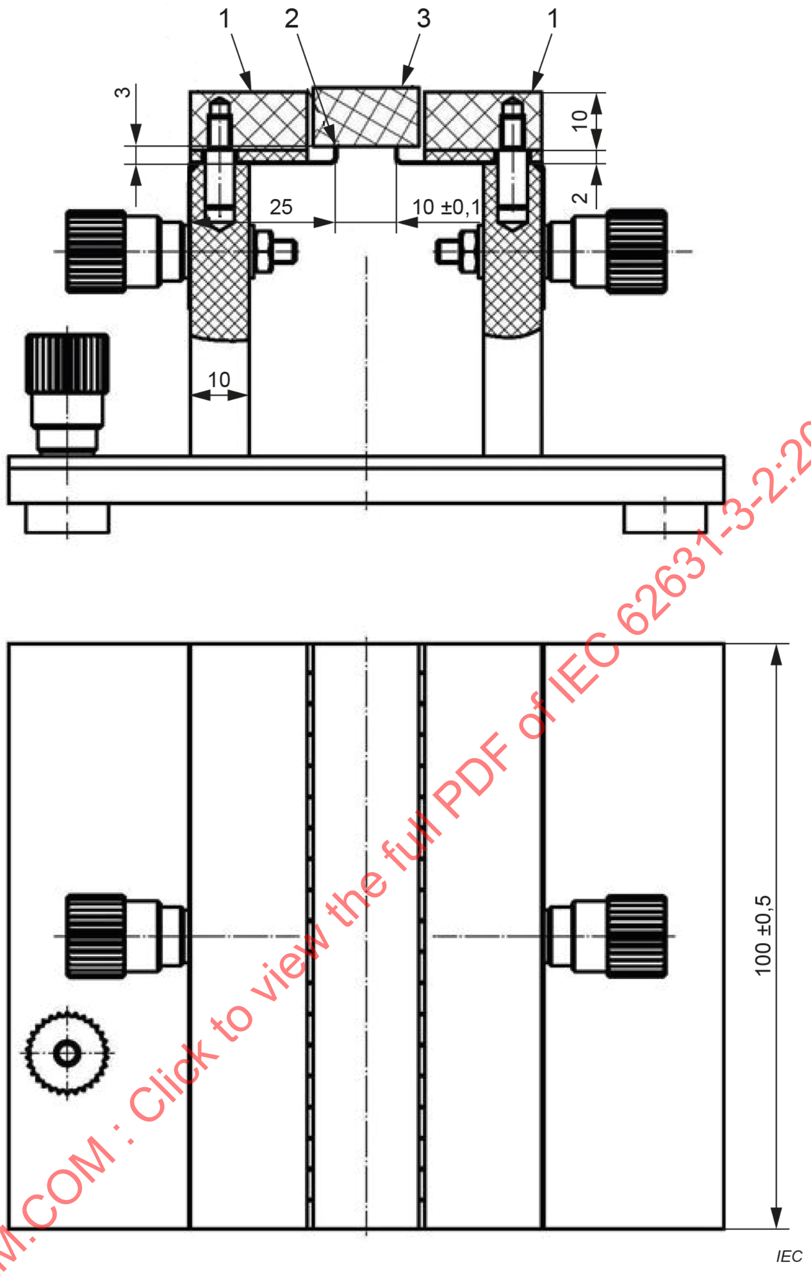
5.3.4.2 Montage d'électrodes A – Électrodes à lame souple

Le montage d'électrodes A doit être constitué de deux bords métalliques tranchants souples d'une longueur de 100 mm avec un espacement de 10 mm, comme cela est représenté à la Figure 1.

Aucune électrode de garde n'est utilisée. Les bords métalliques tranchants doivent être constitués de lames souples placées les unes à côté des autres, espacées d'environ 0,3 mm, d'une longueur inférieure ou égale à 5,0 mm et d'une épaisseur égale à 0,3 mm. La force de contact doit être suffisamment élevée afin que toutes les lames ou tous les segments reposent sur la surface de l'éprouvette, sans l'endommager.

La pièce de métal qui exerce la force de contact doit être recouverte d'une isolation de haute qualité aux emplacements où elle est en contact avec l'éprouvette.

Dimensions en millimètres



Légende

1 barre de guidage (amovible)

2 bords métalliques tranchants

3 éprouvette

Figure 1 – Montage d'électrodes A (exemple)

5.3.4.3 Montage d'électrodes B – Électrodes en forme de petites lignes

Le montage d'électrodes B doit être constitué de deux bornes collectrices en mettant les lames conductrices en contact avec les matériaux conducteurs sur l'éprouvette, comme cela est représenté à la Figure 2. Aucune électrode de garde n'est utilisée.

Pour les besoins du montage d'électrodes B, les matériaux conducteurs doivent être appliqués sous forme de deux lignes d'une largeur de 1,5 mm et d'une longueur de 25,0 mm, avec un espacement de 2,0 mm. Les lignes doivent être appliquées avant le conditionnement.

Les types de matériaux conducteurs et leurs applications sont décrits au 5.6.4.

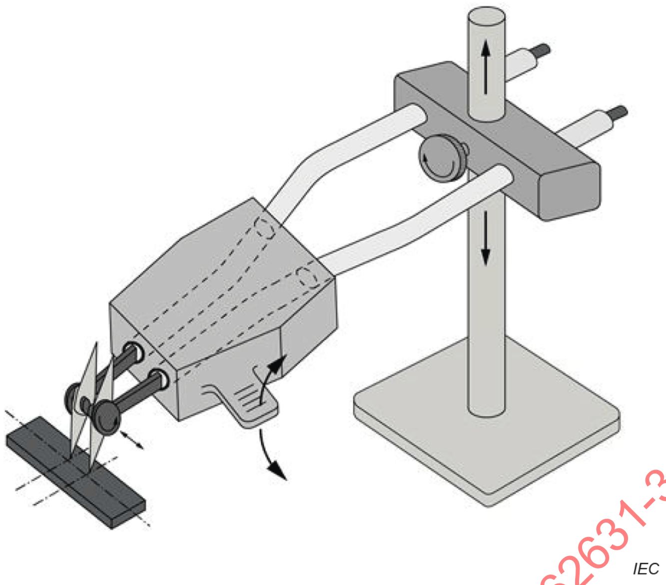
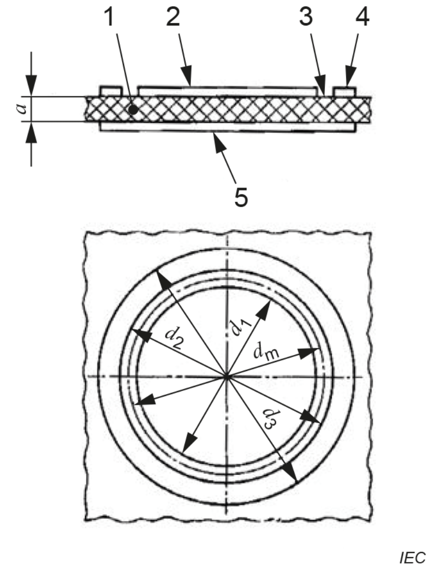


Figure 2 – Montage d'électrodes B (exemple)

5.3.4.4 Montage d'électrodes C – Électrodes annulaires

Le montage d'électrodes C est constitué d'un système d'électrodes à trois bornes, comme cela est représenté à la Figure 3. Les électrodes annulaires sont appliquées sur un côté de l'éprouvette. Une électrode de garde, de dimensions au moins égales à la surface recouverte par les électrodes correspondantes, doit être placée sur la surface opposée de l'éprouvette.



Légende

1 éprouvette
2 électrode 1
3 zone de mesure
4 électrode 2
5 électrode 3 (électrode de garde)
a épaisseur de l'éprouvette
d_1 diamètre de l'électrode 1
d_2 diamètre intérieur de l'électrode 2
d_3 diamètre extérieur de l'électrode 2
d_m diamètre médian de la zone de mesure

Figure 3 – Montage d'électrodes C (exemple)

Sauf spécification contraire dans la norme de produit applicable, toutes les dimensions d'électrodes peuvent être utilisées. Le Tableau 1 fournit des dimensions d'électrodes types. Pour les essais comparatifs, le montage d'électrodes C1 est recommandé.

Tableau 1 – Dimensions d'électrodes types pour le montage d'électrodes C

Montage d'électrodes	d_1 mm	d_2 mm	d_3 mm
C1	50	60	80
C2	76	88	100
C3	25	38	50

Avec le montage d'électrodes C, la résistance superficielle doit être mesurée entre l'électrode 1 et l'électrode 2. L'électrode 3 doit être reliée à la terre.

L'un ou l'autre des matériaux conducteurs décrits au 5.6.4 doit être placé ou peint sur les surfaces, où sont placées les électrodes 1, 2 et 3. Les matériaux conducteurs ne doivent pas être appliqués sur la surface entre l'électrode 1 et l'électrode 2.

NOTE Dans le cas de matériaux de conductivité limitée et occasionnellement de films d'une épaisseur ≤ 10 µm, la résistance d'entrée de l'ampèremètre est significativement inférieure à la résistance volumique de l'éprouvette.

5.3.4.5 Montage d'électrodes D – Électrodes en forme de lignes

Le montage d'électrodes D doit être constitué de deux bornes collectrices en mettant les lames conductrices en contact avec les matériaux conducteurs sur l'éprouvette, comme cela est représenté à la Figure 2. Aucune électrode de garde n'est utilisée.

Pour les besoins du montage d'électrodes D, les matériaux conducteurs doivent être appliqués sous forme de deux lignes parallèles d'une largeur de 1,5 mm et d'une longueur de (100,0 ± 1,0) mm avec un espacement de (10,0 ± 0,5) mm. Ces matériaux peuvent être appliqués avant le traitement.

Les types de matériaux conducteurs et leurs applications sont décrits au 5.6.4.

5.3.4.6 Montage d'électrodes E – Électrodes en forme de lignes pour petites plaques

Le montage d'électrodes E est constitué de trois bornes collectrices, comme cela est représenté à la Figure 4, point B).

Pour les besoins du montage d'électrodes E, les matériaux conducteurs doivent être appliqués sous forme de deux lignes parallèles d'une largeur de 1,0 mm à 2,0 mm et d'une longueur de (50,0 ± 1,0) mm avec un espacement de (5,0 ± 0,5) mm. Ces matériaux peuvent être appliqués avant de conditionner l'éprouvette.

Une électrode de garde, de dimensions au moins égales à la surface recouverte par les électrodes correspondantes, doit être placée sur la surface opposée de l'éprouvette.

Les types de matériaux conducteurs et leurs applications sont décrits au 5.6.4.

NOTE L'Annexe A fournit des exemples de combinaisons possibles pour les types d'électrodes et les dimensions d'éprouvettes.

5.4 Circuit d'essai

Selon le montage d'électrodes choisi, des mesurages à deux ou trois bornes doivent être effectués (voir la Figure 4).

Dans le cas des électrodes annulaires (montage d'électrodes C) et du montage d'électrodes en forme de lignes E, un circuit d'essai à trois bornes est nécessaire, car une électrode de protection reliée à la terre est obligatoire.

Pour tous les autres montages d'électrodes en forme de lignes (A, B et D), un circuit d'essai à deux bornes doit être utilisé.