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INTERNATIONAL STANDARD

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Dielectric and resistive properties of solid insulating materials – Part 2-1: Relative permittivity and dissipation factor – Technical frequencies (0,1 Hz to 10 MHz) – AC methods

Propriétés diélectriques et résistives des matériaux isolants solides – Partie 2-1: Permittivité relative et facteur de dissipation – Fréquences techniques (0,1 Hz à 10 MHz) – Méthodes en courant alternatif

IEC 62631-2-1:2018-02(en-fr)

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International Standard IEC 62631-2-1 has been prepared by IEC technical committee 112: Evaluation and qualification of electrical insulating materials and systems.

This first edition cancels and replaces the first edition IEC 60250, published in 1969. This edition constitutes a technical revision.

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

a) technical frequencies confined to AC methods;
b) update on measurements on solid dielectric materials.

The text of this standard is based on the following documents:

FDIS	Report on voting
112/412/FDIS	112/417/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

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 publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

Tan δ, also called loss tangent, or dissipation factor is a basic parameter for the quality of insulating materials. The measurement of capacitance and loss angle is a classical method well established in the industry over 100 years.

The dissipation factor (tan δ) is dependent on several parameters, such as electrode design, material characteristics, environmental issues, moisture, temperature, voltage applied, and highly dependent on frequencies, the accuracy of measuring apparatus and other parameters applied to the measured specimen.

The frequency range is limited, depending on the test cell and electrode design, the dimension of the samples and connection leads. In this standard the parameters for the frequencies applied are therefore limited in the range of very low frequency (VLF) from less than 1 Hz and up to 10 MHz. However, measuring instruments can provide a broader frequency range, whereby the usable and suitable frequency range is limited by the whole test setup.

DIELECTRIC AND RESISTIVE PROPERTIES OF SOLID INSULATING MATERIALS –

Part 2-1: Relative permittivity and dissipation factor – Technical frequencies (0,1 Hz to 10 MHz) – AC methods

1 Scope

This part of IEC 62631 describes test methods for the determination of permittivity and dissipation factor properties of solid insulating materials (AC methods from 0,1 Hz up to 10 MHz).

NOTE This part of the standard mainly considers measuring setups with guard-electrodes.

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*

ISO 4593, *Plastics – Film and sheeting – Determination of thickness by mechanical scanning*

3 Terms and definitions

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

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

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

3.1
electrical insulating material
solid with negligibly low electric conductivity, used to separate conducting parts at different electrical potentials

Note 1 to entry: The term "electrical insulating material" is sometimes used in a broader sense to designate also insulating liquids and gases. Insulating liquids are covered by IEC 60247.

3.2
dielectric properties
comprehensive behaviour of an insulating material measured with AC comprising the capacitance, absolute permittivity, relative permittivity, relative complex permittivity, dielectric dissipation factor

3.3
absolute permittivity
electric flux density divided by the electric field strength

3.4
relative permittivity
ratio of the absolute permittivity to the permittivity of a vacuum ε_0

3.5
relative complex permittivity
permittivity in a complex number representation, under steady sinusoidal field conditions

3.6
dielectric dissipation factor tan δ (loss tangent)
numerical value of the ratio of the imaginary to the real part of the complex permittivity

3.7
capacitance *C*
property of an arrangement of conductors and dielectrics which permits the storage of electrical charge when a potential difference exists between the conductors

3.8
voltage application
application of a voltage between electrodes

Note 1 to entry: Voltage application is sometimes referred to as electrification.

3.9
measuring electrodes
conductors applied to, or embedded in, a material to make contact with it to measure its dielectric or resistive properties

Note 1 to entry: The design of the measuring electrodes depends on the specimen and the purpose of the test.

4 Method of test

4.1 General theory

The measured permittivity (formerly known as dielectric constant) ε of an insulating material is the product of its relative permittivity ε_r and the permittivity of a vacuum ε_0:

$$\varepsilon = \varepsilon_0 \cdot \varepsilon_r \qquad (1)$$

The permittivity is expressed in farad per meter (F/m); the permittivity of vacuum ε_0 has the following value:

$$\varepsilon_0 = 8{,}854187817 \cdot 10^{-12}\ \frac{\text{F}}{\text{m}} \qquad (2)$$

Relative permittivity is the ratio of the absolute permittivity to the permittivity of a vacuum ε_0.

In the case of constant fields and alternating fields of sufficiently low frequency the relative permittivity of an isotropic or quasi-isotropic dielectric is equal to the ratio of the capacitance of a capacitor, in which the space between and around the electrodes is entirely and exclusively filled with the dielectric, to the capacitance of the same configuration of electrodes in vacuum.

In practical engineering it is usual to employ the term permittivity when referring to relative permittivity. The relative permittivity ε_r of an insulating material is the quotient of capacitance C_x of a capacitive test specimen (capacitor), in which the space between the two electrodes is entirely and exclusively filled with the insulating material in question, and the capacitance C_0 of the same configuration of electrodes in vacuum:

$$\varepsilon_r = \frac{C_x}{C_0} \tag{3}$$

The relative permittivity ε_r of dry air free from carbon dioxide, at normal atmospheric pressure in Pa, equals 100053 Pa, so that in practice, the capacitances C_a of the configuration of electrodes in air can normally be used instead of C_0 to determine the relative permittivity ε_r with sufficient accuracy.

Relative complex permittivity is permittivity in a complex number representation under steady sinusoidal field conditions expressed as

$$\underline{\varepsilon}_r = \varepsilon_r' - j\varepsilon_r'' = \cdot\varepsilon_r \cdot e^{-j\delta} \tag{4}$$

where ε'_r and ε''_r have positive values.

NOTE 1 The complex permittivity $\underline{\varepsilon}_r$ is customarily quoted either in terms of ε'_r and ε''_r, or in terms of ε_r and tan δ. If $\varepsilon'_r > \varepsilon''_r$ then $\varepsilon_r \approx \varepsilon'_r$ which are both called relative permittivity.

NOTE 2 ε''_r is termed loss index.

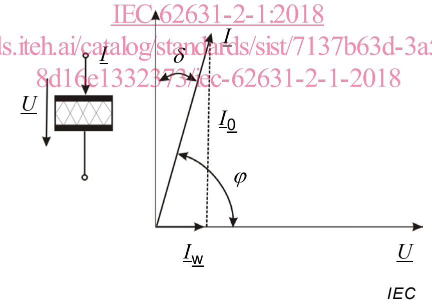


Figure 1 – Dielectric dissipation factor

The dielectric dissipation factor tan δ (loss tangent) is the numerical value of the ratio of the imaginary to the real part of the complex permittivity.

$$\tan\delta = \frac{\varepsilon_r''}{\varepsilon_r'} \tag{5}$$

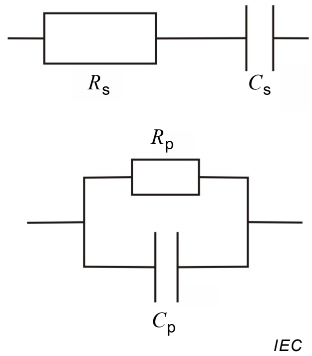


Figure 2 – Equivalent circuit diagrams

Thus, the dielectric dissipation factor tan δ of an insulating material is the tangent of the angle δ by which the phase difference φ between the applied voltage and the resulting current deviates from $\pi/2$ rad when the solid insulating material is exclusively used as dielectric in a capacitive test specimen (capacitor) (compare with Figure 1). The dielectric dissipation factor can also be expressed by an equivalent circuit diagram using an ideal capacitor with a resistor in series or parallel connection (see Figure 2).

$$\tan\delta = \omega C_s \cdot R_s = \frac{1}{\omega C_p \cdot R_p} \tag{6}$$

with

$$\frac{C_p}{C_s} = \frac{1}{1+\tan^2\delta} \tag{7}$$

and

$$\frac{R_p}{R_s} = 1 + \frac{1}{\tan^2\delta} \tag{8}$$

NOTE 3 R_S and R_P respectively are not directly related to but affected by the volume and the surface resistance of an insulating material. Therefore the dielectric dissipation factor may also be affected by these resistive materials properties.

Capacitance C is the property of an arrangement of conductors and dielectrics which permits the storage of electrical charge when a potential difference exists between the conductors.

C is the ratio of a quantity q of charge to a potential difference U. A capacitance value is always positive. The unit is farad when the charge is expressed in coulomb and the potential in volts.

$$C = \frac{q}{U} \tag{9}$$

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

The measurement of permittivity and dielectric dissipation factor is to be done carefully and under consideration of the electric properties of the measuring circuit as well as the specific electric properties of the material.

NOTE 4 To carry out the test, in most cases the use of high voltage is necessary. Care shall be taken to prevent from electric shock.

The basic principles of apparatus and methods are not described here. Some references to the literature is given in the bibliography.

4.2 Power supply (voltage)

The power source shall provide a stable sinusoidal voltage. For the measuring duration the measured value of the supplied voltage shall be maintained within ± 5 %.

The voltage wave shape shall approximate to a sinusoid with the difference of the magnitudes of the positive and negative peak values being less than 2 %.

The deviation of the sinusoidal shape (the ratio of peak to *r.m.s.* values equals $\sqrt{2}$) shall be within ± 5 %.

Preferred voltages are 0,1 V; 0,5 V; 10 V; 100 V; 500 V; 1 000 V; 2 000 V.

Higher voltages may be applicable in order to perform tests at operating field strength. Other voltage levels shall be documented in the report.

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

4.3 Equipment

4.3.1 Accuracy

The measuring device should be capable of determining the unknown permittivity and dielectric dissipation factor in accordance with the expected material properties. The accuracy of the measuring system must be documented in the report.

NOTE The user can choose the measuring system accuracy according to the requirements of the measuring results.

4.3.2 Choice of measuring methods

4.3.2.1 General

Methods for measuring the permittivity and dissipation factor can be divided into three groups:

- null method
- impedance analyser method
- digital phase shift method

4.3.2.2 Null method

For measurements of permittivity and dissipation factor, substitution techniques can be used that is, the bridge is balanced by adjustment mainly in one arm of the network, with and without the specimen connected. The networks normally used are the Schering bridge, the transformer bridge (i.e. a bridge with ratio arms coupled by mutual inductance) and the parallel-T. The transformer bridge has the advantage of allowing the use of a guard electrode without any additional components or operations; it has no disadvantages in comparison with the other networks.

4.3.2.3 Impedance analyser method

There exist a lot of commercially available instruments (impedance analyzers or LCR meters). These instruments determine the impedance of the specimen as the ratio of the measured vector of voltage and current. The vector is the value of the magnitude and a phase. Typically, the impedance is determined at one or more fixed frequencies or as a sweep over a frequency range.

Most instruments allow to express the impedance as a loss capacitance (C, tan δ or D) using either a serial or a parallel equivalent circuit for a given frequency. For the purposes of this International Standard the parallel equivalent circuit is to be used.

Care should be taken that the influence of cables is to be compensated in a correct manner. For this reason typically an OPEN and SHORT compensation of the measuring circuit is to be done and in some cases also LOAD compensation. Irregular compensation will lead to erroneous measurements.

Precision of impedance analysers depends on the instruments quality itself but may also strongly depend on the magnitude of the measured impedance (capacity) and on frequency. Any instrument can be used. However, the precision of the instrument shall be appropriate for the material under test and is to be stated in the test report.

4.3.2.4 Digital phase shift method

The measuring principle is based on precise recording of the currents through the standard capacitor (reference) and the test object path, with the voltage as a reference phase shift marker. The dielectric dissipation factor is calculated by measurement of the phase shift between these currents.

The measurement of sinusoidal-wave current and voltage in both voltage paths with amplitude and time precision is provided by high precision analogue to digital conversion simultaneously. Harmonics and external noise at current and voltage sinusoidal-wave may be suppressed with digital filtering, for example Fast Fourier Transformation (FFT) in the time or frequency domain. The dissipation factor tan δ and capacitance C_x are calculated based on phase shift and amplitude information extracted from the digital current measurement.

To reach a required precision tan $\delta \leq 1{,}10^{-4}$ of the test results, the A/D converter should have a resolution of ≥ 16 bit.

Due to safety reasons it is recommended to decouple the measuring devices, which are placed in the voltage area, from the control unit for the operator, for example fibre optics.

4.3.3 Measurement setup with applied electrodes to the material

4.3.3.1 General

The electrodes for insulating materials should be of a material that is readily applied, that allows intimate contact with the specimen surface and introduces no appreciable error because of electrode resistance or contamination of the specimen. The electrode material should be corrosion resistant under the conditions of the test. The electrodes shall be used with suitable backing plates of given form and dimensions. It may be advantageous to use two different electrode materials or two methods of application to see if significant error is introduced.

The measurement of the dimensions of the electrode shall be according to ISO 4593.

NOTE The accuracy of the measurement of the dimensions of the electrode is directly related to the accuracy of the expected test result.

The mechanical force, which is applied by the fixture electrode to the specimen, should be approximately 1 Pa for pressure sensitive test specimen. Other electrode forces are possible and shall be documented in the test report. The mechanical electrode force should not overstress the test specimen.

4.3.3.2 Guarding

The insulation of the measuring circuit is composed of materials which, at best, have properties comparable with those of the material under test. Errors in the measurement of the specimen may arise from:

- edge effects of the electrical field which influence the measured capacity
- the surface resistance which may influence the dielectric dissipation factor, especially at low frequencies

A satisfactory correction is obtained by using the technique of guarding.

The guard conductors are connected together, constituting the guard system and forming with the measuring terminals a three-terminal network. The basic connections for guarded electrodes used for measurement of permittivity and dielectric dissipation factor are shown in Figure 3.

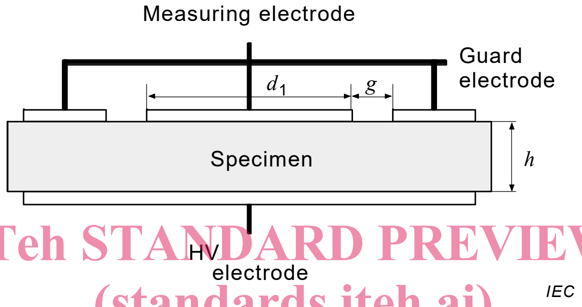


Figure 3 – Cylindrical electrode with guard ring for plate designed specimen

The surface area A (in mm^2) defined in Equation (10), is $\pi/4$ multiplied by square of the sum of electrode diameter d_1 and gap space g.

$$A = \frac{\pi}{4}(d_1 + B \cdot g)^2 \tag{10}$$

$$e_{\%} = \frac{A_{B=1} - A_{B\neq1}}{A_{B\neq1}} \cdot 100\% \tag{11}$$

The factor B is a function of the ratio of the gap and thickness of the specimen and of the dielectric constant. Equation (10) assumes a relative permittivity of $\varepsilon_r \to \infty$. Equation (11) represents the possible error of the effective area, neglecting the factor B.

The specimen with its own electrodes shall then be mounted between metal backing electrodes, these being slightly smaller than the specimen electrodes. The equations for computing the capacitance of different arrangements of disk-shaped or cylindrical electrodes as well as empirical equations for computing the edge capacitance correction for this condition are given in Annex A.

4.3.3.3 Conductive silver paint

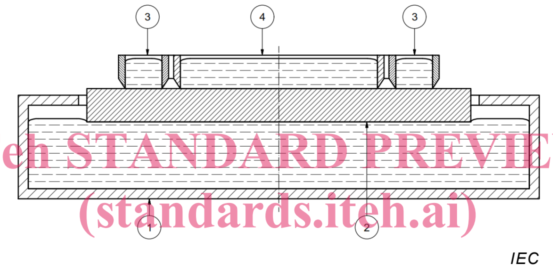
Certain types of commercially available, high-conductivity silver paints, either air-drying or low-temperature-baking varieties, are sufficiently porous to permit diffusion of moisture through them and thereby allow the test specimen to be conditioned after application of the electrodes. This is a particularly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

4.3.3.4 Evaporated or sputtered metal

Evaporated or sputtered metal can be used where it can be shown that the material is not affected by ion bombardment, temperature stress or vacuum treatment.

4.3.3.5 Liquid electrodes

Liquid electrodes can be used and give satisfactory results. The liquid forming the upper electrode should be confined, for example, by stainless steel rings, each of which should have its lower rim reduced to a sharp edge by bevelling on the side away from the liquid. Figure 4, shows the electrode arrangement. Alloys containing for example gallium, indium and tin, which are liquid at room temperature, have been proved as suitable. Mercury is not recommended.



Legend:

1 Test voltage electrode

2 Specimen

3 Guard electrode

4 Measurement electrode

Figure 4 – Specimen with liquid electrodes

4.3.3.6 Metal foil

Aluminum and tin foil are in common use. They are usually attached to the specimen by a minimum quantity of petrolatum, silicone grease, oil or other suitable material, as an adhesive.

All adhesive materials may be of influence on the measurement results and should be minimized.

NOTE Silicon grease with a sufficient low dielectric loss has been found suitable.

4.3.3.7 Tube specimen

The most appropriate electrode system for a tube specimen will depend on its permittivity, wall thickness, diameter, and the accuracy of measurement required. In general, the electrode system shall consist of an inner electrode and a somewhat narrower outer electrode, with a guard electrode at each end. The gap between the outer and guard electrodes shall be small compared with the thickness of the tube wall. For tube specimen of small and medium diameters, three bands of foil or deposited metal can be applied to the outside of the tube, the centre band serving as the working outer electrode with the two bands of foil or deposited metal, one on each side, serving as guard electrodes. Inner electrodes of liquid metal, deposited metal film or a tightly fitting mandrel may be used.