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INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Measurement of internal electric field in insulating materials – Pressure wave propagation method

Mesurage du champ électrique interne dans les matériaux isolants – Méthode de l'onde de pression

IEC 62836:2024-02(en-fr)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMISSION ELECTROTECHNIQUE INTERNATIONALE

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

MEASUREMENT OF INTERNAL ELECTRIC FIELD IN INSULATING MATERIALS – PRESSURE WAVE PROPAGATION METHOD

FOREWORD

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IEC 62836 has been prepared by IEC technical committee 112: Evaluation and qualification of electrical insulating materials and systems. It is an International Standard.

This first edition cancels and replaces IEC TS 62836 published in 2020.

This edition includes the following significant technical changes with respect to IEC TS 62836:

a) addition of Clause 12 for the measurement of space charge distribution in a planar sample;
b) addition of Clause 13 for coaxial geometry samples;
c) addition of Annex D with measurement examples for coaxial geometry samples;
d) addition of a Bibliography;
e) measurement examples for a planar sample have been moved from Clause 12 in IEC TS 62836 to Annex C.

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

Draft	Report on voting
112/627/FDIS	112/632/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.

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- withdrawn, or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.

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INTRODUCTION

High-voltage insulating structures, especially high-voltage DC cables and capacitors etc., are subjected to charge accumulation and this can lead to electrical breakdown if the electric field produced by the charges exceeds the electrical breakdown threshold. With the trend to multiply power plants, especially green power plants such as wind or solar generators, more cables will be used for connecting these power plants to the grid and share the electric energy between countries. Therefore, a standardized procedure for testing how the internal electric field can be characterized has become essential for the materials used for the cables, and even the structure of these cables when considering electrodes or the junction between cables. The measurement of the internal electric field provides a tool for comparing materials and helps to establish thresholds on the internal electric field for high-voltage applications in order to avoid risks of breakdown as much as possible. The pressure wave propagation (PWP) method has been used by many researchers to measure the space charge distribution and the internal electric field distribution in insulators. However, since experimental equipment, with slight differences, is developed independently by researchers throughout the world, it is difficult to compare the measurement results between the different equipment.

The procedure outlined in this document provides a reliable point of comparison between different test results carried out by different laboratories in order to avoid interpretation errors. The method is suitable for a planar plaque sample as well as for a coaxial sample, with homogeneous insulating materials of thickness from 0,5 mm to 5 mm.

MEASUREMENT OF INTERNAL ELECTRIC FIELD IN INSULATING MATERIALS – PRESSURE WAVE PROPAGATION METHOD

1 Scope

This document provides an efficient and reliable procedure to test the internal electric field in the insulating materials used for high-voltage applications, by using the pressure wave propagation (PWP) method. It is suitable for a planar and coaxial geometry sample with homogeneous insulating materials of thickness larger or equal to 0,5 mm and an electric field higher than 1 kV/mm, but it is also dependent on the thickness of the sample and the pressure wave generator.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

3.1 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

3.1.1
pressure wave propagation
procedure where a pressure wave is propagated in a material containing electric charges and the induced electric signal from electrodes is measured.

3.1.2
interface charge
net layer of charges between two different materials, either two different insulators or a conductor and an insulator

3.1.3
space charge
net charge inside an insulating dielectric material

3.2 Abbreviated terms

CB	carbon black
EVA	ethylene vinyl acetate
LDPE	low density polyethylene
LIPP	laser induced pressure pulse
PE	polyethylene
PIPP	piezoelectric induced pressure pulse
PMMA	poly methyl methacrylate
PWP	pressure wave propagation
S/N	signal to noise ratio

4 Principle of the method

The principle of the PWP method is shown schematically in Figure 1, which is for a planar sample. Figure 1 a) shows the principle and the relation between the current measured with the PWP method and the electric field distribution in the sample without space charge. Figure 1 b) shows the principle and the relation between the current measured with the PWP method and the space charge distribution in the sample without applied voltage. Figure 1 c) shows the measuring schematics of the PWP method. In Figure 1, x_f is the position of pulse front, d_0 is the original thickness of sample, and $d_0 \approx d$ in the case of a narrow pulse.

The space charge in the dielectric and the interface charge are forced to move by the action of a pressure wave. The charge displacement then induces an electric signal in the circuit which is an image of the charge distribution in short-circuit current measurement conditions. The expression for the short-circuit current signal with time t is

$$i(t) = C_0 \int_0^d BE(x) \frac{\partial p(x, t)}{\partial t} \mathrm{d}x \quad (1)$$

where

$E(x)$ is the electric field distribution in the sample at position x;

d is the thickness of sample;

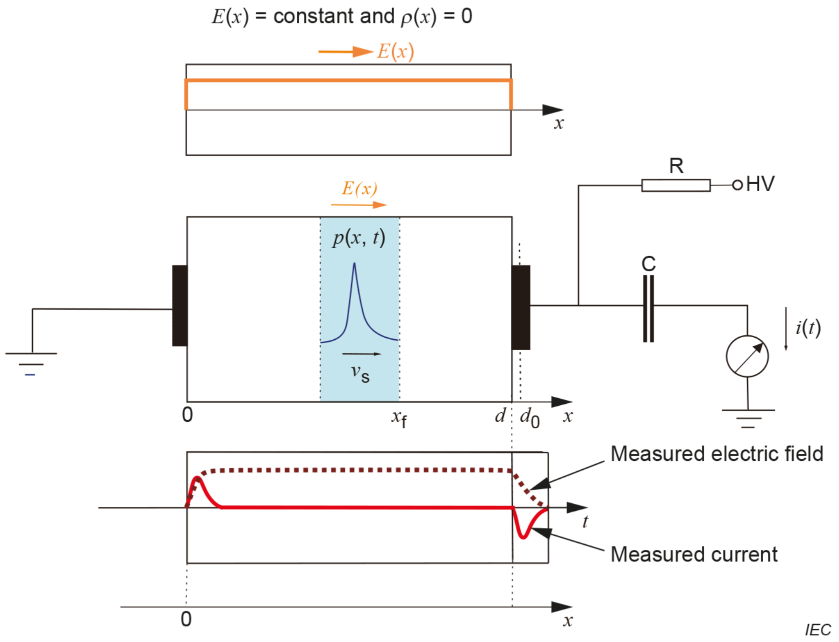
$p(x, t)$ is the pressure wave in the sample, which depends on the electrode materials, dielectric sample material, the condition of coupling on the interface, etc.;

C_0 is the sample capacitance with the action of a pressure wave. The active area is the area on which the pressure wave acts, and it shall be less than the area of the measuring electrode.

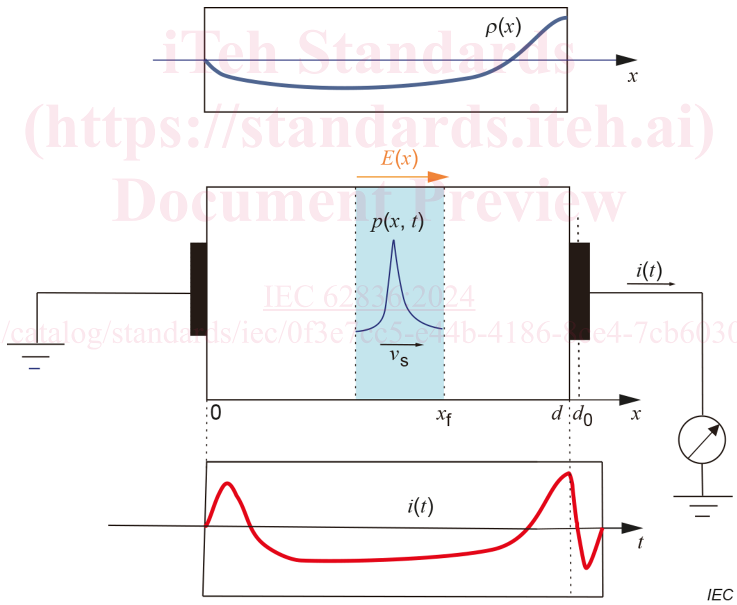
C_0 depends on the thickness of the sample, and its surface area which is equal to the area of action of the pressure wave.

The constant $B = \chi(1 - a / \varepsilon)$ only depends on the characteristics of the dielectric materials. In this formula, χ is the coefficient of compressibility of the material, ε is the permittivity of the material and a is the coefficient of electrostriction of the material. For heterogeneous dielectric materials, B is a function of position. For homogeneous dielectric materials, B is thus put outside the integral as it does not depend on positions. However, B depends on the measurement conditions. The measurement is carried out in given environmental conditions so B shall be determined during the calibration in the same conditions (temperature, humidity and pressure). In this document, only homogeneous dielectric materials are considered, so B is a constant.

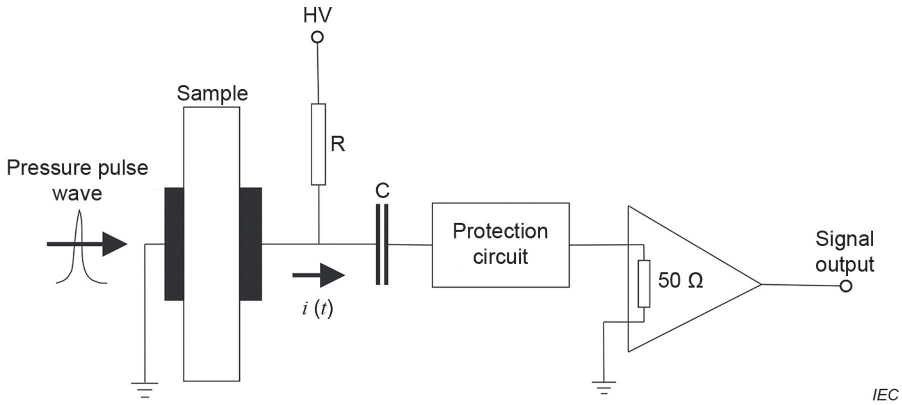
In Equation (1), the electric field distribution can be obtained if it is deconvolved.



a) Applied pressure pulse and measured short-circuit current with applied voltage but without space charge



b) Applied pressure pulse and measured short-circuit current with space charge but without applied voltage



c) Measuring schematics

Key

x_f position of pulse front

d_0 original thickness of sample

$d_0 \approx d$ in the case of a narrow pulse

Figure 1 – Principle of the PWP method

The applied pressure wave can be generated by different techniques, but the same kind of analysis can be done for any of these techniques. The main practical PWP method can be divided into two ways: a pressure pulse is induced by a powerful laser pulse, a technique called LIPP method, and a pressure pulse generated by a piezoelectric device, a technique called PIPP. The sensibility and resolution of the PWP method depends mainly on the amplitude and duration of the pressure pulse. The advantage of the LIPP method is to produce highly sensitive measurements without contact. The advantage of the PIPP method is to obtain the measurement with a high measuring rate and allow a low-cost measurement system.

In the case of a narrow pulse, for example when the duration of the pressure pulse is much smaller than the transit time of the pressure wave in the sample, τ is the pressure pulse duration with $\tau << \left[\min\left(d_0, d_x\right)\right] / v_s$,

$$\begin{cases} \int_0^t i(t')dt' = C_0 B\overline{E(x)}\int_0^d p(x,t)\mathrm{d}x \\ x = v_s t \end{cases} \quad (2)$$

where

v_s is the sound speed in the sample;

$\overline{E(x)},\ x = v_s t$ is the mean electric field during the pressure pulse width at the position x. For simplicity, it is shown as $\overline{E(x = v_s t)}$ in this document.

Because of sound loss and sound dispersion in polymer dielectrics, the amplitude of $p(x,t)$ will decrease, and the width of $p(x,t)$ will increase during the propagation of a pressure pulse in the sample. For polymer dielectrics, the sound dispersion is dominant, therefore, even if $p(x,t)$ is not a constant in the dielectrics, its integral $\int_0^d p(x,t)\mathrm{d}x$ remains constant during its propagation in the sample.

From Equation (2), if the signal is obtained with a sample free of charges and submitted to an intermediate voltage U_0, $B\int_0^d p(x,t)\mathrm{d}x$ can be obtained since the electric field $\overline{E(x=v_\mathrm{s}t)}=E_0$ is uniform in this case and the sample capacitance C_0 is inversely proportional to the thickness of the sample. This can be used as a calibration base for the other measurements.

5 Samples

A dielectric insulating material is suggested, for example polyethylene, with a thickness of 1 mm or 2 mm planar plaque sample with a diameter sufficiently large to avoid edge discharges, typically larger than 200 mm with 50 mm disc form centred electrodes for 60 kV.

6 Electrode materials

The selection of electrode materials depends on the method of the generation of the pressure pulse wave. Usually, semi-conductive electrodes with ethylene-vinyl acetate (EVA) + carbon black (CB) or polyethylene (PE) + carbon black (CB) are used. For laser PWP (also called LIPP), the suitable thickness of the semi-conductive electrode is about 0,5 mm, and it shall be less than 1 mm. If the acoustic impedances are different for the electrode and the insulator, the transit time of the pressure wave through the electrode should be at least half the one in the insulator to avoid spurious echoes.

It is important to keep good contact between the electrode and the insulator. It is recommended to use the hot-press method for marking the electrode on the sample.

NOTE The hot-press method is an effective and simple way for bonding semi-conductive electrode(s) and the PE sample to achieve good interfacial contacts between them. It involves the application of a uniaxial pressure at a temperature in a time duration which depend on the materials of the sample and electrodes.

7 Pressure pulse wave generation

The suggested pressure pulse wave should have a 20 ns to 50 ns duration, and a 1 MPa to 10 MPa amplitude for a sample of 0,5 mm to 5 mm thickness. It can be produced by a piezoelectric driven device, or by a powerful pulsed laser. If a powerful laser is used, the suggested energy is about 300 mJ to 500 mJ per pulse with a 3 ns to 7 ns duration.

NOTE The pressure amplitude, the duration, and the energy of the laser can be adjusted depending on the material tested.