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colour inside

Calibration of space charge measuring equipment based on the pulsed electro-acoustic (PEA) measurement principle

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CALIBRATION OF SPACE CHARGE MEASURING EQUIPMENT BASED ON THE PULSED ELECTRO-ACOUSTIC (PEA) MEASUREMENT PRINCIPLE

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 62758, which is a technical specification, has been prepared by technical committee 112: Evaluation and qualification of electrical insulating materials and systems.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
112/206/DTS	112/219/RVC

Full information on the voting for the approval of this technical specification 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.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,
- replaced by a revised edition, or
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INTRODUCTION

The pulsed electro-acoustic (PEA) method has been used to measure space charge distribution in dielectric materials by many researchers, and it has been accepted, in general, as a useful method to understand the electrical properties of dielectric materials. However, since PEA measurement equipments have been developed/used independently by different researchers over the world, there has not yet been any standard way to evaluate whether a system works properly. The IEC has therefore established a project team to create a standard procedure to evaluate PEA measurement equipment. This technical specification is the result.

CALIBRATION OF SPACE CHARGE MEASURING EQUIPMENT BASED ON THE PULSED ELECTRO-ACOUSTIC (PEA) MEASUREMENT PRINCIPLE

1 Scope

IEC 62758, which is a technical specification, presents a standard method to estimate the performance of a pulsed electro-acoustic (PEA) measurement system. For this purpose, a systematic procedure is recommended for the calibration of the measurement system. Using the procedure, users can estimate whether the system works properly or not.

2 Normative references

None.

3 Terms and definitions

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

3.1
space charge
accumulated charge in materials

Note 1 to entry: This technical specification deals with the space charge in bulk and on surfaces of dielectric materials.

3.2
pulsed electro-acoustic method
PEA
technique for measuring space charge density distribution in solid dielectric materials

Note 1 to entry: In this technique, the pressure wave that is generated from the charge layer in a material specimen by applied pulse voltage to the specimen is observed using piezo-electric transducer attached behind an electrode contacted to the specimen. Details of measurement theory are described in Clause A.1.

3.3
piezo-electric transducer
sensor to detect the intensity of the pressure wave

Note 1 to entry: By applying the pressure wave, the charge is proportionally induced on the surface of the transducer. By connecting an adequate external circuit, the induced charge is converted to voltage signal. In the PEA measurement, the film or plate shaped piezo-electric transducer is usually used. The pressure wave intensity is measured as a voltage signal across the transducer when the wave propagates through the transducer. Details of the measurement procedure are described in A.1.3.

3.4
calibration
set of operations that establish, under specified conditions, the relationship between values of quantities indicated by measuring instrument or measuring system, or values represented by a material measure of a reference material, and the corresponding values obtained by a theoretical model

[SOURCE: IEC 60050-394:2007, definition 394-40-43, modified – the words "obtained by a theoretical model" replace "realized by standards".]

Note 1 to entry: This is the standard way to estimate the performance of a PEA measurement system. In the PEA measurement, the pressure wave generated from the charge layer in the material is measured as a voltage signal. To obtain the charge density distribution, it is necessary to calibrate the measured voltage signal to the charge density distribution. Therefore, in this technical specification, the calibration means the procedure to calculate the charge density distribution from the measured voltage signal.

3.5
deconvolution
procedure to recover the voltage signal from the distorted one

Note 1 to entry: The measured voltage signal is usually distorted by the reflection of the pressure wave at the interfaces between materials constituting the measurement system, the characteristic of the voltage signal detecting circuit and the induced noise with applied pulse voltage. To recover the voltage measured signal, a so-called de-convolution technique is usually used. The details of the deconvolution procedure are described in Clause A.2.

4 Basic theory for measurement

4.1 Permittivity and induced charge density

When a d.c. voltage V_{dc} (V) is applied to a film or sheet shaped dielectric material with thickness of d [m] through the attached electrodes, positive and negative charges with densities of σ_0 and $-\sigma_0$ (C/m^2) are induced at the interfaces between the material and the electrodes. The constant average electric field E_{dc} (V/m) and the charge density are ideally described by the following equations:

$$E_{\mathrm{dc}} = \frac{V_{\mathrm{dc}}}{d} \tag{1}$$

$$\sigma_0 = \varepsilon E_{\mathrm{dc}} \tag{2}$$

Where ε is the permittivity of the dielectric material described with the unit of (F/m). It is also described using the permittivity in vacuum ε_0 = 8,854 x 10^{-12} (F/m) as follows:

$$\varepsilon = \varepsilon_0 \varepsilon_{\mathrm{r}} \tag{3}$$

where the non-dimensional coefficient ε_{r} is called the relative permittivity.

4.2 Charge in dielectrics and Poisson's law

Here, the axis z is defined in the direction of thickness of a film or a sheet shaped dielectric material. When the charge is accumulated in the material with a volume density of $\rho(z)$ (C/m^3), electric field distribution $E(z)$, under static conditions, is described using the following Poisson's equation:

$$E(z) = \frac{1}{\varepsilon_0 \varepsilon_r} \int \rho(z) dz \tag{4}$$

The electric potential distribution in the material $V(z)$ is described as

$$V(z) = -\int E(z) dz \tag{5}$$

4.3 Coulombic force of charge in electric field

When charge q (C) is put in the electric field E (V/m), the following Coulombic force F (N) acts on the charge:

$$F = qE \tag{6}$$

When the charge q is homogeneously distributed as a perpendicular layer to z axis, the charge density of the layer σ (C/m^2]) is calculated by using the area of the material S (m^2) as $\sigma = q/S$. Therefore, the pressure wave p (Pa = N/m^2]) generated from the charge layer when the electric field E is applied to the material is

$$p = \sigma E \tag{7}$$

When the above electric field is generated by the pulse voltage with very short duration, the pulse pressure wave generates from each charge layer and it propagates in the material.

4.4 Reflection and transmission of pressure wave

When a pressure wave propagates through the interfaces between different materials, it is divided into transmitted and reflected waves. The ratio of this division is determined by so called acoustic impedance Z (Pa s/m = N s/m^3). The acoustic impedance Z is obtained by the following equation:

$$Z = mu \tag{8}$$

where m (kg/m^3) and u (m/s) are density and acoustic velocity in the material.

When the pressure wave propagates from material 1 to material 2, the transmission and reflection ratios K_t and K_r are described using the acoustic impedances of the materials Z_1 and Z_2 as

$$K_t = \frac{2Z_2}{Z_1 + Z_2} \tag{9}$$

$$K_r = \frac{Z_2 - Z_1}{Z_1 + Z_2} \tag{10}$$

When the pressure wave is generated at the interface between material 1 and 2, the ratio of propagation towards material 2, say K_{g2} is described as

$$K_{g2} = \frac{Z_2}{Z_1 + Z_2} \tag{11}$$

4.5 Maxwell stress

When a voltage V is applied across electrodes attached to a sheet or a film dielectric material with thickness of d and permittivity of ε, the following Maxwell stress F_0 (N) is generated at the interfaces between the material and electrodes:

$$F_0 = \frac{1}{2}\varepsilon\left(\frac{V_{dc}}{d}\right)^2 = \frac{1}{2}E\times\sigma \tag{12}$$

4.6 Response of linear system

When a delta function $\delta(t)$ (impulse) as a function of time t (s) is input into a linear system, the output of it $h(t)$ is called "transfer function". The relationship between $h(t)$ and $\delta(t)$ is described using the following convolution equation:

$$h(t) = \int_{-\infty}^{+\infty} \delta(\tau)h(t-\tau)d\tau \tag{13}$$

When a certain function voltage $v_{in}(t)$ inputs the linear system, the output voltage $v_{out}(t)$ is obtained using $h(t)$ as

$$v_{out}(t) = \int_{-\infty}^{+\infty} v_{in}(\tau)h(t-\tau)d\tau \tag{14}$$

In the frequency domain, the above relationship is converted into the following equation:

$$V_{out}(f) = H(f)\ V_{in}(f) \tag{15}$$

where $V_{out}(f)$, $H(f)$ and $V_{in}(f)$ are functions of frequency f (Hz) converted from $v_{out}(t)$, $h(t)$ and $v_{in}(t)$, respectively.

5 Procedure to calibrate the space charge measurement

5.1 Principle of calibration

5.1.1 General

A basic principle of calibration for obtaining charge density distribution from the PEA signal is described below. Generally in calibration for measurement, we need a signal from a measuring object which value is known absolutely. In the case of the PEA measurement for a flat sheet sample, the induced surface charges by applied d.c. voltage at the interfaces between the sample and electrodes are theoretically obtained when the permittivity of the sample is known. Therefore, the following calibration process is based on the ideal measurement of the surface charges under d.c. voltage application.

Consider a virgin (not having space charges in its bulk) dielectric (flat) sheet sample, placed between a set of electrodes. The sample thickness and relative permittivity are d and ε_r, respectively. When a small d.c. voltage V_{dc} is applied to the sample, positive and negative surface charges $+\sigma_0$ and $-\sigma_0$ are induced at interfaces between the sample and electrodes, anode and cathode, respectively. Here, the voltage V_{dc} is assumed to be relatively low so that it is not enough to generate any space charge in the bulk of sample. Since these surface charges are located at quite thin layers, they can be treated as impulse (delta) functions on a positional axis z along the thickness of the sample as shown in Figure 1(a). The value of surface charge density σ_0 can be calculated by the following equation:

$$\sigma_0 = \varepsilon_0\varepsilon_r E_{dc} = \varepsilon_0\varepsilon_r V_{dc}/d \tag{16}$$

where E_{dc} and ε_0 are applied average electric field and the permittivity in vacuum, respectively. Under the electric field E_{dc}, when a pulsive voltage $V_p(t)$ is superimposed on V_{dc}, pulsive pressure waves $p_0(t)$ and $p_d(t)$ are generated from the surface charges (see Annex A). In the PEA method, the pressure wave $p(t)$ generated from the charge distribution $\rho(z)$ is observed using a piezo-electric sensor which transforms the pressure to voltage signal $V_s(t)$ (see A.1.3). Therefore, the calibration procedure enables to transform the obtained $V_s(t)$ to the charge density distribution $\rho(z)$. Since the surface charge density σ_0 can be theoretically calculated using Equation (1), the signal voltage of $V_s(t)$ can be easily calibrated by observing σ_0. On the other hand, the position z can be calculated by the following relationship:

$$z = u_{sa}t \tag{17}$$

where u_{sa} is acoustic velocity in the sample.

However, in general, it is hard to obtain an accurate value of relative permittivity of a sample. Therefore, the actual calibration should be carried out using some parameters that are easily measured. As shown in Figure 1(b), the electric field distribution $E(z)$ in the sample can be obtained by integral calculation of charge density distribution $\rho(z)$. It can be seen that the electric field distribution $E(z)$ in the sample for the calibration measurement shown in Figure 1(b) has a simple rectangular shape with the value of flat portion, $E_{dc} = V_{dc}/d$. The thickness of the sample d and the applied d.c. voltage V_{dc} are easy to measure. Therefore, calibration using the electric field distribution $E(z)$ is proposed in this specification.

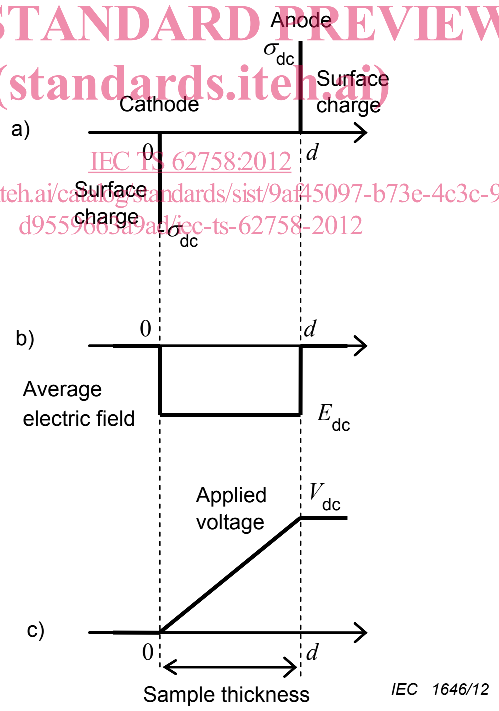

Figure 1(a) – Charge density distribution **Figure 1(b) – Electric field distribution** **Figure 1(c) – Electric potential distribution**

Figure 1 – Theoretical distributions for calibration measurement

5.1.2 Typical result of calibration measurement

Figure 2 shows a typical result of calibration measurement. In this measurement, a PMMA (poly (methyl-methacrylate)) sheet specimen with a thickness of d = 500 µm is used. Figure 2(a) shows charge density distribution obtained by applying a d.c. voltage of V_{dc} = 2 kV to the sample. If the measurement is ideally carried out for the sample without any space charge in its bulk, the charge density distribution should be a pair of delta functions as shown in Figure 1(a). However, they are observed as a pair of peaks with a certain width that is