Space Charge Measurement system for Dielectric Materials under Irradiation

A. Adjerad[1)], H. Salah[1)]

[1)]Centre de Recherche Nucléaire d'Alger, Alger, Algerie

Email contact of main author: a.adjerad@comena-dz.org

Abstract. The increasing request for energy quality and, thus, insulation system reliability associated with significant steps in the manufacturing of new insulating matérials are pushing strongly the research on new techniques for the diagnostic of insulation ageing. Space charge measurement system for dielectric materials under irradiation has been developed by using the pulsed electroacoustic method (PEA). This system can observe space charge profiles in dielectric matérials under irradiation, and was applied to an irradiation chamber. These devices are now under construction. We will start to make a test experiment.

1. Introduction

Materials used are exposed to various charged particles. Upon irradiation, polymeric materials store charges that can affect the function of the equipment or the materials [1]. Charges accumulated on the surface would also be able to inject charge by increasing the electric field across the dielectric materials. Therefore the internal space charge measurement is needed in order to understand the charge behaviour. There are some early works on internal charge measurement of polymers after beam irradiations [2], by the pressurewave propagation (PWP) method and PEA method (*see FIG.1*).
The PWP method uses a pressure wave that is produced either by a piezoelectric device or by a pulse laser to a specimen, and detects the induced current [3]. The PEA method, on the other hand, uses a pulsed electric field to a specimen. The detail are explained in the followin section.
In this paper, films or insulating materials were submitted to an different beam in a vacuum chamber. We attempted to measure the distribution of charges in the volume by PEA method with the aim to carry these measurement in situ. At first PEA measurement were performed ex-situ by using a classical system. Then, we used a specially adapted PEA cell to perform in situ measurement during the irradiation.

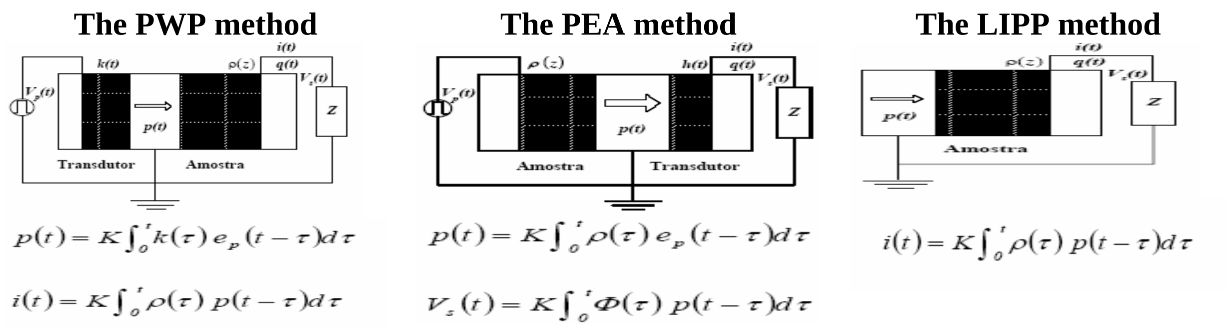

FIG.1. Technique acoustic methods

2. PEA METHOD

The PEA metoh was originally developed by T. Maeno, and has been used by many research groups [4]. It might be useful to introduce the PEA method here. *FIG.2*. shows the schematic diagram of the theory of the PEA method.

This method is widely used, and therefore its detailed description is given here. The method is also known as the electrically stimulated acoustic wave method.

A short electric pulse is put across the sample. The PEA method is based on the coulomb force law, where an externally applied pulse field inducces a perturbing force density on the material in the presence of resident charges. This force causes the charge to move slightly. This movement generates an acoustic wave that is related to the charge distribution in the sample. A piezoelectric transducer (polyvinylidenefloride foil, PVDF) is used to detect the acoustic wave and genrates a voltage signal (PEA output signal) proportional to the pressure wave propagating through it. The weak voltage signal generated by the PVDF is then amplified by two large-band amplifiers, is sent to an oscilloscope and recorder by a personal computer, connected with the oscilloscope through an IEEE-488 bus. A PMMA adsorber is located under the piezoelectric transducer in order to avoid reflections which can distrub the PEA output signal [5].

The dielectric sample is placed between two electrodes A and B. Electrode A. Then follow the sample, Electrode B, piezoelectric transducer and acoustic absorber. An amplifier across the transducer lead its signal to an oscilloscope.

A pulse source and a DC source are connected in parallel across electrode A and B, using a coupling capacitor C and a protecting resistor R. Typical values for the DC voltage are 5-40KV depending on the thickness of the sample under test. The typical values for the pulse voltage is 0.1-2 KV and pulse width 5-200 ns.

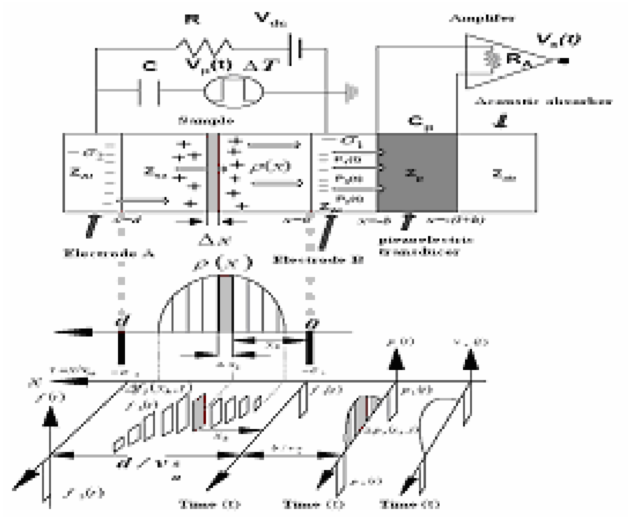

FIG. 2 Circuit description of the PEA measurement system and diagram wave generation and propagation.

2.1. General equation

The Poisson's equation giving the electric field and the charge distribution is given by:

$$\frac{dE(x)}{dx} = \frac{\rho(x)}{\varepsilon}$$

The electric tension in the sample in function of the distance is express for:

$$\int_0^x E(x')dx' = V(x), \text{ com } V(0)=0$$

The induced superficial charge in the electrodes A and B:

$$\sigma_1 = -\varepsilon E_1 \qquad \sigma_2 = \varepsilon E_2$$

E1 and E2 is the electric field.

2.2. The induced charge densities in the electrodes

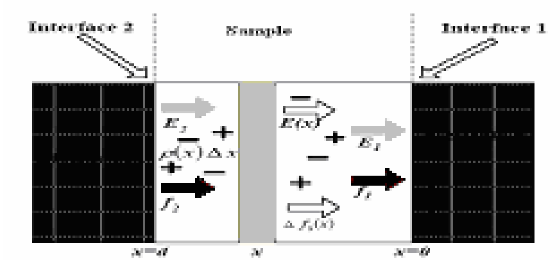

FIG.3 Schematical drawing of the sample/eletrode, showing the electric forces, fields and induced charge. The blue band corresponds to a slice of the space charge in the sample.

The induced charge densities in the electrodes σ_1 and σ_2 depend on the applied pulse of electric field $e_p(t)$, on the external tension V_{dc} of the space charge $\rho(x)$ (*see FIG.3*).

$$\sigma_1 = \varepsilon E_{dc} - \int_0^d \frac{d-x}{d}\rho(x)dx$$

$$\sigma_2 = -\varepsilon E_{dc} - \int_0^d \frac{x}{d}\rho(x)dx$$

2.3. Forces Generated by the Electric Field

The forces generated on the electrodes A and B are express for:

$$f_1 = \frac{1}{2}\sigma \;\; E_1 = -\frac{1}{2}\varepsilon E_1^2$$

$$f_2 = \frac{1}{2}\sigma_2 E_2 = -\frac{1}{2}\varepsilon E_2^2$$

$$\Delta f_3(x) = \rho(x)\Delta x E(x) \qquad 0<x<d$$

The electric field in the interior of the sample is composed of three parts: electric fi E_C field produced for the space charge $e_p(t)$ and the pulse electric fied E_{dc}

Thus the fields in the interfaces of the electrodes, A and B, are:

$$E_1 = E_{dc} + E_C^1 + e_p(t)$$

$$E_2 = E_{dc} + E_C^2 + e_p(t)$$

$$f_1(t) = \left[\sigma_1 + \frac{\varepsilon}{2}e_p(t)\right]e_p(t)$$

$$f_2(t) = \left[\sigma_2 - \frac{\varepsilon}{2}e_p(t)\right]e_p(t)$$

$$\Delta f_3(x,t) = \rho(x_i)\Delta x_i E(x_i,t)$$

2.4. Incidence of the wave acoustics in the transducer

Taking in account the different delays of each part of the waves acoustics, p1 and p2 to reach the transducer (*see FIG.3*), they are written in function of the time:

$$p_1(t) = K_{2G}K_{3T}\left[\sigma_1 + \frac{1}{2}\varepsilon\, e_p\left(t - \frac{b}{v_{Al}}\right)\right]e_p\left(t - \frac{b}{v_{Al}}\right)$$

$$p_2(t) = K_{1G}K_{2T}K_{3T}\left[\sigma_2 - \frac{1}{2}\varepsilon\, e_p\left(t - \frac{d}{v_{sa}} - \frac{b}{v_{Al}}\right)\right]e_p\left(t - \frac{d}{v_{sa}} - \frac{b}{v_{Al}}\right)$$

$$p_3(t) = \frac{K_{2T}K_{3T}}{2}v_{sa}\int_0^t \rho'(\tau)\, e_p\left[t - \tau - \frac{b}{v_{Al}}\right]d\tau$$

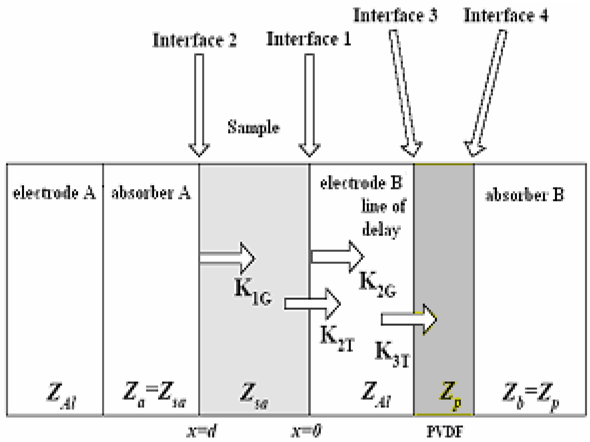

FIG.3. Schematical drawing of the disposal of the elements of system PEA. K is the coefficients of transmission and generation of acoustic signals and Z the impedances acoustics.

The coefficients are given by:

$$K_{1G} = \frac{Z_{sa}}{Z_a + Z_{sa}} \qquad K_{2T} = \frac{2Z_{Al}}{Z_{Al} + Z_{sa}}$$

$$K_{2G} = \frac{Z_{Al}}{Z_{Al} + Z_{sa}} \qquad K_{3T} = \frac{2Z_p}{Z_{Al} + Z_p}$$

$$p(t) = p_1(t) + p_2(t) + p_3(t)$$

$$p(t) = K_{2G}K_{3T}\sigma_1 e_p\left(t - \frac{b}{v_{Al}}\right) + K_{1G}K_{2T}K_{3T}\sigma_2 e_p\left(t - \frac{b}{v_{Al}} - \frac{d}{v_{sa}}\right)$$

$$+\frac{K_{2T}K_{3T}}{2}v_{sa}\int_0^t \rho'(\tau)\, e_p\left[t - \tau - \frac{b}{v_{Al}}\right]d\tau$$

2.5. Generation of electric signals in the transducer

The piezoelétrico effect the acoustics wave that propagates in the transducer it induces the charge q(t) in its electrodes, given for:

$$q(t) = d_{33}\, p(t)\, S$$

where d33 is the constant of piezoelétrica tension and S the area of the transducer. A ddp enters two surfaces of the transducer is express for:

$$V_T(t) = q(t)/C_T$$

the C_T is the electric capacitor of the transducer.

$$V_T(t) = \frac{d_{33}\ell}{\varepsilon^T}\, p(t)$$

$$V_T(t) = K\left[\sigma_1 e_p\left(t - \frac{b}{v_{Al}}\right) + \sigma_2 e_p\left(t - \frac{b}{v_{Al}} - \frac{d}{v_{sa}}\right)\right.$$

$$\left. + v_{sa}\int_0^t \rho'(\tau)\, e_p\left[t - \tau - \frac{b}{v_{Al}}\right] d\tau\right]$$

$$\text{onde } K = \frac{d_{33}\ell\,\chi}{\varepsilon^T}.$$

2.6. Electric measured in the oscilloscope

In *FIG.5*. the circuit is illustrated equivalent of the transdutor/amplifier system:
The signal Vs(t) of the circuit is express for:

$$V_s(t) = \int_0^t V_T(\tau)\,\Omega(t-\tau)\,d\tau$$

$$V_s(t) = \int_0^t V_T(\tau)\,\Phi(t-\tau)\,d\tau$$

$$V_T(t) \longrightarrow \boxed{\Phi(t)} \longrightarrow V_S(t)$$

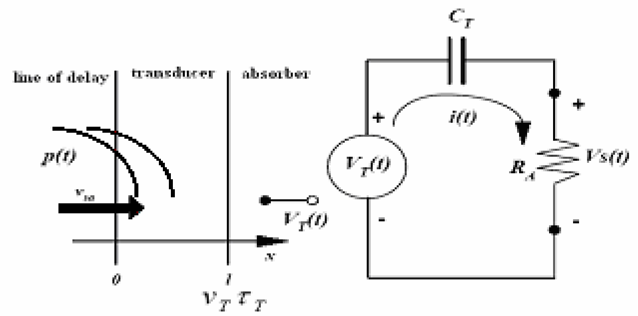

FIG.4. Representation of the performance of the function of transference on the $V_T(t)$ signal

3. Experimental set-up

Two series of experiments will be carried out:

- At first measurement with the classical system after irradiation.
- In the second, a new PEA [6,7] system has been designed to make possible the record of the signal during irradiation (modification of the classical systm are made necessary to leave the irradiated surface free). The detector and amplifier are located in the vacuum chamber whereas the other electronic devices are placed near by the chamber. The signal is carried out through a cable to the oscilloscope placed in the control room.

4. Conclusions and future work

These devices (new PEA system) are now under construction. We will start to make a test experiment from this summer. so that I can compare with the results of the classical system.

4. References

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