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Understanding Charge Dynamics in Elastomers Adopting Pulsed Electro Acoustic (PEA) Technique

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Abstract**—**In the present work, Pulsed Electro Acoustic (PEA) technique was adopted to understand the space charge dynamics in elastomeric material. It is observed that the polarity of the applied DC voltage voltage and its magnitude alters the space charge dynamics in insulation structure. It is also noticed that any addition of compound to the base material/processing technique have characteristic variation in the space charge injection process. It could be concluded based on the present work that the plasticizer could inject heterocharges into the insulation medium. Also it is realized that space charge magnitude is less with the addition of plasticizer. In the PEA studies, it is observed that local electric field in the insulating material can be much more than applied electric field due to space charge formation. One of the important conclusions arrived at based on PEA technique is that one could understand the safe operating electric field of an insulation material and the charge trap sites.

Keywords**—**Pulsed electro acoustic technique, space charge, DC voltage, elastomers, Electric field, high voltage.

I. INTRODUCTION

HIGH voltage DC power transmission has acquired considerable prominence in the recent times for bulk power transmission. The power loss in the insulation is minimum under DC voltages. The major problem of failure under DC voltages is due to the space charge formation. The space charge formed in the medium can cause insulation degradation leading to its failure. The space charge injection formed in the insulation medium can be homo/hetero charge in nature. In general the buildup of injected charge, which is observed near to the injecting electrode were called as homocharges. Hetero charges are the one which are formed due to chemical species degradation or due to contaminant (conducting or non conducting in nature), appear to the electrodes or in the bulk volume of insulation different from polarity of the applied voltage. In recent times, it is observed hetero charges appear near to the electrodes [1]. This accumulated space charge can form non-uniform electric field distribution in the bulk volume of insulation (at some point even raising the electric field much more than the breakdown strength of the insulation causing earlier failure) which can enhance the process of degradation thereby reducing the life of the insulation. Hence it is essential to know the dynamics of charge movement and charge trap sites in the insulation structure to enhance the reliability of the insulation material and the world over researchers are trying to mitigate the space charge formation in insulation material. Earlier studies on space charge identification carried out through thermally stimulated current to understand the magnitude of injected charge in the insulation and by depolarization technique, which can provide information about trap depth distribution [2].The two most feasible techniques adopted recently to measure the space charge distribution in solid insulation material were the pressure wave propagation (PWP) and Pulsed Electro Acoustic (PEA) process. Takada provided complete information about the principle of operation of PEA system in detail [3]. In the present study, the PEA technique was adopted to understand the charge dynamics in elastomeric material. Elastomeric material identified as suitable material for outdoor insulation and also for cable insulation at cryogenic temperatures. In this paper, the charge dynamics in acrylic elastomer and acryl nitryl elastomer are presented. These insulating material straind by the Maxwell stress at high applied electric field. These elastomers have potential application as actuators and soft robots [4,5]. Masuya et al. carried out space charge injection studies with different elastomeric material and concluded that homo and heterocharge formation occurs in the elastomeric materials due to applied DC voltage [6]. The polymer actuator devices, in general, can exhibit their movement at electric field of about 10kV/mm. Hence a methodical experimental study was carried out to understand the charge dynamics in the elastomeric materials, adopting the PEA technique.

II. EXPERIMENTAL STUDIES

Fig. 1 shows typical PEA system. The PEA measurement device (Five Lab Make, Japan) was used for the space charge measurement. It includes high DC voltage source, pulsed generator of variable frequency, high voltage electrodes, sensor for detection of acoustic signal generated due to applied voltage pulse, amplifier and an oscilloscope. In the present study, high voltage DC generated using high voltage amplifier, which can generate voltage up to 12 Kv. The applied DC voltage measured using a high voltage measurement probe.

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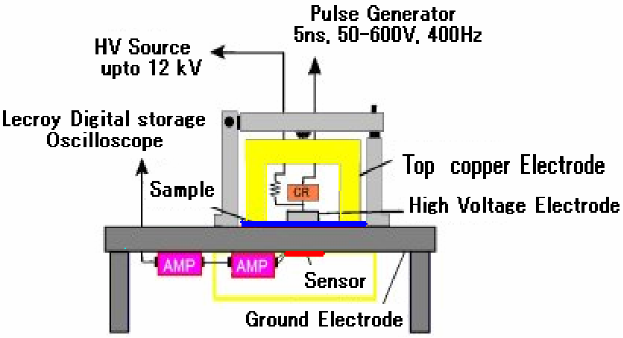

Fig. 1 Typical Pulsed electro acoustic system

The output voltage of pulsed generator used in the present study could generate voltage up to 600V operating at a fixed frequency of about 400Hz. The rise time of the pulse is about 5ns. The PTFE material is used as sensor material. The high electrodes is of parallel plane configuration. The top electrode coated with semiconducting (carbon loaded) material and the bottom ground electrode is aluminium material. The thickness of the materials used was measured using a vernier. The oscilloscope used for measurement Lecroy 500 MHz, with sampling rate of 4GS/s. The insulating material is of flat type sheet. In the present work, the charge dynamics were studied by applying different electric fields up to 50 kV/mm. In the present study three different materials were studied, which includes acrylic elastomeric material (***AEM***), Acryl Nitryl Butadiene Rubber (**ANBR**), which is called as ***TYPE-I*** material and the third material is ANBR with addition of plasticizer, which is identified as ***TYPE-II*** material. The composition of Acryl Nitryl Butadien rubber has 69% Butadiene and Acryl Nitryl of 31%.

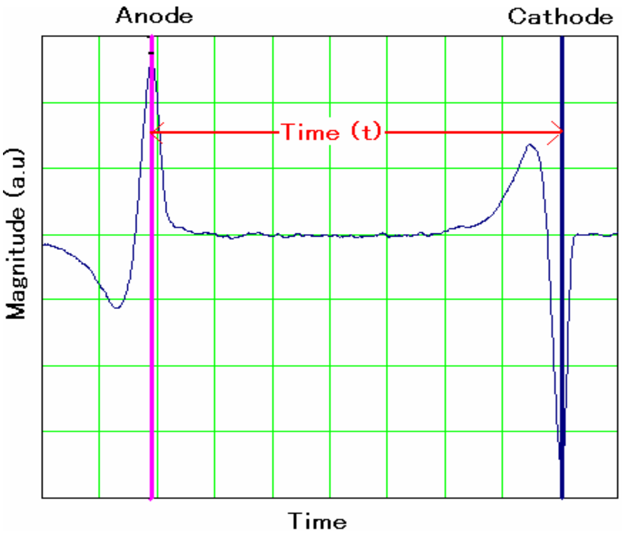

Fig. 2 Typical PEA reference signal used for analysis of velocity of signal in the specimen

III. METHODOLOGY ADOPTED FOR IDENTIFICATION OF ELECTRODES IN PEA STUDIES

Typical PEA signal measured as reference is shown in Fig. 2. It is possible to evaluate the position of the electrodes and from where the injection sites and charge dynamics could be evaluated. The positive peak and the negative peaks correspond to the anode and the cathode of the electrode gap. Once we know the thickness of the sample (d) measured by vernier and the time difference between the positive and negative peak (t), then it is possible for one to evaluate thevelocity of the signal in the sample specimen under test as distance by time as the velocity of the signal in the material. In the present work, the samples are elastomers and once the top electrode is placed over the sample then due to the dead weight of the top electrode the thickness gets reduced. Hence in the present work, the thickness is evaluated using the following procedure. First the sample is placed between the electrodes as it is used for testing. After 10 minutes, the sample is removed and thickness of the specimen where the semi-conducting electrode was in contact, at that location the thickness is measured using a vernier. Such measurements were made at three different locations and the average of it was treated as thickness of the specimen. For thin specimens, identifying the the electrode position is a cumbersome process. The first positive peak and the adjacent negative peak were treated as the electrode separation.

IV. RESULTS AND DISCUSSION

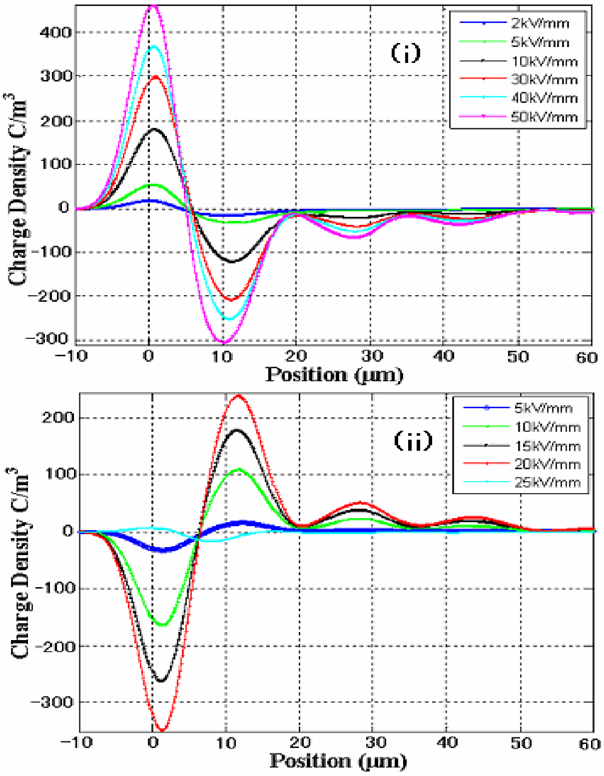

Fig. 3 Variation in charge injection magnitude in acrylic elastomers at different electric fields (i) +DC (ii)-DC

Fig. 3 shows typical variation in magnitude of charge injection into the insulation material at different electric fields under positive and negative DC voltage. It is observed that the magnitude of charge injection is high when the material is subjected to negative DC voltage. The cause for it could be due to application of negative DC voltage and positive nano second pulse for the measurement of space charge, which would have allowed higher magnitude of charges to get injected into the insulation material. This allows one to confirm that any transient voltages of opposite polarity can cause higher space charge formation in to the insulation material. Also it is observed that when the applied electric field is kept constant, it allows space charge injection to occur in the material and with time the material could fail. For instance in Fig. 3(ii), at 25 kV/mm electric field, the specimen has failed during its operation. This confirms that charge movement in the insulation material could cause failure of the insulation material.

Fig. 4 shows a two dimensional variation of space charge in the insulating material, at different electric fields. In this the material stressed for definite time instants at different electric fields. It could be realized that adjacent to the high voltage electrode, the heterocharges gets injected in to the insulating material. Tanaka’s model provides clear visulisation on to the mechanism of hetero charge injection adjacent to the high voltage electrode [1]. In the present study, with AEM material such phenomena could be observed in both positive and negative DC voltages. In the AEM material no hetero charge injection is observed in the bulk volume of the insulation material, irrespective of polarity of the applied DC voltage. Recently Delphino et al. studied the high space charge dynamics in EVA nano composite material and concluded that high space charge dynamics is a positive property of the material, which helps to reduce the charge transient followed with voltage polarity reversal [7].

Fig. 5 shows electric field variation in the AEM material operated at different voltages. The electric field could be obtained by integrating the charge profile [8]. It is observed that even though the material is the same, the characteristic variation of electric field in the material at same operating electrical stress is different. This variation could be due to polarity of applied nano second pulse or could be due to the inherent characteristics of magnitude of charges that gets injected into the bulk volume of the insulating material. In general, it could be realized that local electric field in the bulk volume of the insulating material, is much higher than the theoretically calculated electric field, assuming parallel plane configuration. This indirectly confirms that the point of higher stress can cause ageing of material and initiate the process of damage in the insulation leading to earlier failure. Thus the PEA technique, not only provides the magnitude and position of space charge, it also provides information to understand the local electric field variation in the bulk volume of insulating material and could provide information to the end user to identify the safe operating voltage.

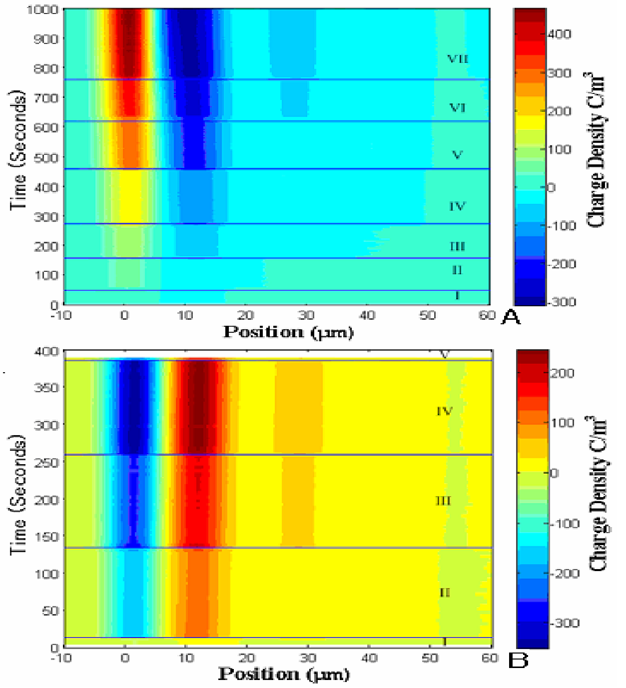

Fig. 4 Two dimension variation of space charge in Acrylic elastomers at different electric fields .Fig 4A (i) 2kV/mm (ii) 5 kV/mm (iii) 20 kV/mm (iv) 20 kV/mm (v) 30 kV/mm (vi) 40 kV/mm (vii)50 kV/mm. Fig. 3B. Fig 4A (i) 5kV/mm (ii) 10kV/mm (iii) 15 kV/mm (iv) 20 kV/mm (v) 25 kV/mm . (A) +DC (B) –DC.

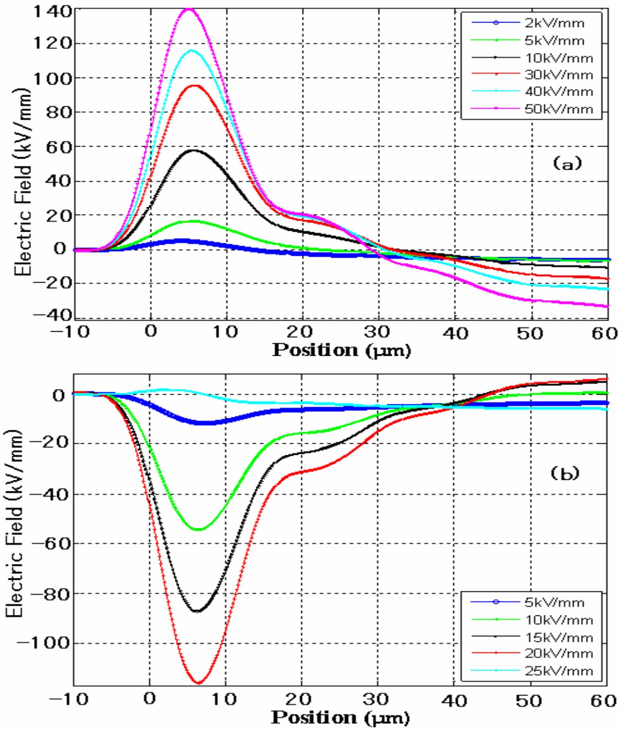

Fig. 5 Variation in Electric field in the bulk volume of the Acrylic elastomer insulation material measured through PEA process (a) +DC (b) -DC

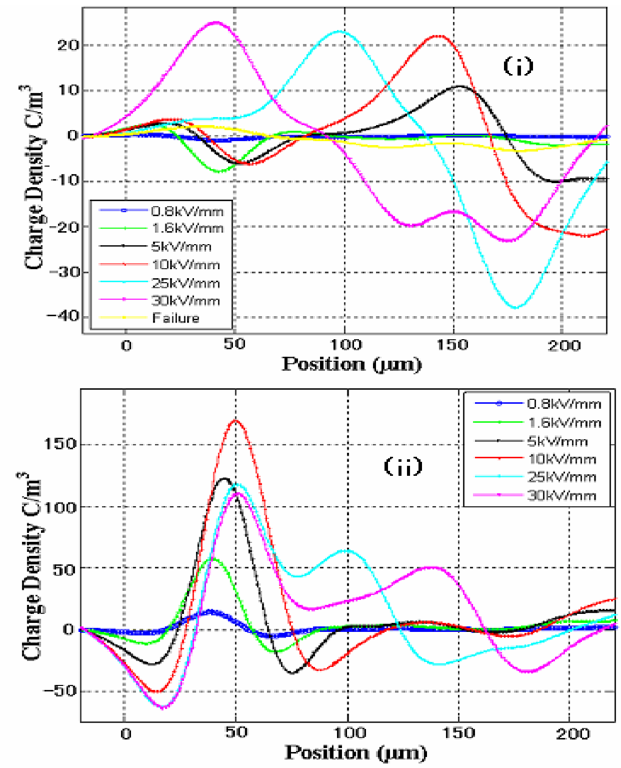

Fig. 6 Variation in charge injection magnitude in Acryl Nitryl Rubber (Type-I) material at different electric fields (i) +DC (ii) -DC

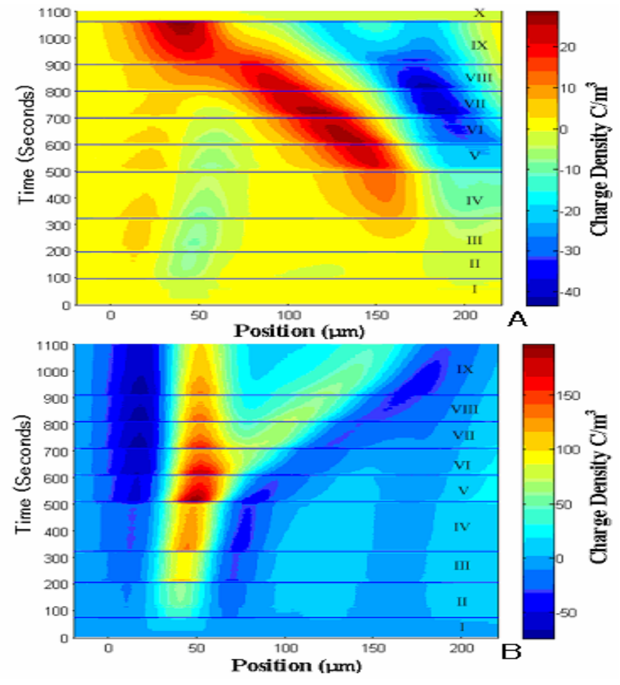

Fig. 7 Two dimension variation of space charge in Acryl Nitrile rubber (Type-I) insulation at different electric fields (i) 0.8kV/mm (ii)1.6 kV/mm (iii)3 kV/mm (iv) 5 kV/mm (v)10 kV/mm (vi)15 kV/mm (vii)20 kV/mm (viii)25 kV/mm (ix)30 kV/mm (x) just above 30 kV/mm . (A) +DC (B) –DC.

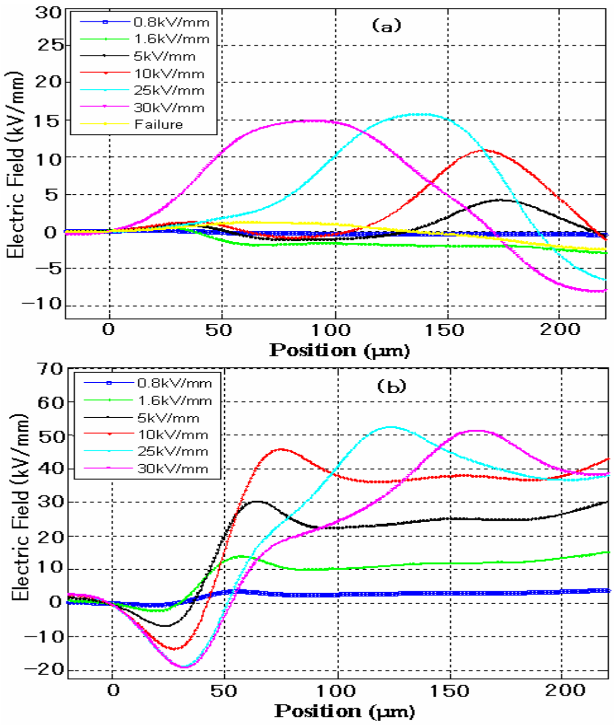

Fig. 8 Variation in Electric field in the bulk volume of the Acryl Nitryl rubber (Type-I) insulation material measured through PEA process (a) +DC (b) -DC

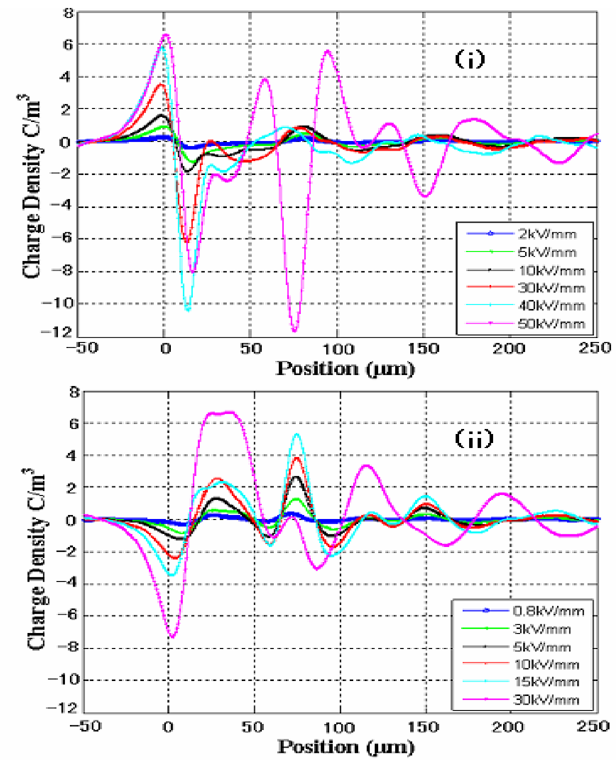

Fig. 9 Variation in charge injection magnitude in aryl rubber material (Type-II) at different electric fields (i) +DC (ii)-DC

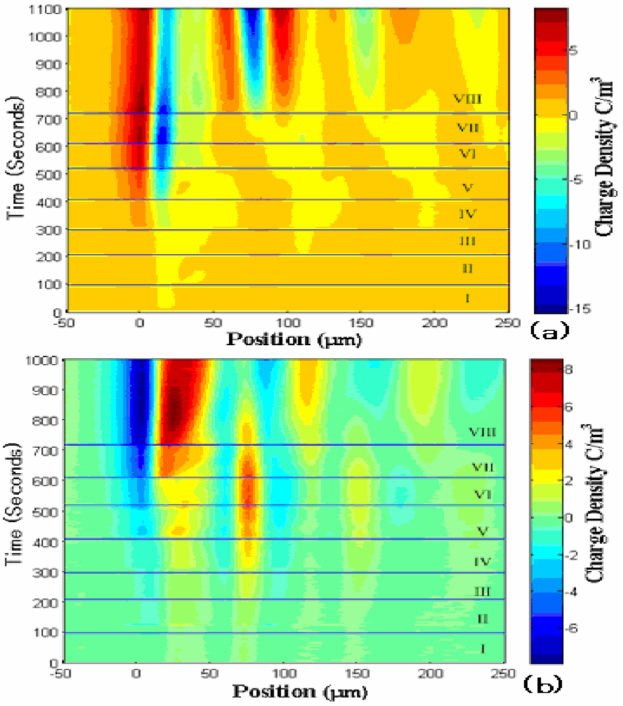

Fig. 10 Two dimension variation of space charge in Acryl Nitryl rubber (Type-II) insulation at different electric fields (I) 0.8 kV/mm (II)3 kV/mm (III) 5 kV/mm (IV) 10 kV/mm (V) 20 kV/mm (VI) 30 kV/mm (VII)40 kV/mm (VIII) 50 kV/mm (a) +DC (b) –DC.

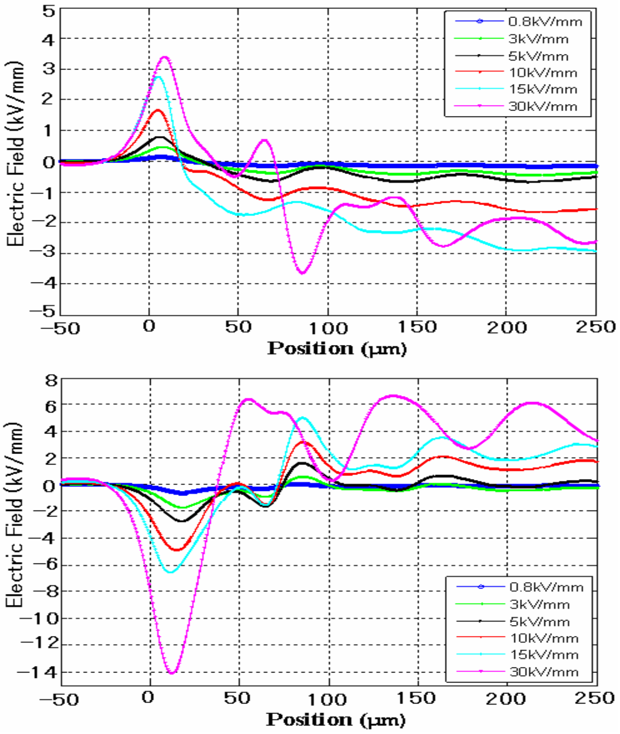

Fig. 11 Variation in Electric field in the bulk volume of the Acryl Nitryl Rubber (Type-II) insulation material measured through PEA process (a) +DC (b) –DC.

Fig. 6 shows a typical variation in magnitude of charge injection into NBR-Type1 material the insulation material at different electric fields under positive and negative DC voltage. It is also realized formation of heterocharges in the bulk volume of insulation. The characteristics of heterocharge injection injection into the bulk volume irrespective of polarity of applied DC voltage. It is also observed that the magnitude of injected charge is high with the negative DC voltage. This could easily be realized in the two dimension variation of space charge in the insulation material (Fig. 7). The heterocharge injection in the bulk volume could be due to charge trap sites in the insulating material. Natsui et al., carried out PEA studies in epoxy composites where they could conclude that charge migrates in to the bulk volume of the material [9].

Fig. 8 shows variation in the electric field in the insulation material under DC stress measured through PEA technique. It could be observed that operating electric field in the bulk volume is not constant and vary accordingly with the injected charge magnitude. Also it is observed from Fig. 8 that electric field magnitude due to space charge could enhance local electric field much higher especially under negative DC voltage.

Fig. 9 shows variation in injected charge magnitude under different electric fields in the Type-II insulating material. Comparing Figs. 6 and 8, it is observed that Type-II material where the magnitude of charge injection is less compared to that in the Type-I material. This could be due to addition of plasticizers. Hayase eat al studied space charge dynamics in LDPE nanocomposite material and could conclude that addition of nano material could reduce the space charge injection [10].

Fig.10 shows two dimensional pattern of space charge variation in the Type-II material. It is observe that heterocharge formation occurs in the bulk volume of the insulation. This formation could be formed because of the plasticizers, which could activate the process of heterocharge formation. Fig. 11 shows the variation in local electric field in the TYPE-II insulation material. It could be easily realized that the local electric field variation is less compared to Type-I material, allowing one to conclude that addition of plasticizer, eventhough it aids the formation of hetero charges in the bulk volume of insulation, due to less charge magnitude, in the volume, the electric field variation is also very much limited, thus allowing the material to operate at high electric field compare to TYPE-I.

Comparing Figs. 3, 6 and 9 the space charge magnitude is less with Type-II material. In addition, it could be realized that addition of any compound could alter the space charge injection characteristics of the insulating material. Also it is observed that addition of plasticizer could alter the charge injection process and could reduce charge trap sites.

V. CONCLUSION

The important conclusions obtained based on the present study are the following:

1. The PEA technique not only provides information about space charge dynamics, it could allow one to understand the safe operating electric field of the material.
2. Addition of any new compounds to the base material could alter the the charge injection process in insulation material.
3. Addition of plasticizers alters the charge injection magnitude and the mechanism
4. The characteristics of charge injection mechanism is almost the same under Positive or negative DC voltage but magnitude of charge injection is always high when it is operated with positive pulse and negative DC, which can cause early failure of insulation.
5. In acryl elastomers the heterocharges occurs adjacent to the operating electrode by fast charge injection process
6. In Acryl nitryl rubber insulation, heterocharge formation occurs. Also the addition of plasticizer into the acryl nitry rubber allows the material to operate at high electric fields.
7. It is confirmed, based on the present study that space charge injection can cause failure of insulating material during operation.

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