An Improved Pulsed Electroacoutic System for Space Charge Measurement under AC Conditions

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***Abstract*—In this paper, an improved space charge measurement system based on the pulsed electro acoustic technique (PEA) is presented. The new system gives an essential way to examine the role of space charge in electrical aging process under AC conditions. The system setup for AC measurement is presented and detailed in this paper with comparison to the old system. There are two features with improved PEA system. A pulse generator with a 3 kHz repetition rate is utilized to reduce the measurement time. The Eclipse data acquisition system is used to achieve the high data acquisition rate. The results which were taken from both old and new PEA system show that hetero-charge can be formed in the region close to the lower electrode under AC electric field. Apparently the results captured from the new system have better phase resolution than the old system. The space charge decay profile measured by the new system can reflect vividly on the charge dynamically changing. The utmost space charge information was saved as the measurement time was dramatically shortened by the improved system.**

Keywords-Space charge, PEA, AC electric stress, Eclipse

I. INTRODUCTION

Many studies have been carried out on space charge in polymeric materials under DC conditions. The attention paid to the space charge behavior under AC condition is limited because there are many factors which can affect the results such as varying magnitude of the sinusoidal voltage, charge injection/extraction due to the polarity reversal, material degradation, the measurement intervals, etc. However, information about charge dynamics under AC conditions is important for understanding ageing mechanism in the material.

As a most widely used technique in the field of space charge measurements, the pulsed electro-acoustic method (PEA) utilises the interaction between high voltage pulsed and the charge layer in the insulating material to produce the acoustic pressure waves. The waves travelling across the material are proportional to the charge at the layers. They are converted into an electrical signal by a piezo-electric transducer and amplifier and then they are captured with the digital oscilloscope.

The acquisition time of space charge profile is an important factor under ac conditions because the magnitude of the applied voltage varies with time. The faster acquisition will lead to a better representation of charge dynamics. Over the years, there are a few papers concerned with space charge measurement under AC stress [1-5]. The method presented in this paper has a better resolving ability under AC conditions.

II. SYSTEM STEUP AND EXPERIMENT DETAILS

A. Old AC Measurement System Setup

For space charge measurement under AC conditions, the correlation between the applied voltage and captured space charge density is needed to be considered carefully. A principle diagram for our previous AC PEA system is shown in Fig.1. It is capable of measuring space charge distribution in LDPE and XLPE films under AC stress at varible frequency from 1Hz to 50Hz controlled by a function generator [6-7]. The pulse generator is the key factor to detemine how fast the data acquisition is in the whole system. The specially built pulse generator with a 2ns pulse width and 600V ampilitude gives a good spatial resolution of the system. However this pulse generator uses a mechanical relay switch which has a working frequency of 500Hz. The space charge density result is transferred to the digital oscilloscope where averaging is performed.

The measurement control between the AC applied voltage and the triggering HV pulse in the old system is achieved with the method of the point on wave (P.O.W), as shown in Fig. 2(a). The pulse bursts on a defined point on the waveform and this yields space charge density output of corresponding magnitude and polarity on the required phase of the AC waveform.

The number of the points which can be chosen in one cycle is determined by the switching frequency of the pulse generator and frequency of the AC waveform. Because of slow data transferring between the oscilloscope and the GPIB card, there is only one data set that can be recorded in one cycle of the pointed wave as shown in Fig.2(b).

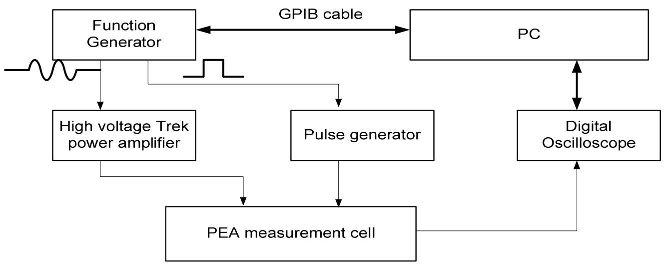

Figure 1. The old AC-PEA measurement system setup.

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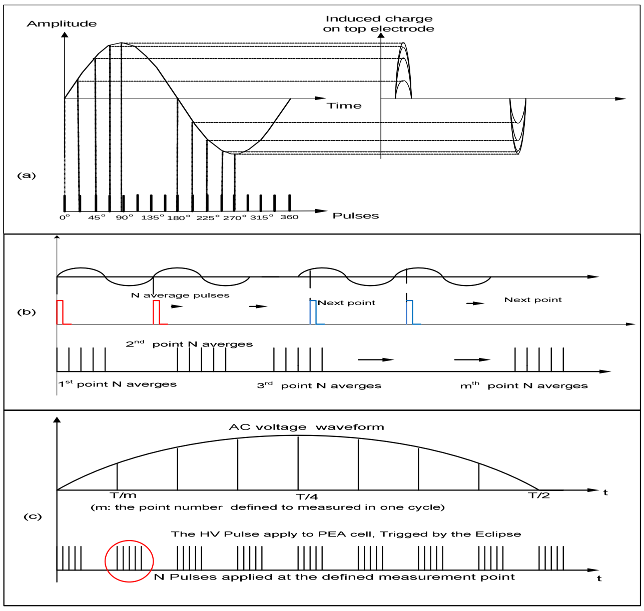

Figure 2. The point one wave method and the demonstration of pulse train and applied voltage.

In Fig.2 "m" is defined as the point number required to measure in one cycle and "N" is the average number to achieve a good signal to noise ratio for space charge signal. After completing a measurement of the expected averages N for first point, the pulse requires to burst on the next point with a phase shift for next N cycles till the last defined point m. The data transferring mode described above limits the number "m" in one cycle of waveform because the relationship between the frequency of pulse and waveform should satisfy the condition of $f_{pulse} < m f_{ac}$. The frequency of the pulse generator used in the old system is 500Hz. If 50Hz sine waveform is selected, the maximum points that can be chosen are 10, i.e. 36° between two measurement points. To get a better signal to noisy ratio, 100 to 500 data are required to be averaged. To complete all the measurement it will take a long time. For example the total time to complete 500 data for 8 points on 50Hz ac waveform is about 20ms×8×500=80s. The long measurement time is not desirable as it limits the accuracy of space charge profiles obtained. The problem becomes more obvious at high electric fields as charge evolution within the sample is faster.

B. New AC PEA Measurement System Setup

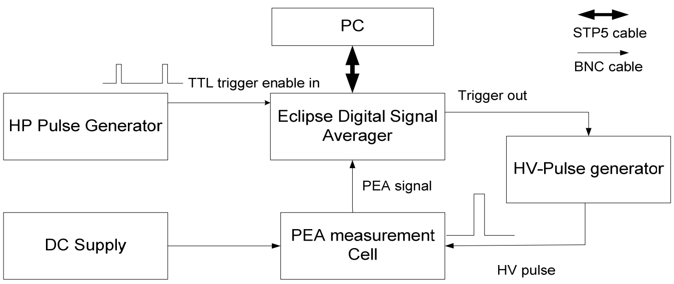

Figure 3. The Eclipse PEA system setup for DC measurement.

To overcome the problem mentioned above, a new PEA measurement system has been developed with a better performance.

Firstly, a specially built pulse generator is used in the new system. The solid-state switch of the ultra fast high voltage transistor from Behlke (HTS 50-08-UF) [8] has been used for the high voltage pulse generator. This pulse generator can produce high voltage up to 4kV with a narrow pulse width up to 5ns, which enables it to deliver a good spatial resolution signal for the PEA system. The maximum switching frequency of the HTS 50-08-UF switch is 3 kHz.

To achieve a short rise time of pulse (1.2 ns at present), the switch is placed next to the load in order to avoid the parasitic inductance and capacitance due to a long coaxial cable used or the mismatched impedance. According to our test, the amplitude from this pulse voltage decreases with the increase of pulse frequency. This may be due to the power dissipation of the switch which is in-directly proportionate to the switching frequency.

Secondly, the Eclipse signal average console [9] used in the new system differs from the oscilloscope which uses the trigger input and starts the acquisitions on receiving a suitable trigger pulse. Eclipse has a trigger output that must be used to trigger the PEA measurement when the data acquisition is in progress. A similar approach has been used in [10]. The new system has been initially tested under DC conditions to ensure it is in good work order. Fig.3 shows the diagram for DC measurement. The waveform from the PEA is captured and digitized by the Eclipse console. The signal input accepts signals within a bandwidth from DC to 450MHz. The analog input signal is added in a summing amplifier to the output of a 12-bit DAC before it is added to the 8-bit ADC. The Eclipse trigger is used to initiate the HV pulse generator in our PEA system and then the repeatable output waveform from the PEA cell is applied to the input connector of the Eclipse. The Eclipse permits a 2GHz effective sampling rate with a 500MHz (2ns per point) real time sampling clock. The number of scans to form a complete record is done by selecting sampling intervals of 0.5ns, 1ns, and 2ns. After the trigger generated by the Eclipse, a series of digitized voltage samples is taken to comprise a successive scan and the sampling interval (1ns or 0.5ns) will be introduced between the sampling clock and the trigger output signal. The resulting sampled points from the coming scans are then interlaced with the existing points from the previous scan to generate a complete record with a 1GHz (for 1ns) or 2GHz (for 0.5ns) effective sampling rate.

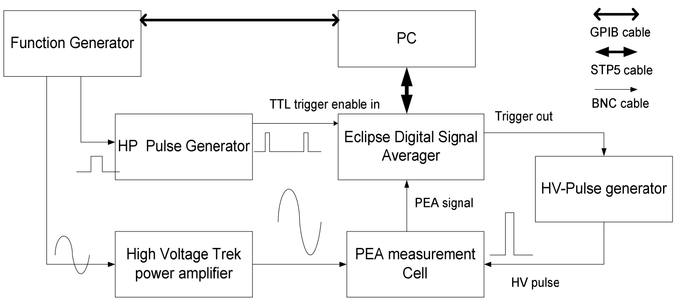

Figure 4. The Eclipse PEA system setup for AC measurement.

The TRIGGER OUTPUT of Eclipse is used to trigger the HV pulse generator, which is built with the FET switch. For our PEA system the trigger rate generated by the Eclipse is too fast (60ns width, 2.5V amplitude and up to 1.5µs period). The frequency of the TTL burst should match the maximum switching frequency, f(max), of the HTS 50-08-UF (3kHz). In this case the signal into the TRIGGEE ENABLE IN input of the Eclipse console can successfully trigger the Eclipse and control the output trigger, which is used to trigger the HV pulse generator. The TTL pulse triggering into the Eclipse is achieved by using a HP 8180 pulse generator with a frequency less than 3 kHz, a narrow pulse width between 300ns to 1µs and a pulse amplitude going above 3V.

Once the concept of the DC PEA system based on the new pulse generator and new aqusition system has been proved, modifications are made for its AC applications. Fig.4 shows the diagram of the AC PEA measurement system. Comparison to the DC PEA system, the synchronization of the pulse and the AC waveform is crucial. This is achieved by the function generator which gives the trigger signal to both the HP pulse generator and the HV Trek amplifier. The HP generator, Eclipse and HV pulse generator are trigged in sequence. Subsequently, the HV pulse and the amplified HV are applied to the PEA cell. The time delay of the pulse trigger transferring through the connections is considered and the compensation for the delay is added in the control signal.

Fig.5 shows the signal linked between every two components of the PEA system. The time delay is ignored in the diagram for easy discussion. The signal with the frequency of f_{ac} is generated from the function generator and added to the PEA cell after the HV amplifier. The frequency of the HV pulse generator is f_{pulse}. The "m" is the number of points defined to measure in each cycle. N is the pulses applied to the defined point. It can also be considered as the averages set in one cycle of the ac waveform, which is discribed in Fig.2(c). The relationship can be shown as $f_{pulse} = N \times m \times f_{ac}$, which is different from the old system. The average number N can be described from Eclipse as the records number multiplied by the sampling interval (2ns, 1ns, and 0.5ns), e.g. 0.5ns interval and 10 records gives 40 averages because of the interlacing requirements in the Eclipse system. The "N×m" value depends on the selection of f_{ac} and f_{pulse}. For example, if 2 kHz HV pulse and 10Hz ac waveform are applied to the PEA cell, 4 measurement points are defined in each cycle, 50 averages can be accomplished at every point. If 20 points are defined, 10 averages can be accomplished. Of course, 50 averages may not be enough to achieve a good signal to noise ratio, so a few more cycles may be required. If 20 cycles are selected to average for every defined point, it will take a total of 2 seconds to finish 200 averages at 20 measurement points under 10Hz. This is significantly faster than the old system using traditional P.O.W method to finish 200 averages at 10 Hz (200×0.1×20=400s).

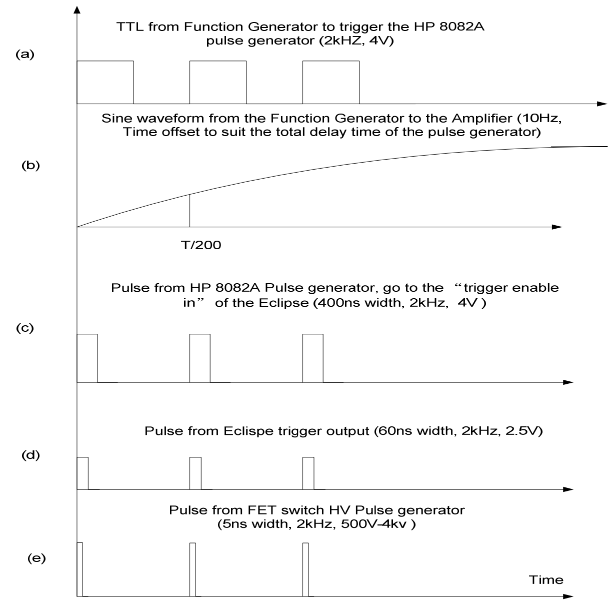

Figure 5. The diagram of the pulse contrl in the new AC PEA system.

The new system can achieve a very high data acquisition rate with a good phase resolving capability. For low frequencies e.g. 0.5Hz, maximum 3 kHz pulse, 30 points in one cycle, 200 averages can be achieved. The measurement can be completed in a single cycle. For high frequencies e.g. 50 Hz, maximum 3 kHz pulse 20 points in one cycle, 3 averages can be obtained and 67 cycles are required to achieving 200 averages in total, which takes 1.34s.

The data transfer through the PCI link between the Eclipse console and the PC is up to 25 Mbytes/s [9]. The record length of Eclipse can be chosen within the range of 512 to 262,000 points. For the thickness of the 50 to 200µm polymeric sample used in our experiments, the acoustic signal transfer between the two electrodes is about 25-100ns. The recording time less than 0.512µs is suitable to the PEA output signal capturing. Then the record length should be less than 1024 points, which is determined by the "recording time per record" and the "sampling interval," e.g. 0.512µs record, 0.5ns interval then the record points are 1024 or 1ns interval get 512 points. Each data point consists of 3 bytes. The max PEA measurement is 3000 data per second due to the max frequency of HV pulse is 3kHz, the equivalent rate is 3000×1024×3=9.3 Mbytes/s and this is much less than the 25 Mbytes/s series link from the PCI BUS master interface card.

III. EXPERIENTAL RESULTS

The sample used in the present experiment is additive-free low density polyethylene (LDPE) film of 180µm thickness.

A. Results Measured from the Old System

The result shown in Fig.6 is the space charge profile of the LDPE sample at various phases (every 45°) of the 50 Hz ac waveform, 8 points are selected. 1000 averages are taken to obtain smooth results and the total measurement time is 160s. The RMS value of the applied voltage is 3.5kV and the 600V with a 2ns width pulse is used. The result is taken after 2 hours AC stress ageing, hetero-charge can be found clearly next to the lower electrode area, and the positive charge can be found close to the upper electrode.

B. Results Measured from the New System

The new PEA system is initially used to measure charge distribution in the sample under DC stress. The pulse generator frequency is chosen as 2 kHz. The measurement takes 12 seconds and 60 series data were captured with 400 averages per data (0.5ns 100 records selected). The curves shown in Fig.7 were selected from the 60 data. The charge distribution shows that the new PEA system works as expected. The distinctive characteristic of the new PEA system is capable of illustrating smooth changing of the charge decay. The new PEA system will enable the space charge dynamic to be recorded in real time.

Fig.8 gives the results of the space charge profile under AC stress tested by the new system. The AC supply added to the sample is 1Hz and RMS value of the field applied is 2.8 kV. There are 24 series data selected in one cycle, 1 second. According to the expression of following, the average number N added to each point is around 80.

$$f_{ac} = 2kHz = N \times m \times f_{pulse} \approx 80 \times 24 \times 1Hz$$

To be recognized from each other, few curves with typically phase angle were selected from the 24 series data and shown in Fig.8. The induced charges captured at both electrodes show a good phase resolution at every 15° in one cycle. Polarity reversal waveform gives the hetero-charge in the region close to the lower electrode which is similar to the results shown in Fig.6. Compare to Fig.6, the space charge distribution along the thickness in Fig.8 is not so smooth. There are two possible reasons: (i) the average is less than 100 in the present case resulting in a lower signal to noise ratio, and (ii) reflecting true charge profile which is impossible for the old system.

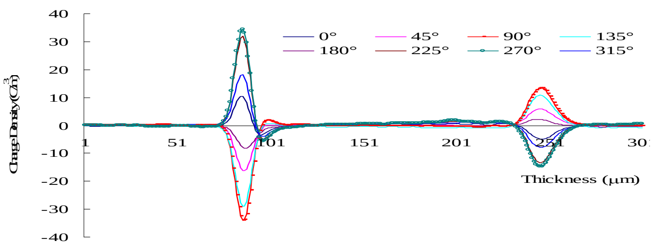

Figure 6. Space charge profile of LDPE sample under ac supply.

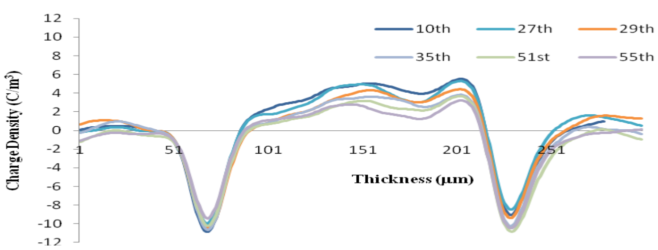

Figure 7. Space charge profile of Volts-off condition 60 series data tested in 12 second on the new system.

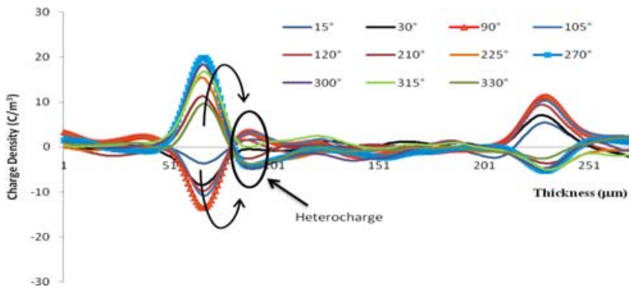

Figure 8. Space charge profile udner AC condition, f=1Hz, every 15° in one cycle.

IV. CONCLUSION

The PEA system based on the pulsed electro-acoustic technique for measuring space charge distribution in polymeric material under AC stress has been improved.

The purpose built pulse generator with the high frequency up to 3 kHz is used in the new system. The high speed measurement and good resolution give more details of charge dynamic in short period. The high data acquisition rate can be achieved by introducing the high speed real time data acquisition unit Eclipse in the new system. The frequency range of the AC supply is less limited due to the extraordinary resolving ability in the new system. The measurement time is dramatically shorted by the new system especially for the lower frequency; hundreds of averages can be achieved in one cycle. The good phase resolution can be found for both high and low frequency applied voltage.

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