ACOUSTIC SIGNAL PROPAGATION IN SOLID INSULATING MATERIALS

Abdul Samad[*1], *WH Siew*[1], *Martin Given*[1], *John Liggat*[2], *Igor Timoshkin*[1]

[1]*Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow*
2Department of Pure and Applied Chemistry, *University of Strathclyde, Glasgow*
* *abdul.samad@strath.ac.uk*

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Abstract

Polymeric insulating materials are considered as a crucial part of most high voltage components. The continuous high electric stress applied across the insulation material may, over a long-time duration, initiate partial discharges which deteriorate the insulation and lead towards dielectric failure. The detection of the acoustic pressure pulses generated as a result of partial discharges can be helpful in detecting and locating the PD at the initial stage. Detection of Acoustic Emissions (AE) is a well-established technique for gas and liquid insulation systems but is not fully explored in the public domain for solid insulation systems. In this work, propagation behaviour of the pressure acoustic wave in nylon 6,6 rods of differing lengths were analysed in the laboratory. The discharge events were created in air but near the surface of one end of the polymeric rod. The acoustic transducer was attached to the opposite end of the polymeric rod to detect the arrival of the propagated acoustic signal. It was determined, based on the first peak of arrival for all data, that the drop-in magnitude of the propagating pulses follows the $1/r^2$ relationship where r is the distance away from the discharging site.

1 Introduction

Insulation safety of the high voltage electrical components is vital for the continuous electrical power supply. Polymeric materials have better dielectric strength, cheaper and easy to process, therefore, these are being used as an insulation in high voltage electrical transmission networks. The initiation of partial discharge (PD) events due to the high electric stress over a long time or formation of electrical treeing due to protrusion or roughness of the surface, deteriorate the insulation characteristics of the polymeric materials which can lead towards the insulation breakdown and which can be costly for the supplier and utilities. In recent years, attempts were made to synthesize the materials with better dielectric characteristics [1] but, in parallel to that, it is necessary to develop suitable monitoring techniques to check the health of an electrical power cable and detect the discharge events at the time of initiation to prevent subsequent outage of the power supply system.

Many PD detection techniques, both on-line and off-line, have been implemented to monitor the insulation failure at early stages [2, 3]. Acoustic emission (AE) technique is a well-established technique to detect and locate the acoustics signal initiated from a PD event in liquid and gas insulated systems [4, 5], however, this technique has not been fully explored on solid insulating materials. The energy emitted from the discharge event is partially converted into heat and light, while rest of the energy is converted into a pressure pulse which can propagate through the material.

The motivation to conduct the research reported in this article was to investigate the propagation characteristics of an acoustic impulse in solid insulating materials and highlight and address the potential challenges in applying acoustic detection techniques to detect and locate the PD/electrical treeing in underground cable and cable joints. In this work, Nylon 6,6 was used to analyse the propagation behaviour of AE signal emitted from a discharge event in laboratory. A discharge was initiated in air near the surface of the one end of the Nylon 6,6 rod and an acoustic detector was connected with the surface of the other end of the rod to detect the acoustic impulse propagating through the materials. The propagation capability of AE signal in Nylon 6,6, speed of propagation of AE signal in Nylon 6,6, and relationship between drop in magnitude of the AE signal with distance were analysed. The results obtained can enable industry and engineers to consider the best way of using the technique to detect and locate PDs in solid insulating materials.

2. Methodology

Nylon 6,6 rods from Stockline Plastic limited were used as samples to investigate the propagation of acoustic impulses

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arising from an electrical discharge. The rods were cut into different lengths and acoustic impulse signals were observed at the end of each length of the rod. The discharge was created in air, 25mm away from the surface of the rod, using a needle-needle electrode topology with a separation of 2mm. The R15I-AST-150 KHz, AE acoustic sensor with integral preamplifier (Physical Acoustics, MISTRAS Inc) was used to detect the acoustic impulse. This sensor has the nominal frequency operating range of 50-400 kHz, and the resonant frequency of 150 kHz (ref V/μbar), [7]. The sensor was attached to the other end of the rod. Silicon gel was applied to the mating surfaces of the rod and the sensor to get better coupling of the acoustic impulse between the rod and the sensor.

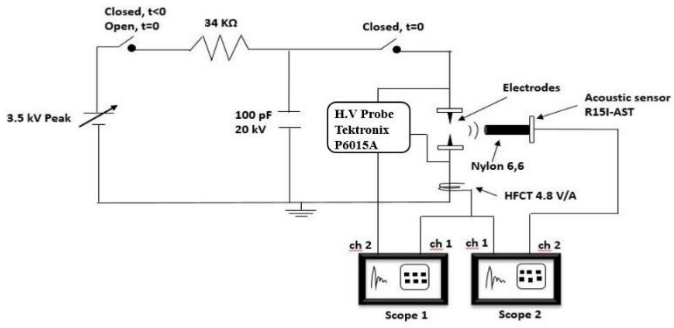

Fig. 1: Acoustic impulse test circuit arrangements

Figure 1 shows the acoustic testing arrangements. Two Tektronix oscilloscopes were used to record the information. Scope 1 was used to record the voltage and current developed across the electrodes before and after breakdown of the gap while scope 2 was used to record the acoustic impulse detected by the sensor. Further, current signals from the high frequency current transformer HFCT100, (4.7V/A calibration ratio, 100 kHz – 20 MHz -3dB frequency response, 22 ns risetime response) were fed to both scopes. To record each individual pulse from the discharge event on the scopes, the triggering mode of the scopes were used: both scopes were set to trigger by to the current impulse. As both of the scopes were triggered at the same time, Scope 1 was used to record the voltage and current waveforms while Scope 2 was used to analyse the acoustic impulse from the sensor. The advantage of using the two scopes was to observe the current impulse and voltage pulse which are very short duration and was recorded on scope 1, while the arrival time of the acoustic impulse was high and it was recorded separately on scope 2. Therefore, it was significantly advantageous to use two scopes to record the maximum information about current, voltage and AE impulse.

2.1 Initiation of Discharge

A 3.5 kV (adjustable) DC high voltage source was used to energise the electrodes for creating a discharge. The voltage was increased to charge the capacitor and breakdown the gap between the electrodes. Further, a 34 kΩ resistor was used to increase the time constant and achieve enough time delay between the discharge events. The output of the high frequency current transformer) and the high voltage probe (Tektronix P6015A, 75MHz bandwidth) were used to determine the time instant of discharge initiation.

3 Results

The acoustic impulses from the discharge were analysed for Nylon 6,6 rods of different lengths. The choice of the maximum length of the rod was made according to the propagation capability of the acoustic impulse. The 10 cm long rod was used as a starting point and then the longer rods were until the acoustic impulse was non-detectable by the acoustic sensor.

3.1 Voltage and Current

The capacitor was charged to develop the voltage across the gap between the needle electrodes until the breakdown point of the air gap between the needle electrodes. The output voltage and current impulses were recorded on scope 1. Figure 2 shows the current and voltage impulse across the needle gap.

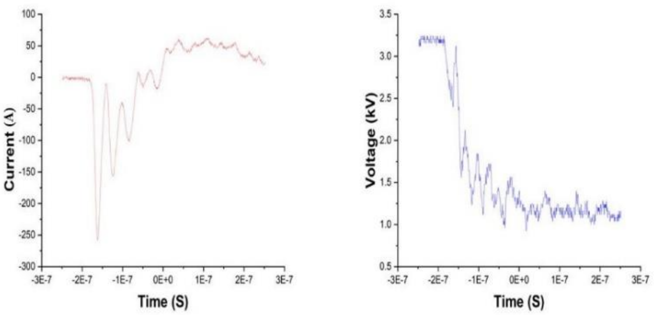

Fig. 2 (a) Current Impulse after gap (b) breakdown Voltage impulse across the needle gap

3.2 Acoustic Impulse

The propagating acoustic impulse was observed at scope 2. To ensure the fine contact between sensor and the rod, 20 measurements were taken for each length of the rod. The sensor was disconnected after each measurement and consistency of the output was ensured. Figure 3 shows the acoustic impulse detected at the sensor for different lengths of the Nylon 6,6 rod.

Further, the speed of the propagating acoustic impulse was estimated by using an adaptation of the time of arrival method, as described hereafter. The scope was synchronized with the discharge current pulse, and the launch of the acoustic pulse was assumed as the moment when the current pulse occurred, thus triggering the scope. As the acoustic impulse travels through the rod, the moment the transducer starts recording the signal was considered as the arrival time of the acoustic pulse. The propagation speed was then estimated based on the time of arrival and the length of the rod. The authors understand that the procedure used is not in accordance with the Standard but the adaptation gives a reasonable estimate for the purpose of this preliminary study. Experiments were conducted with rods of different lengths and the arrival time of the pulse was recorded for each length to analyse the relationship between the length of the rod and the corresponding arrival time of the pulse before estimating the propagation velocity. The propagation velocity of the acoustic pulse was estimated to be 2100 ± 10 m/s by using the distance travelled and the time of arrival of the first peak of propagating acoustic pulse.

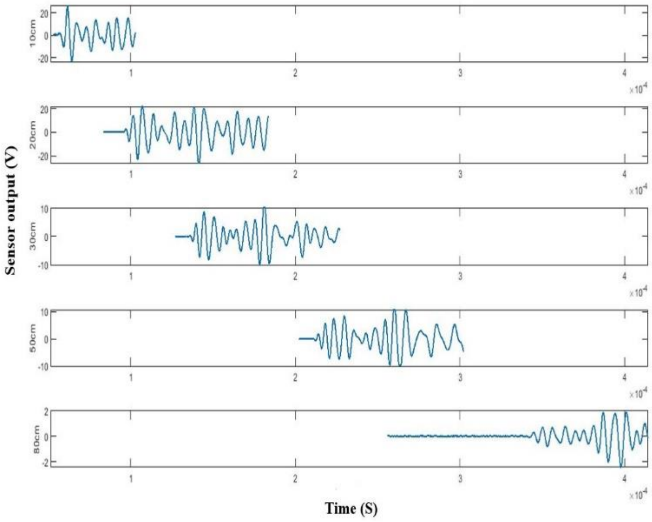

Fig. 3 Voltage signal associated with acoustic impulse detected by acoustic sensor for different lengths of Nylon 6,6 rod.

Moreover, drop in magnitude of the propagating acoustic impulse is the key factor to analyse the propagation capability of the acoustic impulse in Nylon 6,6. For each length of the rod, a total of twenty measurements were conducted. In each measurement, the drop in the peak magnitude of the first acoustic impulse was recorded. This process was repeated for all the different rod lengths to investigate any variability of the observed data. Figure 4 illustrates the plot of the analytically measured peak magnitude of the first acoustic impulse for each length of the rods used. The error bars represent the deviation observed in the twenty measurements conducted for each rod length. The x-axis represents the lengths of the rods, while the y-axis represents the measured peak magnitude. The inclusion of error bars provides a visual depiction of the variability and uncertainty associated with the measurements. It was observed that the magnitude of the voltage signal associated with propagating acoustic impulse has a $1/r^2$ relation where, r is the distance from the discharge site to the observation point.

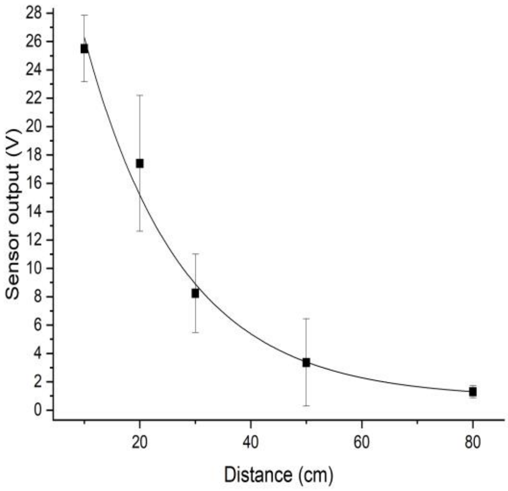

Fig. 4 Drop in acoustic impulse magnitude along the length of the rod.

4 Discussion

The results show that the acoustic impulse from a discharge has the capability to propagate through the polymeric materials and was detectable until 80cm long Nylon 6,6 rod unlike the observation made in a FEA based COMSOL simulation model by T. Czaszejko [7]. The COMSOL based model simulation was carried on different polymers other than Nylon but, significant difference in the propagation characteristics suggest that each individual of polymer family reacts differently towards the propagating acoustic impulse. Therefore, we cannot rule out the use of the acoustic detection techniques to detect and locate the fault in solid polymeric insulations based on the characteristic's behaviour of some of the polymers. The results suggest that the propagation capability of AE impulse significantly depends upon the physical characteristics and morphology of the polymers. Further investigations will be carried to highlight the effects of the morphology and physical characteristics of material on propagating AE impulse.

Moreover, AE detection technique is well established to detect and locate the PD fault in transformer oil but, analysis of the detected AE signal is a very challenging task. The properties like, density, viscosity, and elasticity of the propagating medium, the nature of the sound source, and the external environment in which the acoustic source is located, greatly affect the propagating AE signal. This complex interplay between the properties of the propagating medium, the nature of the source and the environment in which the source is located causes the AE signal to follow different path lengths or travel with different velocities. This results in a complex signal at the detector. Unlike liquid insulation systems where the reflections are very high due to the non-uniform propagating medium, there was no significant reflections observed in Nylon 6,6. From figure 3, AE signal detected at sensor has more than one impulse in each case. The presence of multiple impulses can be traced by the external reflections. As the discharge was created in air away from the surface of the rod and the acoustic impulse emitted from the discharge site travels in air and strike with the surface of the rod. It was observed that some of the acoustic energy was reflected back from the surface of the rod. This acoustic pulse after being reflected, can collide with the electrode setup and the rebounded back to the surface of the Nylon rod, subsequently propagating through the material as shown in figure 5. However, these reflections can be avoided by creating a discharge event within the insulation.

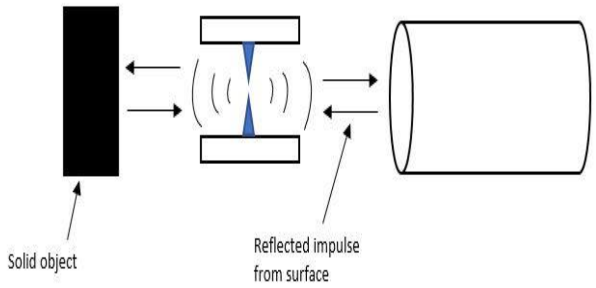

Fig. 5 Reflection of AE impulse model.

Furthermore, prior to striking the surface of the Nylon rod, the acoustic impulse travels through air which results in dissipation of the acoustic energy. When this impulse strikes with the surface of the rod, some of the energy is transmitted into the material, while the remaining energy is reflected back from the surface. However, we all know that in actual PD event in a cavity in an underground cable insulation or cable joint, some of the energy is converted into heat and light while rest of the energy is available to initiate the acoustic impulse. In our case, significant decay in the energy of the acoustic impulse occurred due to two reasons; first, the propagation of the acoustic impulse through air before striking the surface of the rod, and second, the reflections from the surface of the rod. This is in addition to the energy loss incurred by heating and lighting. Further, investigations will be carried to determine the proportion of energy distributed as heat, light, and acoustic pulse component that emanate from a discharge source. However, despite all this energy loss, the partially transmitted acoustic energy was still detectable after 80cm of propagation through the material. This suggests that the acoustic impulse may be able to travel until hundred centimetres, which is promising for it`s application in detecting PD in cable joints.

5 Conclusion

This article describes the propagation capability of an acoustic impulse in Nylon 6,6 rods emitted from an electrical discharge event. Although the decay rate of AE impulse is high which limit the use of the acoustic detection technique in solid insulating materials but, the results suggest that the acoustic impulse can propagate through the Nylon rod up to 80cm. The propagation of acoustic impulse in other members of the polymeric family can be investigated using the above approach to validate the acoustic detection approach in locating and detecting the PD event in solid insulating materials. Further investigations are required to explore the effects of material`s physical properties and morphology on the propagating pressure acoustic wave. The results of the study can be used to inform engineers how best to use the technique for partial discharge detection and location in solid insulating materials.

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