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Analysis of Dielectric Properties of Polyurethane Between 50 Hz and 400 Hz Frequencies

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***Abstract*:** *Insulation is very important for electrical equipment especially in power grid. Insulation failures cause short-circuits and damage equipment. Also insulation fails can create danger for human life. So it is important to know dielectric behaviors in different operation conditions. Ideally a solid dielectric can be represented with a capacitor but practically every dielectric have losses and that loss is represented with a parallel or series resistance. Fundamental parameters of a dielectric are permittivity, loss factor, dissipation factor, capacitor value, resistance and power loss. Common seen problems with solid dielectrics are breakdown, partial discharge and various physical decays. In this paper, effects of frequency to dielectric parameters and problems are investigated theoretically with models and existing works in literature. After that dielectric analysis methods are studied and experiments are done for polyurethane at 50 Hz-400 Hz frequency range. Results are given with graphics and effects of frequency are explained. At high frequencies, the dielectric characteristics can be perishable.*

Keywords: *dissipation factor, polyurethane, solid dielectrics.*

1. Introduction

The introduction of insulators begins with the development of the electrical equipments in 1800s. Complex dielectrics products are not manufactured up to 1920s and instead of dielectrics, rubber, some fabrics, etc. the ingredients were used. In the beginning of 19 th century, with the increase of the use of the alternating voltage, higher voltages began to be used, and stepped in transformers and isolation has become critical. In 1925, alkyl resins and bakelite has been used as first synthetic insulators [1-3]. After then 1930's PVC has been used at electrical insulations. High quality insulators have been produced by the development of composite and synthetic materials. Research on this subject is still going on. Today, with the technological developments, the usage areas of electrical insulators are also increasing. At the beginning of these fields, high voltage power system components and low voltage high frequency applications (RF transmitters, SMPS circuits, etc.) are used as main insulators. The determination of the insulation quality provided by various conditions are very important for safe operation. For this reason, it is necessary to measure the dielectric properties under the conditions in which the insulating materials used in different fields and operating conditions. In the first part of the article, the effect of frequency on various electrical parameters, theory and case studies in the literature have been examined. Experiments are carried out to show the effect of frequency on polyurethane insulators and the results are given in graphical form with insulators under the same conditions. In this way, the behavior of insulators between 50-400 Hz frequencies has been tried to be understood theoretically and experimentally.

2. The Effect of Frequency on the Electrical Properties of Insulators

The properties and parameters affecting frequency in solid insulators can be listed as breakdown voltage, treeing, partial discharge, capacitance, conductivity, complex dielectric constant, loss factor, temperature and humidity. There are situations that distort the smoothness of the electric field with increasing frequency. Positive and negative ions travel from one electrode to another under the influence of an electric field. In high frequency voltages, ions sometimes cannot complete the path between the electrodes because the polarity of the electric field changes very quickly. This creates noise which leads to distortion of the electrical field uniformity. However, after a critical frequency value, the breakdown voltage is reduced by up to 20% in smooth and nearly uniform electric fields and up to 50% in uneven electric fields. Treeing that shorten the life of the insulator significantly, causing electrical punctures over time are gas and water bubbles, mechanical deformations and conductive particles. The effect of frequency on this process can be seen in high-frequency applications, as well as in advancing technology, with many non-linear charges leading to harmonics in the electrical network [4]. Partial discharge affects the life of solid insulators at the critical level. One of the many factors that affect partial discharge is the frequency of applied voltage. In general, the frequency increase leads to more frequent lower amplitude emitters [5].The process of planting can be divided into 3 phases as initiation, development and escape (inception, propagation, runaway). The frequency of the applied voltage affects the starting point of the treeing and the shape of the treeing. Capacity is expressed in formula (1). It depends the geometry of substances and the real dielectric constant.

$$C_x = \frac{\varepsilon.\acute{\varepsilon}.S}{a} \tag{1}$$

Conductivity is expressed in formula (2). It appears to be connected to the frequency and loss factor (the virtual part of the dielectric constant).

$$\sigma = \omega.\varepsilon_0.\acute{\acute{\varepsilon}} \tag{2}$$

The complex dielectric constant, which is one of the most important parameters of an insulator, is shown at (3).

$$\varepsilon = \acute{\varepsilon} - j\acute{\acute{\varepsilon}} \tag{3}$$

The real part refers to the ideal isolator (the energy storage level of the capacitive part) and the virtual part refers to the loss of the insulators (loss due to resistance). In practice, there is no lossless insulator, so a resistor representing losses is placed, either in series or parallel to the model. In this case, a phase difference of 90 ° between the current and the voltage will occur in the pure capacitor. This difference has the "δ" angle and is expressed as "tan δ" dissipation factor (4).

$$\tan \delta = \frac{\acute{\acute{\varepsilon}}}{\acute{\varepsilon}} \tag{4}$$

The complex dielectric constant expression can be expressed by the Debye curve (fig.1).

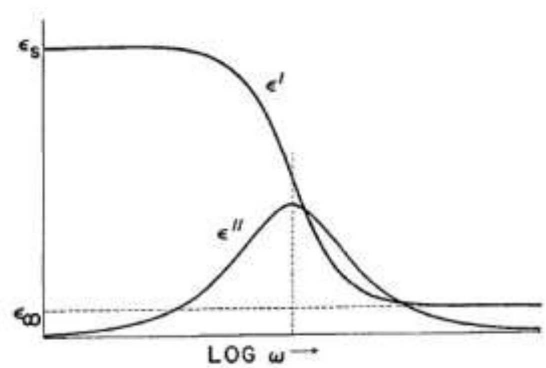

Fig. 1: Debye Curve

With the increase in temperature, the period of relaxation decreases and the frequency at which the loss factor of the Debye curve reaches its peak value (ε ") shifts to a higher value [6]. Moisture is an important factor that seriously weakens electrical insulation. Composite insulation, which is preferred due to its lightness, mechanical strength and high resistance to contamination is high moisture absorption in high voltage systems[7-8].

3. Experimental Study

In the experimental studies, the dielectric properties of polyurethane dielectric materials such as capacitance and loss coefficient are examined and the insulation qualities are compared with other solid insulations.
Rp and εr values are calculated by using the values of Cp, tanδ and Pk obtained by the measurements made with CP TD1 device. Parallel insulator model is used in all calculations.

$C_x = \frac{\varepsilon_r.\varepsilon_0.S}{a}$ (Capacitance of sample) (5)

$C_0 = \frac{\varepsilon_0.\varepsilon_{r\,air}.S}{a}$ (capacitance of air at the same geometry) (6)

S = 18,0956 cm^2 (Electrodearea)

a = Sample thickness (mm)

$$\varepsilon_r = \frac{C_x}{C_0} \quad (7)$$

$\tan\delta = \frac{1}{\omega C_p R_p}$ (dissipation factor) (8)

tanδ and C_p values are obtained from the measurements so R_p for the insulators is obtained from (8).

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} \quad (9)$$

$$\varepsilon = \varepsilon' - j\varepsilon'', \qquad \varepsilon = \varepsilon_{0.}\varepsilon_r \quad (10)$$

$$\varepsilon' = \varepsilon_r \cos\delta \; \varepsilon'' = \varepsilon_r \sin\delta \quad (11)$$

The dielectric loss index tanδ value is used in the comparison of the dielectric losses. Since the dielectric loss is directly proportional to the square of voltage and frequency ($P_k = U_2.\omega_p.C_p.\tan\delta$), the relative dielectric constant and loss (scattering) factor values determine the true quality of the dielectric material. The smaller the loss index, the better the insulation.

3.1. Test Results

All measurements are made at ambient temperatures of 18.7-20.4 ° C, relative humidity of 35-41%, pressure values of 30.21-30.33 inHg (76.73-77.03 cmHg).3kV, 2kV and 1kV are applied according to the strength of the material. In all measurements, the frequency is applied between 50 Hz and 400 Hz with 50 Hz increments. All materials are cut into 1.5, 2, 3, 4 mm thicknesses as 15 cm x 15 cm. The electrodes used are Rogowski geometry and the surface area is 18.0956 cm^2. The following figures are for 2kV and 1.5 mm thickness of sample.

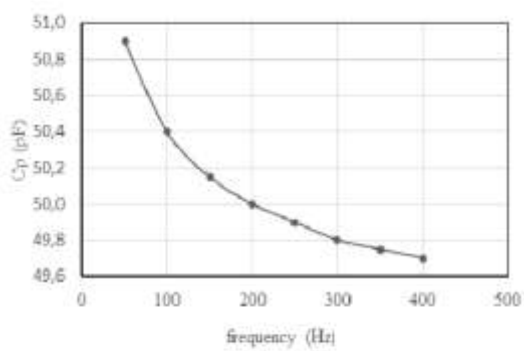

Fig. 2: Variation of Capacitance Depending on Frequency

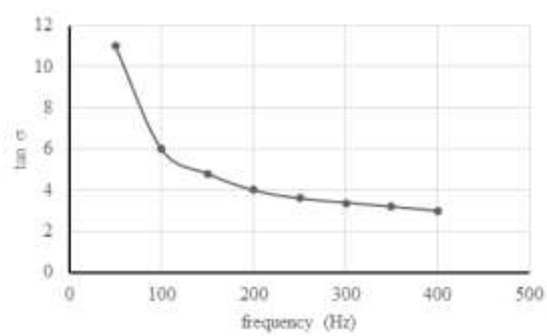

Fig. 3: Variation of Dissipation factor Depending on Frequency

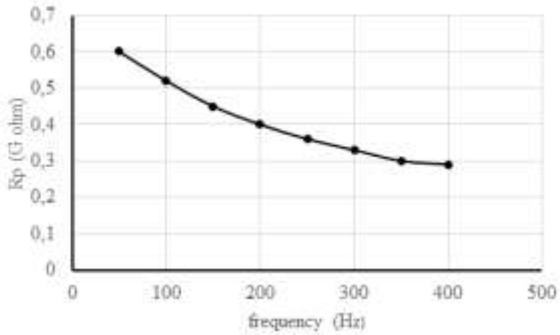

Fig. 4: Variation of Resistive Value of Dielectric Depending on Frequency

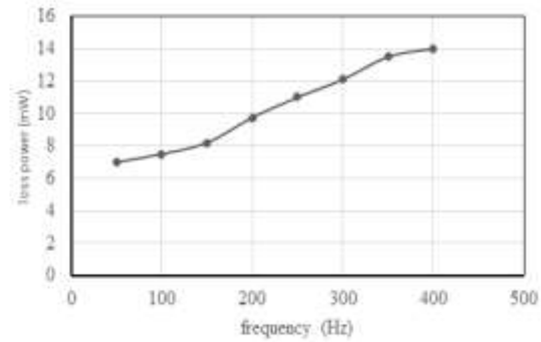

Fig. 5: Variation of loss power depending on frequency

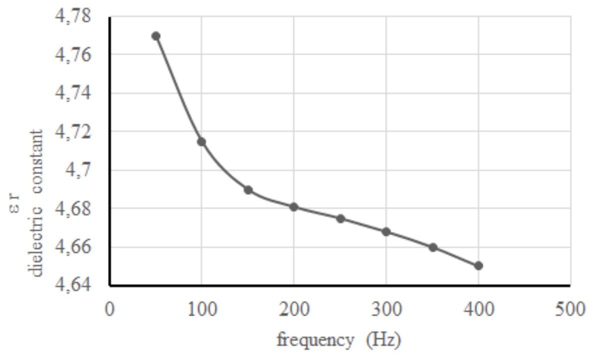

Fig. 6: Variation of dielectric constant depending on frequency

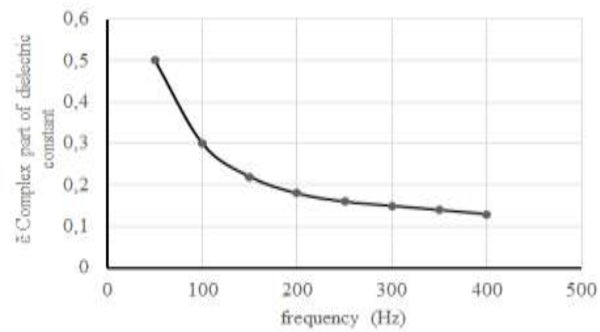

Fig. 7: Variation of complex part of dielectric constant depending on frequency

The above results for polyurethane with a thickness of 1.5 mm are shown. For polyurethane with a thickness of 4 mm, the value is in the range of 19.45-18.96 pF (50 Hz - 400 Hz values). The Rp value is at the level of 2.811-0.674 Gohm. The tanδ value is in the level of 5.8217-3.1122 percent. The relative dielectric constant increased to 4.86-4.74. By examining with the loss index, the polyurethane at a low frequency of 4 mm and at a high frequency of 1.5 mm has better insulation.

4. Conclusion

Polyurethane has excellent resistance to rupture, tearing and abrasion between -30 and -100 ° C. It is resistive to air and ozone and also resistive mineral oils, grease and aliphatic hydrocarbon. Especially it is used as high pressure sealing element and shaft stripper. In all the measurements, the parallel insulator model capacity (Cp) showed a very small decrease. It is observed that the capacity increase of the materials together with the frequency increase. A relatively small amount of relative dielectric constant (εr), which varies in direct proportion to the capacitance (thickness constant), has been found to decrease. According to the Debye model, there is a decrease in the dielectric constant due to the frequency increase. In the real part of dielectric constant, there is a slight decrease according to the capacity decrease. A relatively small amount of relative dielectric constant (ε_r), which varies in direct proportion to the capacitance (thickness constant), has been found to decrease.

According to the Debye model, there is a decrease in the dielectric constant due to the frequency increase.It is seen that all of the materials decrease together with the parallel resistance (Rp) frequency increase. Given that an ideal parallel insulator model requires parallel resistances to be zero, it has been observed that with increasing frequency, the isolators move away from the ideal and the leakage current flowing with the falling resistance increases. The loss of power (Pk) in proportion to the increase of the current has increased in all of the materials. With increasing frequency, more current flow and power loss of the insulators can lead to overheating of the insulator and deformation in case of severe heating. In general, it can be said that insulators functioning smoothly at the power frequency of 50 Hz and 60 Hz. It can safely be used at frequencies below the power frequency, whereas insulators above the power frequency, especially at frequencies above 1 kHz, can partially lose their function. When choosing the insulators in high frequency applications, the basic electrical parameters of the insulators must be taken into as well as their frequency-dependent behavior.

5. References

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