Investigation of the Sound Transmission of a Partial Discharge through a Solid Dielectric Multilayered Device

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Introduction

Electric discharges that do not completely bridge the electrodes are called partial discharges (PD) [1]. Inside a solid dielectric PD are caused by small gas filled cavities or inclusions consisting of dirt or textile fibres. During a partial discharge event an electromagnetic pulse and light are emitted. Fundamental for this investigation is the fact, that additionally an elastic wave is generated which propagates through the solid dielectric. PD take place in the interior parts of high-voltage cable devices. A representative high-voltage cable device is the outdoor termination. The outdoor termination is a device to realise the transition from the cable to the overhead line. A sketch of outdoor termination is given in Figure 1. The insulation (2) and the stress-cone (3) form the **solid dielectric multilayered device**. The inner layer is made by cross-linked polyethylene (XLPE), whereas the outer layer is made by liquid silicone rubber (LSR). In this multilayered device the PD occur. Hence, in the following a layer system is investigated, consisting of XLPE and LSR.

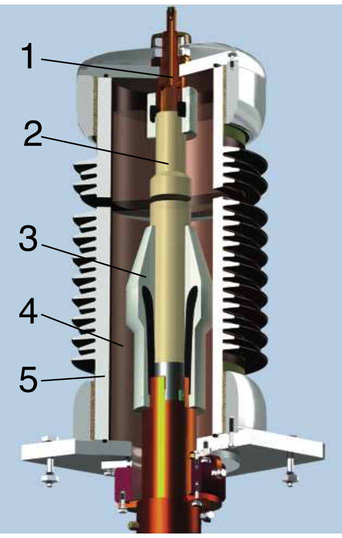

Figure 1: Setup of a high-voltage outdoor termination.1 - conductor, 2 - insulation, 3 - stress-cone, 4 - insulating fluid, 5 - housing.

Modelling the sound transmission

The solid dielectric multilayered device is simplified to a stack of two parallel layers that are rigidly bonded at their interface (layer 2 and layer 3). The modell is completed by an upper (layer 1) and a lower liquid semi infinite half-space (layer 4), see Figure 2. When an incoming longitudinal plane wave of magnitude $A_{L,1}$ and angle of incidence $\theta_{L,1}$ is arriving the interface between layer 1 and layer 2 a fraction of the wave of magnitude $B_{L,1}$ will be reflected. The remainder will split into a longitudinal wave $A_{L,2}$ and transversal wave $A_{T,2}$ for the forward direction and waves of magnitudes $B_{L,2}$ and $B_{T,2}$ for the backward direction respectively. In layer 3 the waves will be refracted again into the components $A_{L,3}$, $A_{T,3}$, $B_{L,3}$ and $B_{T,3}$. Finally in layer 4 only a longitudinal wave of magnitude $A_{L,4}$ and angle $\theta_{L,4}$ will propagate.

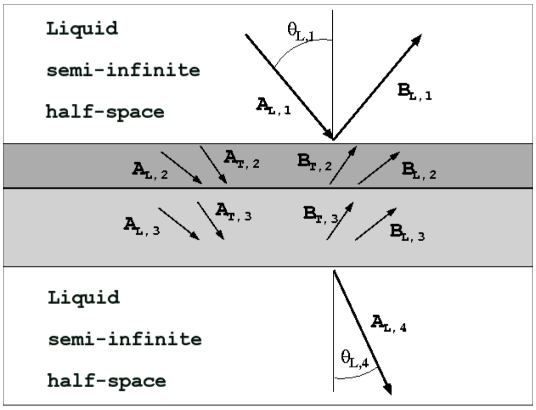

Figure 2: Modell of the multilayered system.

The sound transmission is described by the transmission efficiency a_T which is defined as

$$a_T = \frac{transmitted\ sound\ intensity}{incident\ sound\ intensity} \quad [\,] \qquad (1)$$

The lower and the upper half-space is filled with same fluid. This leads to a simple expression for the transmission efficiency which relates the outgoing wave ($A_{L,4}$) to the incoming wave ($A_{L,1}$).

$$a_T = \left| \frac{A_{L,4}}{A_{L,1}} \right| \quad [\,] \qquad (2)$$

To evaluate the expression in Equation (2) a transfer matrix technique is applied to analyse the solid layers. Herein it is assumed that each solid layer has isotropic homogeneous properties. Since both longitudinal and transversal waves can propagate, the transfer matrices have the size of 4 x 4. The overall transfer matrix is achieved by multiplying the matrices of the individual layers. To make quantitative computations it necessary to have the material properties complex longitudinal wave modulus L, Poisson's ratio μ and the mass density ρ of the solid layers. Especially the values for L were not

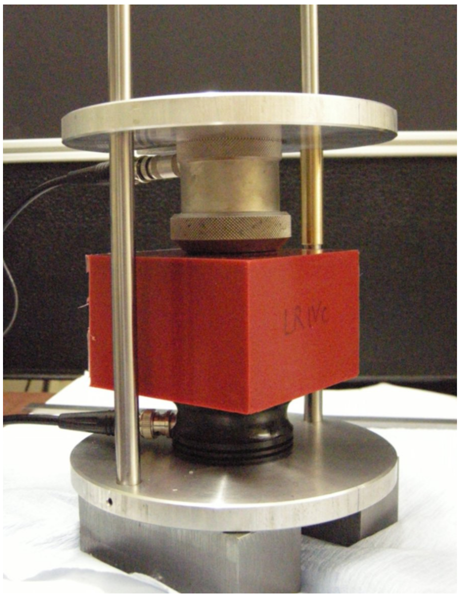

Figure 3: Measurement cell operating in through transmission at a center frequency of 500 kHz.

fully available in the literature, therefore measurements had to be done.

Material characterisation by means of Ultrasonic Spectroscopy

With the measurement cell depicted in Figure 3 the longitudinal wave velocity c_L and the attenuation a_L has been determined in the frequency range from 200 kHz to 700 kHz. The longitudinal wave velocity is calculated using the two sample technique by measuring the sample thicknesses d_A and d_B and the transmission times t_A and t_B as shown in Equation (3).

$$c_L = \frac{d_B - d_A}{t_B - t_A} \qquad \left[\frac{\mathrm{m}}{\mathrm{s}}\right] \qquad (3)$$

Also the attenuation is achieved by applying the two sample technique. The variables u_A and u_B in Equation (4) are the corresponding amplitude spectra of the transmitted pulses [3].

$$\alpha_L = 20 \log \left(\frac{u_A}{u_B}\right) \frac{1}{d_B - d_A} \qquad \left[\frac{\mathrm{dB}}{\mathrm{m}}\right] \qquad (4)$$

With the known wave speed and the attenuation the loss factor η as given in Equation (5) can be determined [4].

$$\eta = \frac{\alpha_L c_L}{\pi f} \qquad [\,] \qquad (5)$$

For the materials investigated namely cross-linked polyethylene (XLPE) and liquid silicone rubber (LSR) the loss factors are $\eta_{XLPE} \approx 0.03$ and $\eta_{LSR} \approx 0.006$ at 300 kHz respectively. Since the loss factors are smaller than one ($\eta \ll 1$) Equation (6) holds for the longitudinal wave modulus L.

$$L = \rho c_L^2 (1 + j\eta) \qquad \left[\frac{\mathrm{N}}{\mathrm{m}^2}\right] \qquad (6)$$

Mat.	Layer	ρ	L	c_L	d
		$[\frac{kg}{m^3}]$	$10^9\,[\frac{N}{m^2}]$	$[\frac{m}{s}]$	$[cm]$
Si-oil	1, 4	900	0.9	1000	∞
XLPE	2	920	$4.2 + j0.14$	2140	2
LSR	3	1104	$1.2 + j0.008$	1035	5

Table 1: Set of parameter used for the analysis.

Finally the evaluated parameters are given in Table 1.

The last unknown material parameter which is necessary for the computation of the transfer matrices of the solid layers is the Poissons's ratio. For the LSR-layer the Poisson's ratio is set to $\mu_{LSR} = 0.499$. For the XLPE-layer the value is varied ($\mu_{XLPE} = [0.35, 0.40, 0.45]$).

Results

For this set of parameter (Table 1) and the defined Poisson's ratios the transmission efficiency a_T is computed for normal incident plane waves shown in Figure 4 and for oblique incident plane waves and fixed frequency shown in Figure 5.

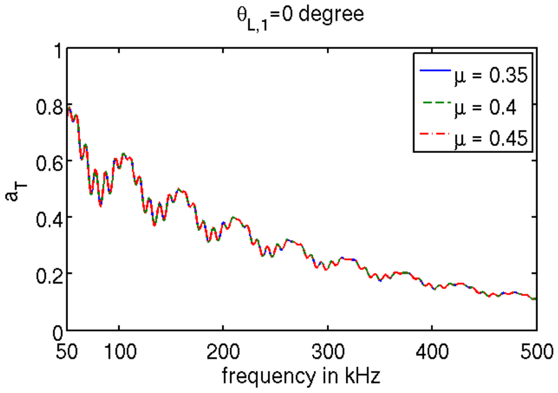

Figure 4: Transmission efficiency at normal incidence.

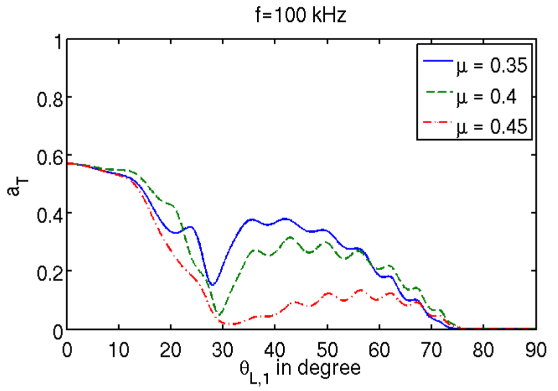

Figure 5: Transmission efficiency depending on the angle of incidence at a frequency of 100 kHz.

Remarks

It is found out that there is sufficient transmission of sound at 50 kHz and a low angle of incidence ($\theta_L \leq 15°$) to detect PD internal to the structure. Another observation is that the Poisson's ratio of XLPE of the example investigated has a big influence on the transmission behaviour at angles $20^\circ \leq \theta_L \leq 60^\circ$.

References

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