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doi:10.15199/48.2016.04.44

Using of wavelet transform in the analysis of AE signals accompanying the process of epoxy resins electrical treeing

Abstract. *The paper presents a computer application developed for analysis of acoustic emission signals accopanying the process of electric treeing occurring in polymeric materials, and in particular epoxy resins used as high-voltage solid insulation. A method for measuring, recording and registration of signals was presented. In particular,it is shown how the developed application uses wavelet transformation to remove noise from the recorded signal, and to carry out a time-frequency analysis of these signals. The results of the sample analysis of the recorded signals were also shown.*

Streszczenie*. W artykule zaprezentowano aplikację komputerową opracowaną w celu analizy sygnałów emisji akustycznej towarzyszących procesowi drzewienia elektrycznego materiałów polimerowych, w szczególności żywic epoksydowych stosowanych jako wysokonapięciowa izolacja stała. Zaprezentowano sposób pomiaru, rejestracji i rejestracji sygnałów. W szczególności pokazano w jaki sposób opracowana aplikacja wykorzystuje transformację falkową do usunięcia szumów z zarejestrowanego sygnału, a także do prowadzenia analizy czasowo-częstotliwościowej tych sygnałów. Pokazano również wyniki przykładowej analizy zarejestrowanych sygnałów.* ***Analiza sygnałów emisji akustycznej towarzyszących procesowi drzewienia elektrycznego materiałów polimerowych***

Słowa kluczowe: transformata falkowa, drzewienie elektryczne; badania nieniszczące, izolacja wysokonapięciowa.
Keywords: wavelet transform, electrical treeing, nondestructive testing, high voltage insulation.

Introuduction

The high-voltage devices with insulation made of solid dielectrics major factor acting destructively on these dielectrics are partial discharge (PD) occurring on their surfaces or in their structures. The presence of PD causes deterioration of electrical insulation properties and leads to progressive destruction of the insulation. In the PD present in solid dielectrics is very often associated electrical treeing process comprising forming a conductive tubular channels in dielectric structure. Discharges occurring in these tubules causing its further development by creating a form of tree or shrub, leading eventually to short-circuit of the electrodes. So these predictions are for the insulation in which the tree began are catastrophic. Therefore, the diagnosis condition for the high-voltage insulation is very important information about whether the process treeing in the insulation started. This paper concerns the analysis of the signals recorded during the treeing dielectric constant which is epoxy resin and a continuation of the work presented in [4,6]. A computer program for time-frequency analysis using wavelet transform is presented.

First publication concerning of study on solid dielectrics breakdown, including phenomena of electrical treeing, dates back to the first half of the twentieth century [13]. Later, continuated research concerned inter alia the impact of physical and chmiacal properties of solids on the intensity of the electrical treeing and impact of this process on the high insulation performance. Discribed were, the relationship between rust and partial discharges as well as the degradation of the insulation and the shape of voltage. In [8, 9] was described the influence of the PD intensity depending on the phase of a sinusoidal signal. It revealed the presence of PD in increasing quadrants of period of sine wave voltage.

Analysis of the phenomena of electrical treeing in this researches was based on partial discharge measurements in use of electric methods and recording optical phenomena taking place during PD (eg. registration under the microscope electrical treeing process, measuring the luminance of a registered image).

This article concerns the study of electrical treeing process using one of non-destructive device diagnosing methods - acoustic emission. In this method, measured, recorded and analyzed are acoustic waves, propagating in the dielectric solids.

Measurement stand

The study has been performed on cuboidal samples of the dimensions 25×10×4 mm. One of the cuboid sample walls of the dimensions 25×4 mm was covered with a conducting paint. Into the opposite wall a surgical needle of T-25 type was melted into during preparations of sample. Such a needle has a tip with 12 μm radius of curvature. The distance between needle and conducting paint layer was regulated before painting the wall by honing it.

The sample prepared this way was located in a transparent cuboid container made of methyl polymethacrylate, filled with transformer oil.

The alternating voltage was obtained from a single phase 220 V/ 30 kV 10 kVA test transformer fed from a low-voltage distribution network through an adjustment autotransformer. One of the test transformer terminals was connected to the conducting paint layer while the other, through a R=200 kΩ resistor, for limiting the breakdown current, to the needle electrode.

The high voltage was measured with an electrostatic voltmeter.

Measurement stand schema and photo of the sample in a holder is shown on Fig. 1.

The sample located in the electroinsulating oil filled container has been observed under an STM 723 type microscope with adjusted magnification (from 40 to 160×). The microscope was provided with CCD camera of medium resolution. The vision signal from the camera was recorded with a TV card installed in a computer.

For purpose of measuring the acoustic emission signals an R3α type piezoelectric converter manufactured by PAC has been used. The elastic waves generated in the sample were transmitted to the converter with a wave-guide. The wave-guide was made of a steel rod of 2mm diameter and a length of 20 cm. One of the wave-guide ends was located in a hole bored in the dielectric sample (next to the needle, at a distance 2,5 cm), while the other was fixed in a cone made of polymethacrylate methyl. The cone was connected to the converter through an acoustic paste . That length is guaranteed not to incite the rod during measurement. The electric signal from the converter was amplified with a 2/4/6 PAC preamplifier and then filtered with a filter of 20÷1000 kHz transmission band. Afterwards, the signal was amplified by an AE5A PAC amplifier and recorded on a computer hard disk with the use of a measuring card NI USB-6251. This card allows to record signals from 16 different analog channels with sample frequency up to 1 MS/s.

Parallel to signal recording, picture of studied sample - given by microscope - were captured by monochromatic camera connected to PC by TV CARD. Thanks to this, parameters of acoustic emission signal were synchronized with visual diagnosis of sample internal structure.

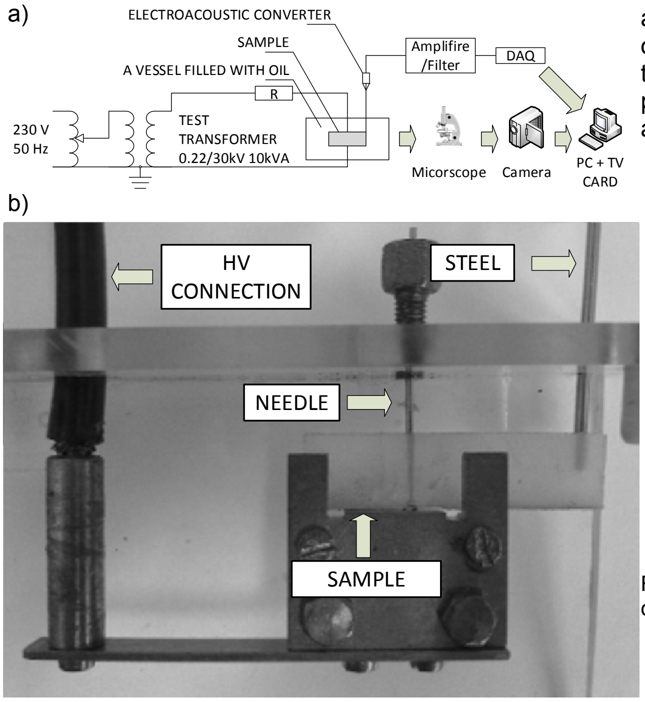

Fig. 1. Measurement stand schema a) and photo of the sample in a holder b)

Application

For the purposes of recording and analyzing EA signals a computer application in .NET Framework was developed. In measuring unit of the program samples recorded by measuring card are transferred to computer drive with the use of developed by producer, NIDAQmx drivers. This software after selection of used card channel, connected to measurement equipment creates sufficiently long cyclical data buffer. After filling half of the buffer with samples, the program begins, parallel to filling next part of the buffer, transferring data from buffer to a file. This procedure allow for continuous signal registration, without losing (overriding) part of signal as a result of delays caused by buffer release. Samples recorded with signal were saved in binary file as a series of double precision values with head section contains parameters of measurement (i.e. date, sampling frequency).

With recorded signals off-line analysis were performed. At the beginning signal was subjected, with use of Matlab Wavelet Toolbox, to wavelet transformation according to formula 1:

$$CWT(a,b)=\frac{1}{\sqrt{a}}\int_{-\infty}^{\infty}s(t)\psi\left(\frac{t-b}{a}\right)dt\,, \tag{1}$$

where: a – scale coefficient, b – time shift coefficient, s(t) – recorded signal, ψ – basic wavelet function (transformation kernel).

Thanks to the signal decomposition accordance with Mallat's pyramid algorithm, described in [12], signal has been decomposed into low-pass part (totality) and high-pass part (detail). Noise recorded with AE signal were removed by cutting off detail at chosen decomposition level. Figures 3, 4, 5 shows respectively: part of recorded signal, signal after de-noising and wavelet transformation of this signal as a scaleogram, graph analytical to amplitude spectrum in Fourier Transform, defined by formula 2:

$$S(a,b)=\left|CWT(a,b)\right|^{2}. \tag{2}$$

The filtered signal, with reduced coefficients at low scale values were subjected to statistical analysis. As part of this analysis calculated inter alia: real mean squared value of one-second part of the signal, AE events and emissions in time increase, AE event rate. To calculate those signal properties application lets user to define event threshold and emission threshold as shown in figure 2.

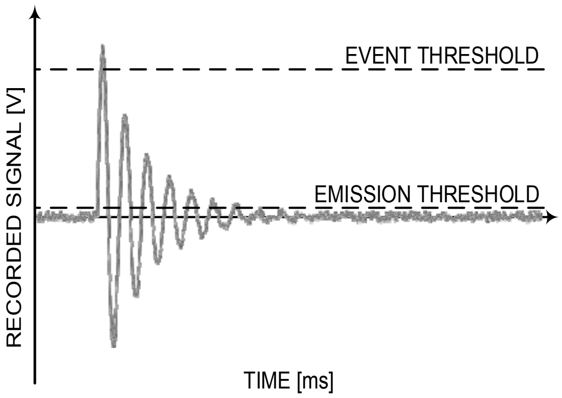

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Fig. 2. Configurable threshold for event and emission rate calculation

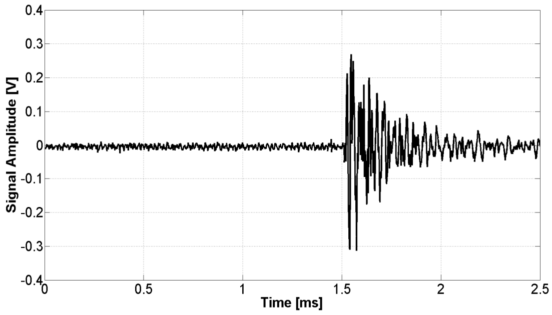

Fig. 3. Sample of recorded signal

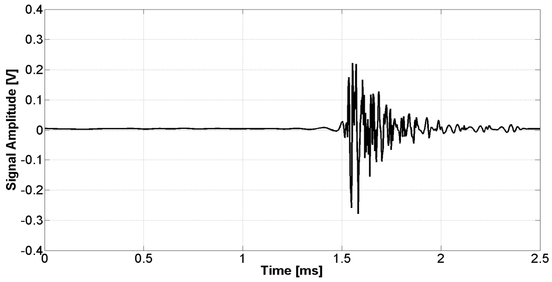

Fig. 4. Signal from fig.3 after filtration

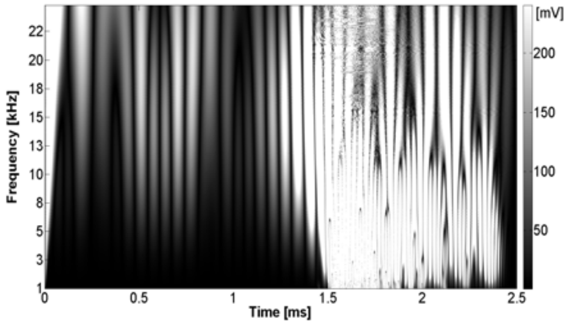

Fig. 5. Scaleogram of filtred signal

Figure 6 shows spectrum of whole recorded signal. It was cut-off to frequency 200 kHz (maximum frequency of FFT for recordings is 0,5 MHz) because higher frequency amplitude level is less then noise level.

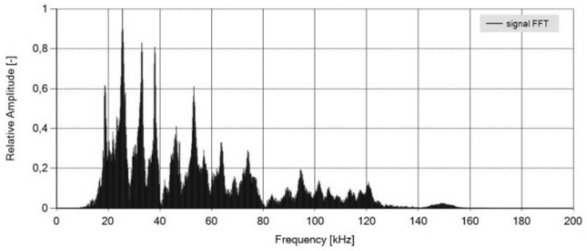

Fig. 6. Spectrum of sample of filtered recorded signal

Figure 7 shows amount of acoustic emissions per one second of recorded signal. Figure 8 shows amount of acoustic emission events, defined on figure 2, per one second of recorded signal.

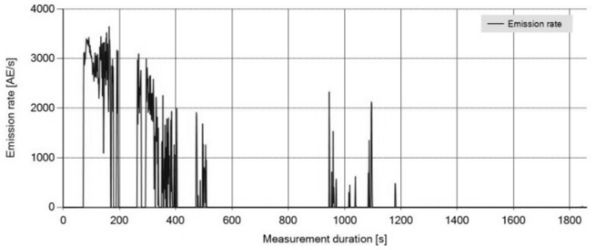

Fig. 7. AE rate during attempt

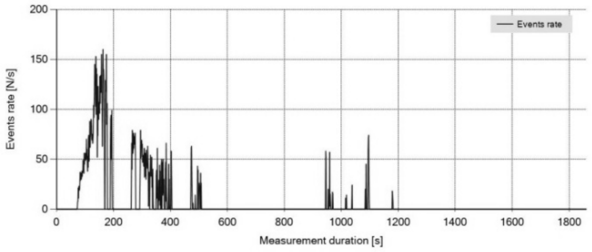

Fig. 8. Events rate during attempt

Figure 9 shows RMS value of one-second parts of recorded signal calculated for all recorded data.

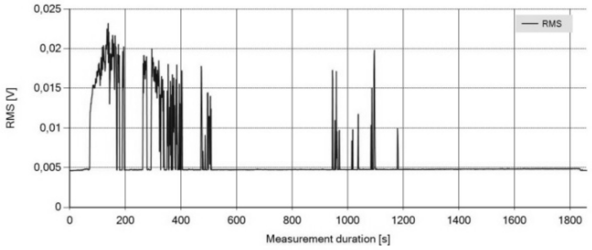

Fig. 9. RMS value during attempt

Summary

Our previous researches proved that measuring, registering and analyzing of AE signals related to electrical treeing of solid dielectrics is possible and can give an information about this process [4,6].

Presented computer application is a step ahead, because AE signals connected with the epoxy resins electrical treeing has smaller amplitudes and energy than previous analyzed materials (i.e. methyl polymethacrylate). It was necessary to improve analyzing software for analyzing such signals.

Concluding:

1. Described application allows noise reduction and then determination scaleogram of signals of small amplitudes (very small signal to noise ratio).
2. Use of the Matlab Wavelet Toolbox gives possibility to use different transformation parameters, in particular the selection of wavelet function coefficients, i.e. the order and scale. This possibility let to find the most suitable wavelet function for our purpose.
3. Presented examples of calculations confirm the effectiveness of the method and the versatility of application program developed for the analysis of non-stationary signals.
4. The applications can be useful for time-frequency analyzing of non stationery signals, such AE signals accompanying the process of electrical treeing.

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