MEASUREMENTS OF ACOUSTIC EMISSION INDUCED BY PARTIAL DISCHARGES IN FOIL-BASED CAPACITORS FOR THEIR QUALITY ASSESSMENT

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Abstract − There is a continuous pressure to increase quality of the passive elements at reduction of their production costs. Therefore, present methods of their quality assessment have to be reconsidered to avoid usage of the elements that could break down and lead to serious economical losses. This paper compares results of capacitor tests introduced by the obligatory technical standards and measurements of acoustic emission induced by partial discharges within voids in foil-based capacitors. We suppose that presence of voids within dielectric and foil structures can lead to capacitor damage and can not be detected by measurements of dielectric loss or capacitance only.

Keywords: acoustic emission, partial discharges, quality

1. INTRODUCTION

Almost all domestic electrical equipments comprise foils-based capacitors used for reduction of electromagnetic interferences emitted by these tools. Such popularity means a continuous need of their quality enhancement when costs of the used materials and of the assembly process have to be reduced. Both requirements are contradictory and lead to the necessity of a more strict quality monitoring than required by the present and obligatory technical standards. These standards are time-consuming and there is no clear answer which of the tests is more informative than the others.

The presently-applied procedure tests only a small fraction of the capacitors production and takes even 1000 hours of their extensive charging and discharging. The capacitors are treated as well prepared when any of the capacitors breaks down. The tiny number of the tested (and even smaller of the eventually broken) capacitors causes that we need more sensitive tool to collect more data about their quality.

The obligatory technical standards, except of the mentioned time-consuming procedure, demand that the tested capacitors have to sustain excessive supply voltage within interval of 60 s. The voltage exceeds a few times the capacitors rate voltage and can lead to their dielectric destruction. Thus, we propose to observe whether partial discharges are present within this period. The acoustic emission (AE) signals caused by partial discharges can be analyzed and applied to characterize capacitors quality.

2. CAPACITOR IMPERFECTIONS

The foil-based capacitors are produced within five separate stages: winding the metalized foils, baking and shaping, spraying metalized contacts, terminal welding and final packing [1-3]. The production stages can introduce various imperfections within the capacitor structure which limit their durability. These defects can appear due to poor quality of the applied materials or incorrect production parameters, especially during foil winding (creation of air voids) or sprayed metalized contacts. Distribution of voids that can exist in the capacitor structure illustrates fig. 1.
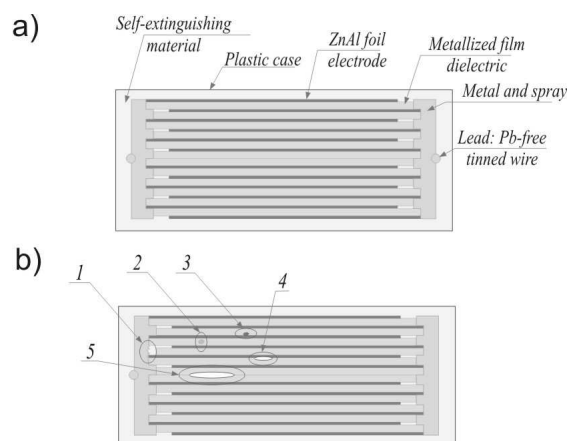

Fig. 1. Capacitor cross-section: a) across the wound foil, b) with the distinguished imperfections; 1 – faulty connection between the metalized head and dielectric, 2 – intrusion inside the dielectric structure, 3 – intrusion at the metal surface, 4 – air void at the metal surface, 5 – air void between the dielectric layers.

All the illustrated voids can be characterized by a higher voltage gradient than the rest of dielectric that leads to partial discharges there. This phenomenon causes a partial breakdown of the dielectric by sparking across the existing voids. Intensity of this phenomenon depends among other things on a void size and the inside humidity that characterizes conditions at their production process. It does not result immediately in a complete insulation breakdown but can cause rapid deterioration of the dielectric film and/or metallization due to the hot spot temperature resulting from the heat concentrations during the sparkling [4-6].

The sparking can be characterized by charge amount that takes part in the event or by sound emitted during the event. This effect is similar to the sounds of thunder after lighting [7].

3. ACOUSTIC EMISSION MEASUREMENTS

The measurement were performed within the set of 60 foil-based capacitors of nominal capacitance 27 nF (type WYP, class Y2) and of the rate voltage 275 V_{RMS}, produced by the polish company Miflex S.A. Capacitance (fig. 2a) and dielectric loss (fig. 2b) of the tested capacitors was measured just after their production by the bridge GenRad 1689M. These measurements can not single out the capacitors of various qualities because variation of these parameters between the samples is not remarkable.
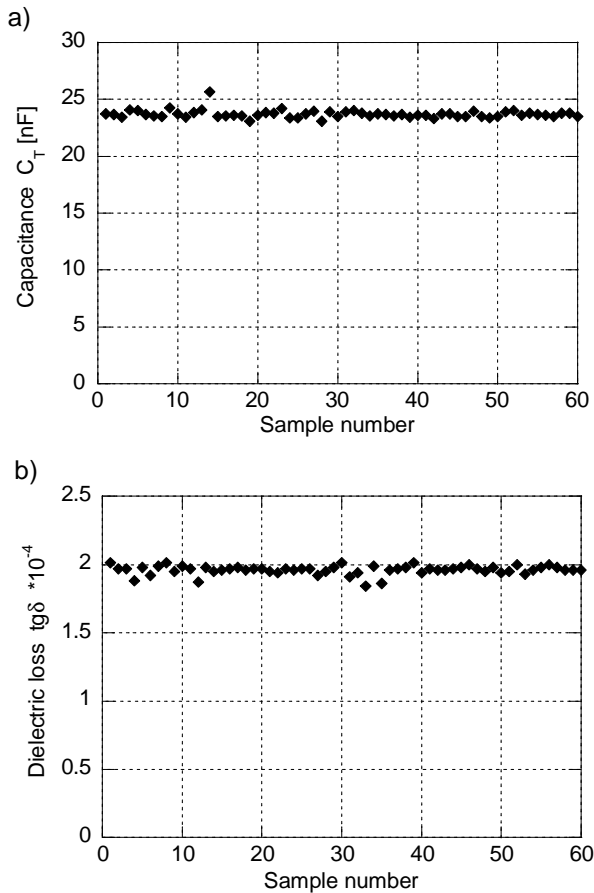
a)

b)

Fig. 2. Variations within the set of tested capacitors: a) capacitance C_T, b) dielectric loss $tg\delta$; the measurements were done at 1 kHz and capacitor polarization 1 V.

Therefore, we propose to measure AE signals to gather more information about their quality. The multichannel oscilloscope Tektronix TDS5034B was utilized to register parallel (fig. 3):
- AE signal emitted by the capacitor under test C_T,
- current pulses, that flow through the discharge free capacitor C_S=500 pF and are caused by partial discharges in C_T, measured as a voltage drop across the resistor R=50 Ω,
- voltage at the moment when partial discharge took place (attenuated by capacitor voltage divider C_1=14.9 pF and C_2=13 nF).

AE signal was measured by the piezoelectric sensor VS45-H of bandwidth 20÷450 kHz, produced by Vallen-Systeme GmBH and joined directly to the oscilloscope input. The sensor was placed on top of the tested capacitor and hold slightly by the elastic band (fig. 4). The slit between the capacitor C_T and the sensor was filled with the same gel as used during USG check-up.
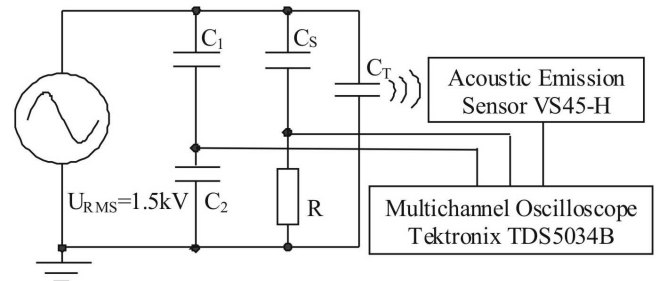

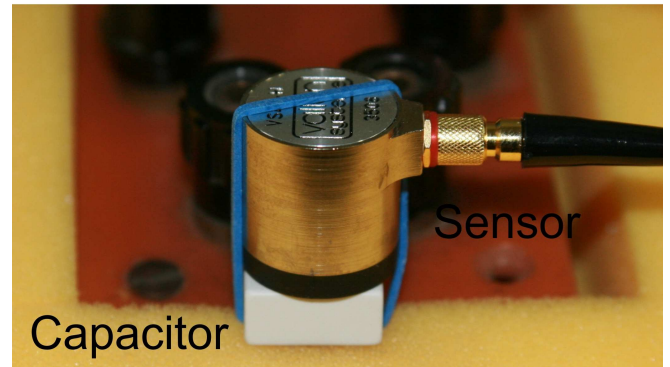Fig. 3. Measurement setup applied for investigation of partial discharges in the tested capacitor C_T.

Fig. 4. Photo of the tested capacitor under the applied acoustic sensor.

The capacitor C_T was tested by applying alternating voltage of 50 Hz and of 1500 V_{RMS} intensity within period of 60 s, as is assumed by the obligatory technical standards for the electrical strength test in the class Y2 capacitors. When the acoustic signal exceeded the threshold value that was set a little bit over the system background noise the oscilloscope registered all three signals. Only some of the tested capacitors exhibited partial discharges. We observed up to 20 events of various intensity but similar shape, typical for acoustic emission phenomenon (fig. 5a) [8]. The current pulses, observed as a voltage drop U_R across resistor R were

less intensive than AE signals (fig. 5b). We registered sequence of 10000 samples separately for each event at sampling frequency 10 MHz.
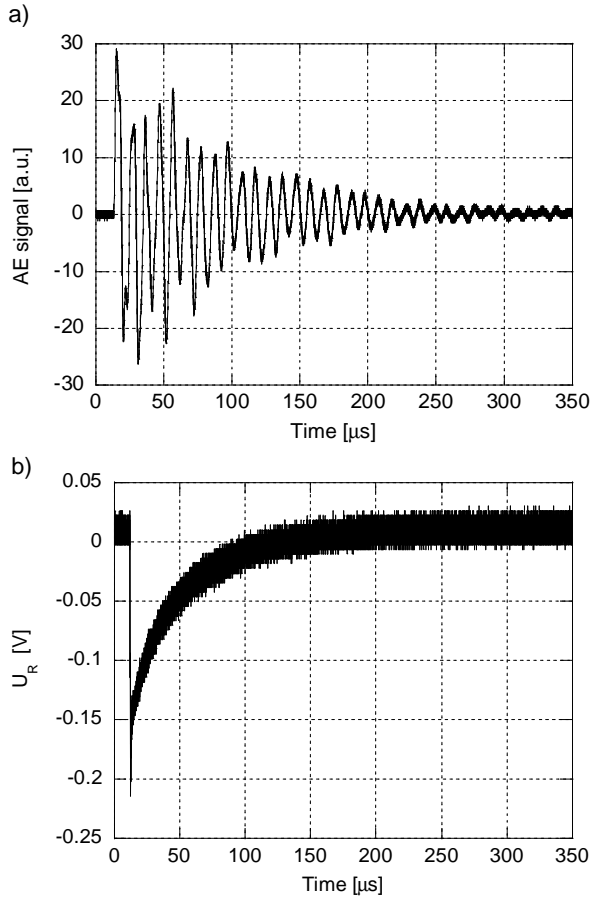
a)

b)

Fig. 5. Signal observed during partial discharge event: a) AE signal, b) voltage drop U_R across the resistor R.
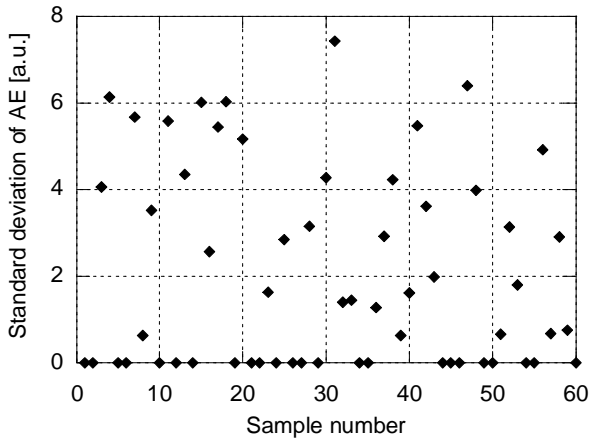

Fig. 6. Standard deviation of the AE signal observed in the set of tested capacitors.

We used statistical parameters (standard deviation, skewness and kurtosis [9]) to characterize the registered AE signal as was proposed by Gulski and Kreuger [10]. Standard deviation σ of random signal x indicates dispersion of the registered samples [11]. Skewness measures asymmetry of the probability distribution of the analysed signal x as in (1).

$$\gamma_1 = \frac{E(x - E(x))^3}{\sigma^3} \tag{1}$$

where operator E denotes averaging. Skewness is zero for samples having normal distribution.

Kurtosis is a measure of the "peakedness" of the probability distribution of the signal x as defined in (2).

$$\gamma_2 = \frac{E(x - E(x))^4}{\sigma^4} - 3 \tag{2}$$
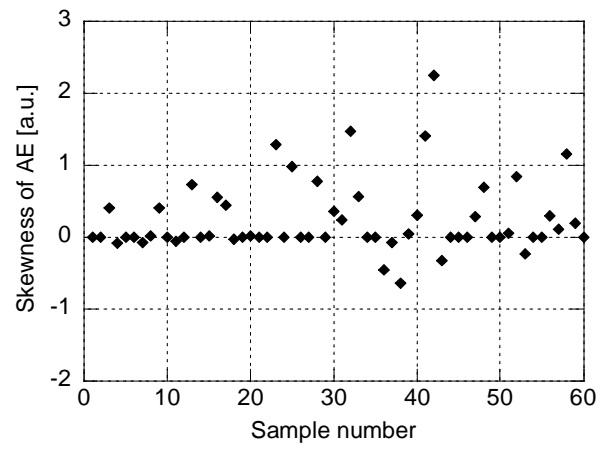
Kurtosis is zero for normal distribution.

Fig. 7. Skewness of the AE signal observed in the set of tested capacitors.
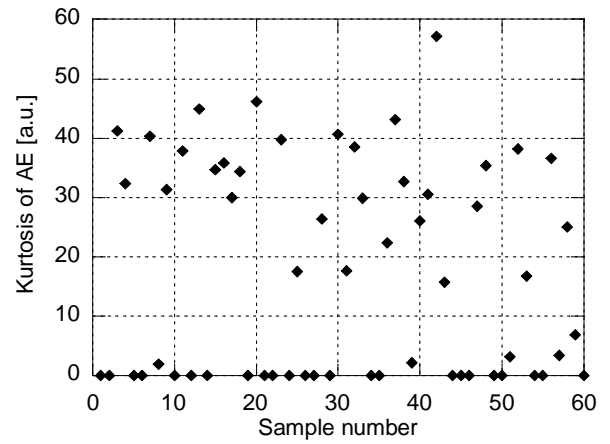

Fig. 8. Kurtosis of the AE signal observed in the set of tested capacitors.

All these parameters were estimated by analysing sequence of the registered AE signal events (10000 samples long each), separately for each capacitor. The standard deviation measures intensity of the registered AE signal (fig. 6) and validates that there are serious variations between the capacitors. The skewness exhibits smaller variation between the tested samples (fig. 7) than observed

for the estimated standard deviation. When kurtosis was estimated (fig. 8) there was more visible division of the capacitors for two separate groups. We suppose that this effect is due to the AE signal shape. This signal consists mainly of two harmonics: approx. 100 kHz and 280 kHz. This conclusion was learned from the spectrogram (fig. 9) that was estimated by applying the *specgram* function available in Matlab software. Probability distribution of sum of two harmonics is symmetric and means that more of the variance is due to infrequent extreme deviations when compared with the Gaussian distribution. Thus, kurtosis looks as the most valuable parameter for the observed AE signal characterization.
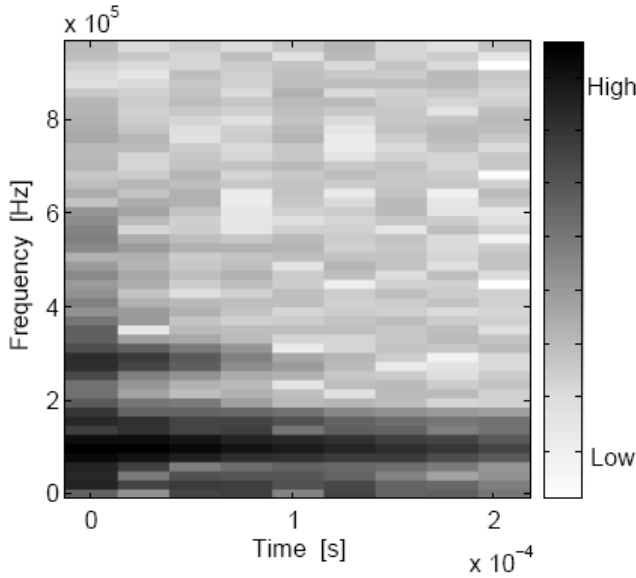

Fig. 9. Spectrogram of the part AE signal presented at fig. 5a.

The capacitors changed their parameters (e.g. capacitance, dielectric loss) after extensive charging and discharging test of duration 1000h. Thus, to asses which of AE parameters can predict quality of the capacitors, we applied linear correlation coefficient r_{xy} that measures whether there is any statistical dependence between the series of two random variables x and y having standard deviation σ_x, σ_y adequately:

$$r_{xy} = \frac{E\big((x - E(x))(y - E(y))\big)}{\sigma_x \sigma_y} \qquad (3)$$

Experimental data showed that there was no significant correlation between skewness or kurtosis of the registered AE signal and the measured capacitors parameters. We suppose that there are a few independent mechanisms that can determine capacitors quality and do not cause generation of AE signal. The investigated capacitors with relatively low capacitance can probably fail by bad contacts and not by defects of the applied dielectric which has relatively low volume and therefore causes lower probability of failure. Additionally, duration of the test was too short to lead to more significant destruction within capacitors. We observed deterioration of capacitors parameters (decrease of their capacitance and isolation resistance). There was only some

small correlation ($r_{xy} = 0.071$) between their capacitance loss and power spectral density of AE signal at frequency $f = 19.5$ kHz (tab. 1). Additionally, there was negative correlation between isolation resistance R_I and power spectral density of AE signal at frequency $f = 293$ kHz ($r_{xy} = -0.181$).

These results can be rationally interpreted. Low frequency AE signal means that partial discharges take place on extensive voids and lead to decrease of capacitance (due to dielectric deterioration within these voids) after their intensive charging and discharging. While fast AE signal components can be bounded with abundant and tiny voids within dielectric structure and give rather information about general quality of the applied dielectric that decreases with lower R_I.

We suppose that similar or even more clear conclusions about r_{xy} behaviour as for the power spectrum of AE signal could be reached when kurtosis would be estimated for the filtered within suitable frequency bandwidths components of the registered AE signal.

Table 1. Estimated linear correlation coefficient r_{xy} for a set of 60 capacitors between their AE signal power spectrum at given frequency and their relative capacitance drop $\Delta C/C$ after 1000 h long test or their initial isolation resistance R_I.

Frequency [kHz]	$\Delta C/C$	R_I
19.5	0.071	-0.063
97.6	0.049	0.049
293.0	-0.009	-0.181

4. CONCLUSIONS

Partial discharge phenomenon occurs only within some of the tested foil-based capacitors and can be characterized by the concomitant AE signal. This signal gives additional information about quality of the produced capacitors (existence of voids within structures) when compared with measurements of their capacitance or dielectric loss exclusively.

Intensity of the AE signal was characterized by its standard deviation, higher than two statistical moments (skewness and kurtosis) and power spectrum.

The results of extensive charging/discharging test (1000 h) shows that partial discharges are only partly responsible for capacitors deterioration. Power spectrum of AE signal at relatively high frequency (97.6 kHz) gives some information about quality of the applied dielectric. Presence of extensive voids can be probably detected by power spectrum of AE signal only at lower frequency range (19.5 kHz). Unfortunately, AE signal can not unambiguously predict capacitor quality because there are other reasons of their failures, not connected with dielectric quality (e.g. bounded with badly sprayed metalized contacts). We suppose that for capacitors of higher capacitance and bigger dielectric volume intensity of AE signal should be more valuable for their quality prediction. Additionally, 1000 h long test can be too short to cause

sufficient deterioration of the capacitors. Thus, the test of capacitors was prolonged further.

ACKNOWLEDGMENTS

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