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Comparison of the Measurement Results of Electrical Discharges Registered by the Acoustic Emission and Optical Spectrophotometry Methods

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The basic aim of the current research work on electrical discharges is a thorough study of the phenomena that accompany their generation so that we can measure them effectively, recognize their forms and locate the place of their generation in various types of insulation systems. Moreover, there is also a need to correlate the measurement results of electrical discharges obtained through various diagnostic methods in order to obtain as complete as possible information of the aging degree of the insulation measured. Within the paper there will be presented the results of measurements and analyses of optical and acoustic signals emitted by discharges in the point-point system in air.

Keywords: discharge, optical and acoustic signals, acoustic emission and optical spectrophotometry, gap modeling.

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Introduction

The occurrence and development of partial discharges (PDs) in insulation systems are accompanied by various physical phenomena. The most important, from a power appliance diagnostics point of view, are: chemical changes of insulation, the occurrence of the current pulse and emission of an electromagnetic wave, and a percussive elastic strain with an acoustic wave generation that accompanies it. Based on these phenomena various methods of detection, measurement and electric discharge analysis have been developed, out of which of practical importance are: electric, gas chromatography, of the return voltage measurement, of light measurement, of pressure and heat change occurring during PD generation, and that of the acoustic emission (AE). The current development of diagnostic methods of insulation systems results from the necessity to improve operational reliability of power appliances and extend the time of their operation, which, in consequence, can bring measurable economic profits. It refers especially to high power transformers, the investment cost of which in relation to the total value of the appliances used for transmission, division and distribution of power energy is about 20%. Moreover, the estimated cost value of a transformer failure may, in extreme cases, exceed the cost of its construction even five times. It justifies undertaking a broad diagnostic research, the range of which should be correlated with technical and economic significance of a power appliance measured [1-7].

Each measurement method of partial discharges has its own instruments. Within a definite measurement method various systems of receiving, processing and interpreting signals can be used. They depend on metrological conditions and the selection of the quantity measured. In recent years non-destructive methods, which can be used in industrial conditions during a regular operation of an appliance, have become of more significant. To such methods belong the optical spectral diagnostics basing on the measurement and analysis of electromagnetic radiation for the waves of the lengths in the range from 10 nm to 30 mm, and the acoustic emission method which makes it possible to measure a spherical wave of the acoustic pressure generated [1-7].

The basic aim of the current research work on electrical discharges is a thorough study of the phenomena that accompany their generation so that we can measure them effectively, recognize their forms and locate the place of their generation in various types of insulation systems. Moreover, there is also a need to correlate the measurement results of electrical discharges obtained through various diagnostic methods in order to obtain as complete as possible information of the aging degree of the insulation measured. Within the paper there will be presented the results of measurements and analyses of optical and acoustic signals emitted by discharges in the point-point system in air.

The aim of the research carried out by the authors is to correlate measurement results of electrical discharges measured by the methods of acoustic emission and optical spectrophotometry.

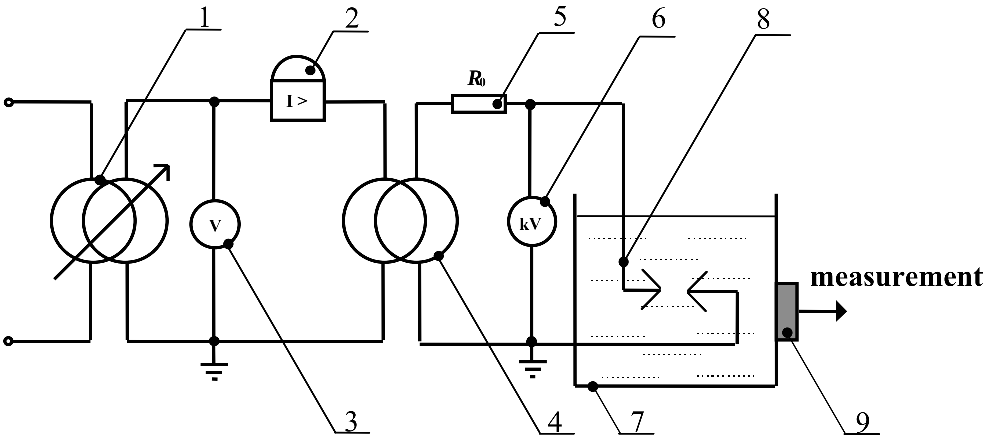

Fig. 1. Diagram of the set-up for PDs of the point – point type in air generation: 1 – autotransformer, 2 – over–current relay, 3 – digital voltometer, 4 – test transformer, 5 – resistor, 6 – electrostatic voltometer, 7 – spark gap modeling PDs of the point – point type, 8, tank, 9 – measuring transducer

I. Characteristics of the set-up for generation and measurement of AE pulses generated in spark gap modeling PDs of the point – point type in air

The diagram of the set-up used for generation of PDs of the point – point type in air was presented in Fig. 1.

The set-up was supplied by an alternating voltage of a root-mean-square value equal to 32 kV, which was 80% of the breakdown voltage value of the spark gap. The high voltage was obtained from a test transformer of a transformer voltage ratio equal to 220/110000 V/V.

The set-up under study generated PDs, the AE of which was measured by a measuring transducer placed 0.5 m away from the spark gap. Te AE pulses generated by PDs were registered using a standard measuring set-up by the Brüel&Kjær firm consisting of a wideband contact piezoelectric transducer, an amplifier, a filter and a measuring card, the detailed characteristics of which have been presented in the work [1,2].

Fig. 2 shows an idea diagram of a spark gap which makes generation of PDs of the point-point type in air possible. The distance between the electrodes is 3 cm. Detailed presentation of supplying system spark gap, geometric dimensions of the fixing constructions have been presented, among others, in the works [7, 8].

To measure the AE pulses a piezoelectric wideband contact transducer series WD type AH 17 by the firm Physical Acoustic Corporation was used, which was placed on the surfaces of the side walls and the upper lid of the transformer tub. Its application made the measurement of the AE signals possible at a practically flat amplitude characteristics for the frequency in the range (0 – 1.5) MHz at the maximum value of amplitude

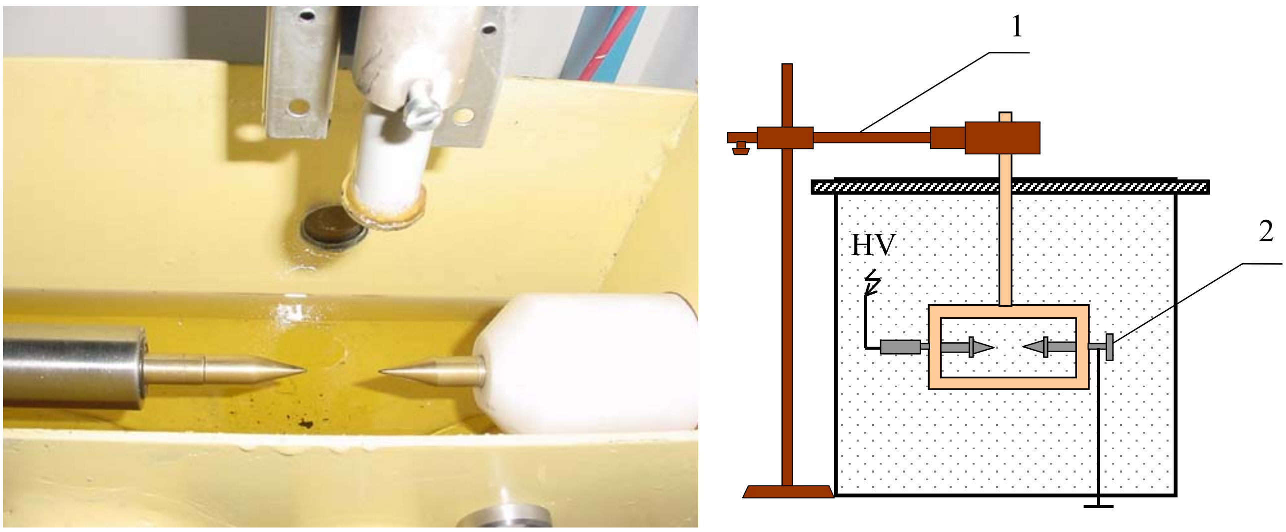

Fig. 2. Schematic of a point-point grounded spark gap
1 – structure fastening the gap, 2 – point and point electrodes

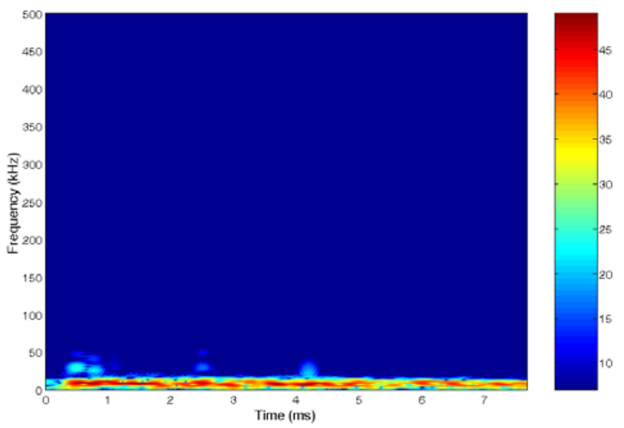

Fig. 4. Spectrogram calculated for the AE pulses generated in spark gap modeling PDs of the point – point type in air during the positive voltage half-period

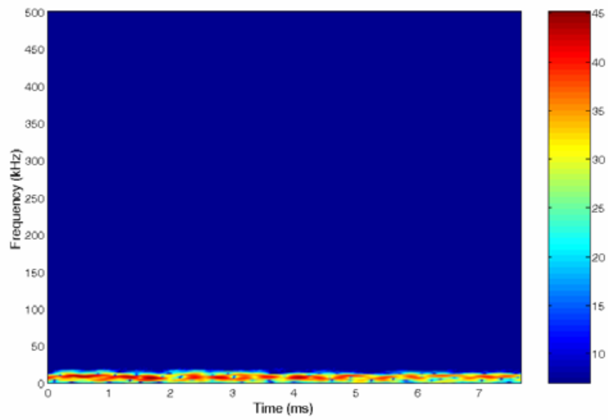

Fig. 7. Spectrogram calculated for the AE pulses generated in spark gap modeling PDs of the point – point type in air during the negative voltage half-period

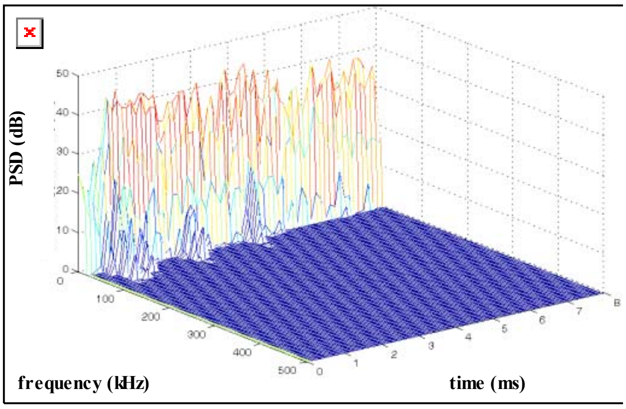

Fig. 5. Three-dimensional spectrogram of power spectrum density calculated for the AE pulses generated in spark gap modeling PDs of the point – point type in air during the positive voltage half-period

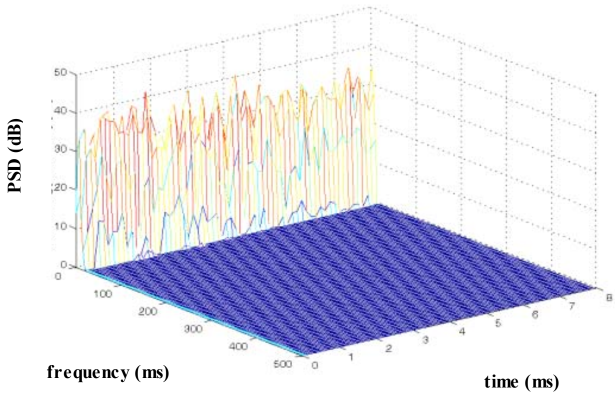

Fig. 8. Three-dimensional spectrogram of power spectrum density calculated for the AE pulses generated in spark gap modeling PDs of the point – point type in air during the negative voltage half-period

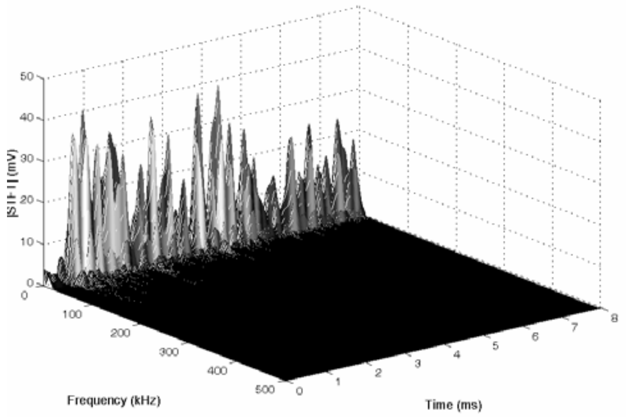

Fig. 6. Three-dimensional spectrogram of amplitude spectrum calculated for the AE pulses generated in spark gap modeling PDs of the point – point type in air during the positive voltage half-period

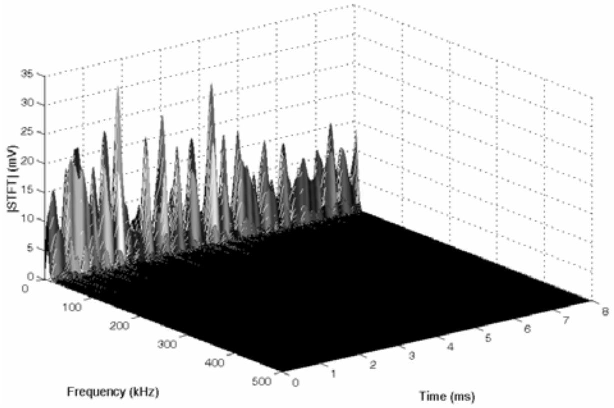

Fig. 9. Three-dimensional spectrogram of amplitude spectrum calculated for the AE pulses generated in spark gap modeling PDs of the point – point type in air during the negative voltage half-period

drop equal to ± 5 dB. The AE signals measured were amplified and then were subject to initial filtration with a standardizing measuring amplifier Nexus type 26921 – OS1 by the Brüel and Kjær firm.

The registration of the AE pulses measured was done by means of the measuring card National Instruments type NI 5911 compatible with a PC computer. The card is equipped with an A/C transducer of a maximum sampling frequency at an adjustable resolution in the range from 8 to 21 bites and of 100 MHz. The AE pulses registered underwent the analysis in the time, frequency and time-frequency domains and were visualized by the computer programs: Mathcad 2001i and Matlab 6.0.

A detailed presentation of the parameters of the particular elements that were used in the measuring line and the conditions in which the experiments were carried out have been presented in the works [1,2].

II. Characteristics of the system used for generation of PDs and measurement of the optical spectrum emitted

To measure a light radiation spectrum emitted by PDs and generated in model spark gap a spectrophotometer was used the optical transducer of which was placed in a specially profiled ebonite pipe with its opening placed right over the discharge generation area and which was tightly closed with a quartz glass.

An AVS-USB2000 spectrometer by the firm AVANTES was used for measurements, the main element of which is a multistage diffraction grating which enables the analysis of the spectrum in the range (270-1600) nm with the resolution of about 0.5 nm. A signal is delivered to the grating by a light pipe. After splitting the radiation falls on the CCD matrix (SonyILX511). The integration time can be changed in the range from 3 ms to 60 seconds. The measurement in the particular element of the CCD matrix (2048 elements sized 12.5 x 200 micrometers) is based on the photon counting in a time unit. One counting corresponds with the activation by 86 photons, which is the equivalent of the sensitivity of $2.9\ 10^{-17}$ J/pulse. The relative sensitivity depends of the length of the wave analyzed. The dependency of the relative sensitivity on the wave length is shown in Figure 3. The root-mean-square value of the dark current is from 2.5 to 4 countings.

A detailed presentation of the parameters of the particular elements that were used in the measuring line and the conditions in which the experiments were carried out have been presented in the works [1-7].

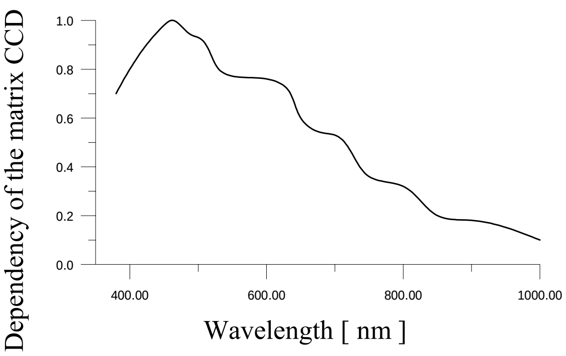

Fig. 3. Dependency of the spectrometer matrix sensitivity on the radiation wave length

III. Results of time-frequency analysis of AE pulses generated in spark gap modeling PDs of the point – point type in air

Figs 4-9 show spectrograms determined for the AE pulses generated in spark gap modeling PDs of the point – point type in air.

The spectrograms of the AE pulses generated by PDs of the point-point type in air indicate the occurrence of structures in the frequency range form 0 to about 50 kHz (Figs 3-6) for the positive voltage polarization and from 0 to about 20 kHz for the negative (Figs. 7-9). In the positive half-time three single short-duration (about 0.5 ms) structures occur in the range from 20 to 50 kHz. The time range analyzed can be divided into three ranges: first from 0.5 to 1 ms, second from about 2.3 ms to 2.7 ms and third from about 4 ms to 4.3 ms. The areas in the frequency range form 20 to 50 kHz, however, are relatively less active.

Figs 10-11 show time runs and scalograms determined by using the continuous wavelet transform (CWT), of the AE pulses generated by PDs, which are presented separately for the positive and negative voltage polarizations.

In the case of PDs generated of the point – point type in air (Figs. 10 – 11) the spectrum structure is contained in the bands of the frequencies (35-40) kHz and (80-100) kHz. These ranges are similar for both the positive and the negative polarizations The pulse duration time for higher frequencies is from 0.02 to 0.05 ms. In the case of structures in the range of lower frequencies this time is longer and is from 0.1 to 0.2 ms. In the time of discharge initiation for the negative voltage polarization a short-duration (0.01 ms) fluctuation of the frequency around 400 kHz occurs.

The results of the multiresolution analysis obtained for the AE pulses generated by PDs are shown for the positive voltage polarizations in Fig. 12 and for the negative voltage polarizations in Fig. 13. These figures present in order: original time runs of the AE pulses generated by PDs, approximation A on the seventh decomposition level, and details D on the levels from 1 to 7, then power density spectra (PSD) runs and columnar diagrams visualizing the size of the energy transferred by the particular details. For both voltage polarizations the highest activity is shown by the runs of the highest frequency details from D1 to D3. For the positive polarization these are single structures of the duration time not exceeding 0.2 ms. For the AE pulses generated by PDs in the negative half-time, there occur more broadened structures, the duration time of which is even longer than 0.6 ms. The biggest participation in the energy transferred by the AE pulses measured, for both voltage half-times, has Detail D4, but its value is by an order higher for the positive polarization.

The frequency characteristics do not contain resonance peaks, their median frequency is of 203.5 kHz, and the ranges of dominant frequencies, determined for the discrimination threshold equal to –70 dB, are within

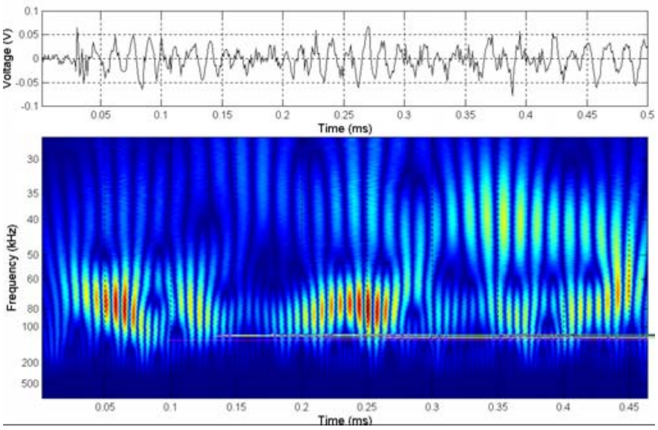

Fig. 10. CWT of a series of AE pulses generated in spark gap modeling PDs of the point – point type in air during the positive voltage half-period

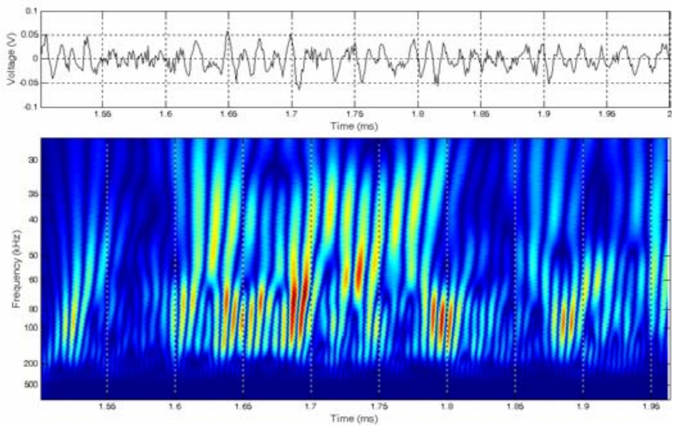

Fig. 11. CWT of a series of AE pulses generated by in spark gap modeling PDs of the point – point type in air during the negative voltage half-period

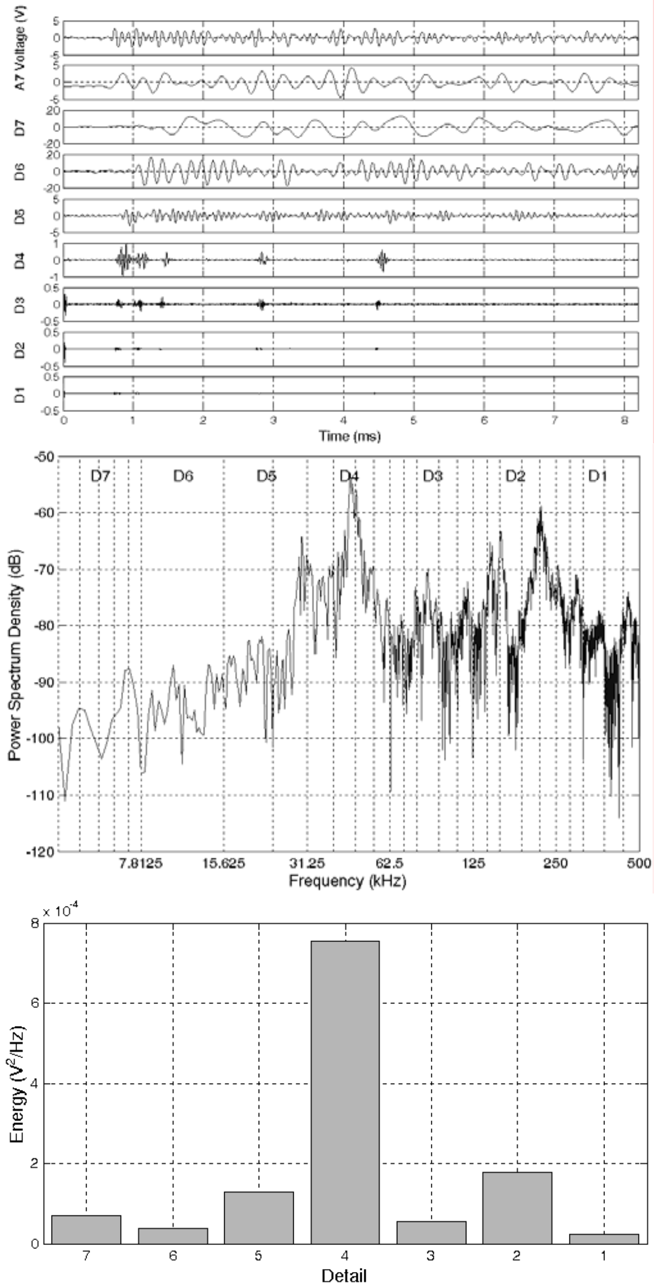

Fig. 12. DWT, PSD, the value of the energy transferred of a series of AE pulses generated in spark gap modeling PDs of the point – point type in air during the positive voltage half-period

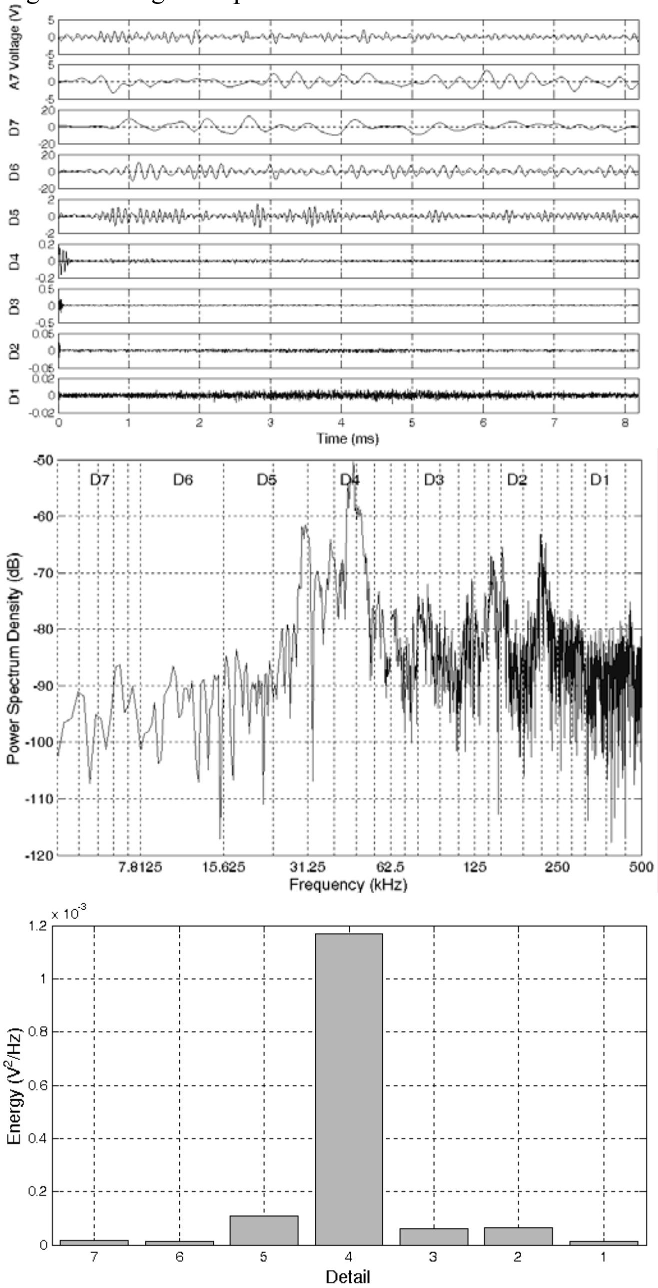

Fig. 13. DWT, PSD, the value of the energy transferred of a series of AE pulses generated in spark gap modeling PDs of the point – point type in air during the negative voltage half-period

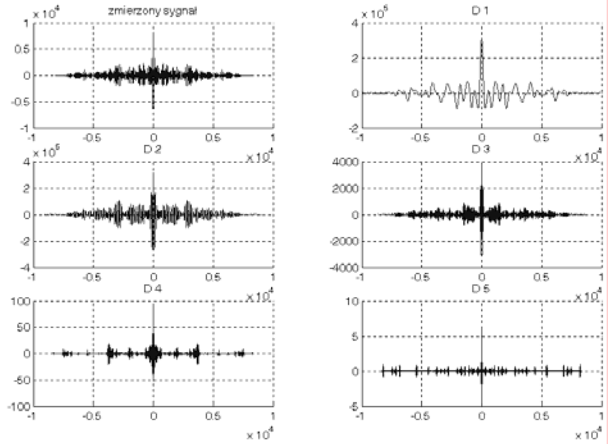

Fig. 16. The autocorrelation function (ACF) of a series of AE pulses generated in spark gap modeling PDs of the point – point type in air during the positive voltage half-period

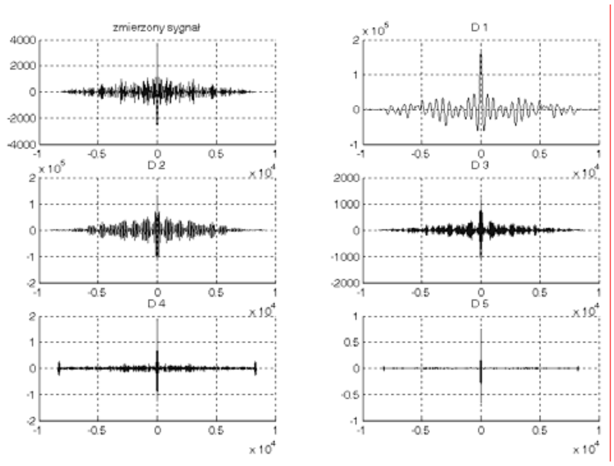

Fig. 17. The autocorrelation function (ACF) of a series of AE pulses generated in spark gap modeling PDs of the point – point type in air during the negative voltage half-period

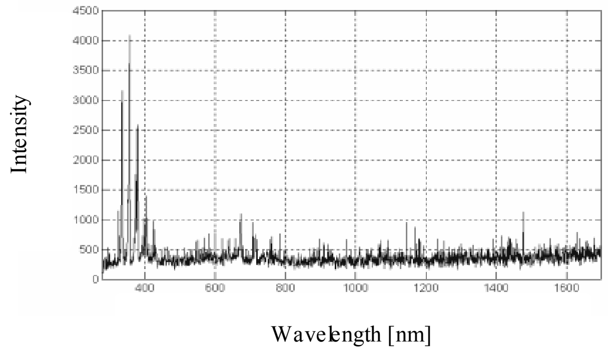

Fig. 18. Optical spectrum of partial discharges generated in the point – point system in air, at the voltage of 0.5 U_b

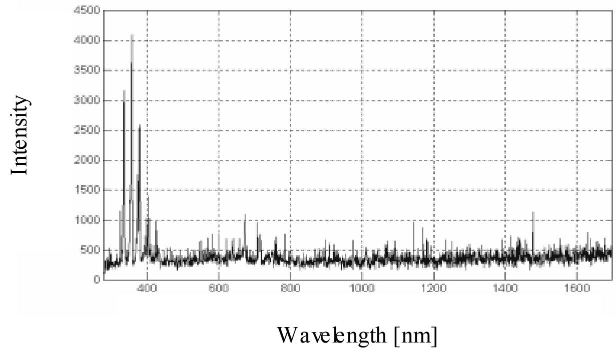

Fig. 19. Optical spectrum of partial discharges generated in the point – point system in air, at the voltage of 0.8 U_b

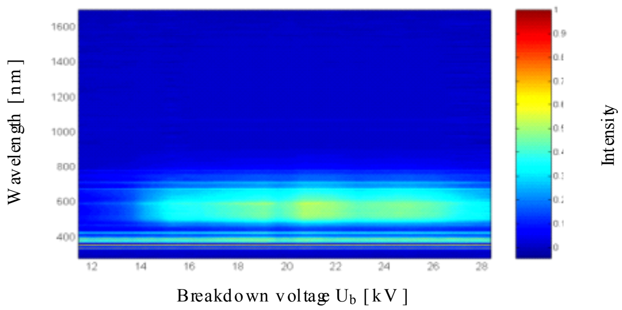

Fig. 20. The influence of the supplying voltage value in the point-point spark gap in air on the length of the light wave emitted

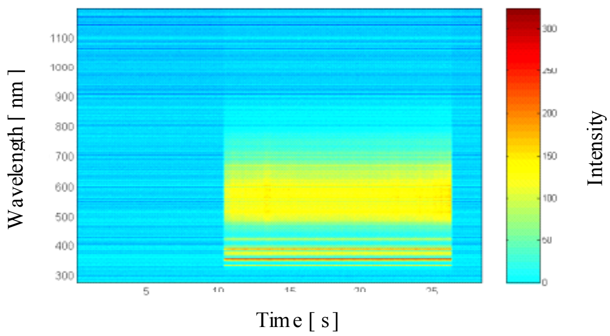

Fig. 21 Changes of the optical spectrum during the arc burning time of the disruptive discharge in the point-point spark gap in air

the ranges: (30-50) kHz, (135-165) kHz and (220-250) kHz for both voltage polarizations.

Moreover, Figs 14-17 show PDF runs (Figs 14-15) and ACF runs (Figs 16-17), which were determined for the details analyzed, separately for the positive and the negative voltage polarizations supplying the spark-gap under study. For the AE signal registered and for the particular details different PDF and ACF were obtained, which can be used for recognizing the participation of the particular frequency ranges in the signals measured and in consequence it can be helpful in identification of basic PD forms.

IV. Results of analysis of light pulses generated in spark gap modeling PDs of the point – point type in air

Figs 18 and 19 present the runs of the light radiation spectra emitted by PDs generated in the system modeling discharges of the point-point type in air at the supplying voltage equal to 0.5 (Figure 18) and 0.8 (Figure 19) of

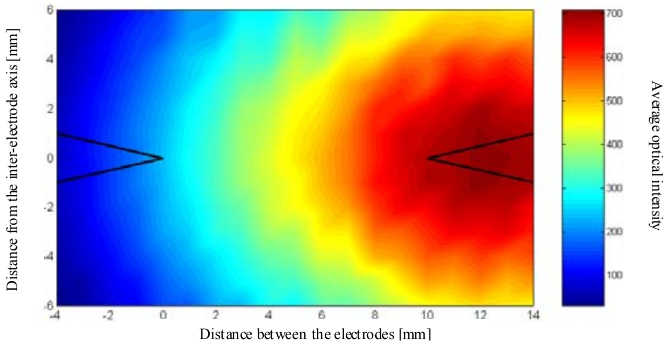

Fig. 22. Optical spectrum distribution in a point tangent to the surface of the spark-gap points for discharges of the point-point type in air

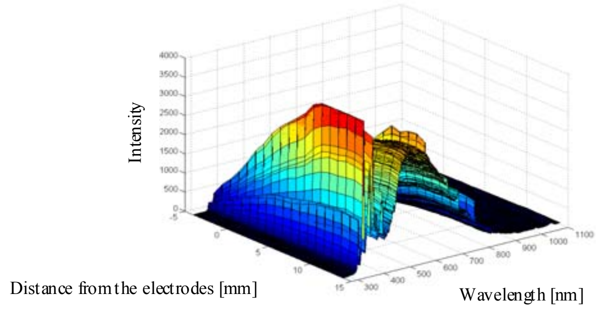

Fig. 23. Optical spectrum distribution on the inter-electrode axis for a point-point spark-gap in air

the breakdown voltage (U_b) of the spark gaps under study.

The characteristics presented in Figure 20 shows the influence of the voltage value of the partial discharge generation in the system modeling surface discharges in oil in the range from 0.5 to 0.8 U_b.

Figure 21 shows the dependence of the average light radiation intensity during the burning time of the electric arc accompanying disruptive discharges in the point-point spark gap on its ignition to extinction, at the constant value of the supplying voltage and at the increasing distance between the electrodes.

Summing-up

The results presented in this paper proved to be useful in the spectral analysis and the acoustic emission methods, which as non-destructive methods can constitute a valuable supplement of classical measurement methods of partial discharges used during a regular operation of power appliances. The results obtained can contribute to the development of knowledge on the mechanism of the occurrence and development of electrical discharges in air insulation systems and they can find their physical implementation in diagnostics of power appliance insulation. The research work carried out by the authors presently refers to determining the possibilities of correlating the measurement results of electrical discharges occurring in paper-oil insulation systems obtained by the acoustic and optical methods.

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Т. Бохцар, П. Фракс

Порівняння результатів вимірювання електричних розрядів, досліджених методами акустичної емісії і оптичної спектрофотометрії

Технічний університет в Ополє, Польща

Основною даної роботи є дослідження електричних розрядів – повне дослідження явищ, які їх супроводжують, для того щоб ми могли фактично знати їх форми і визначити місце їх знаходження в різних типах систем ізоляції. Крім того, виникає необхідність корелювати результати вимірювання електричних розрядів, отриманих за допомогою різних діагностичних методів, для того, щоб отримати повну інформацію про ізоляцію. В статті представлені результати вимірювань і досліджень оптичних і акустичних сигналів, які випускаються розрядами в системі точка - точка на повітрі.