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APPLICATION OF STATISTICAL ANALYSIS IN RESULT REPEATABILITY EVALUATION OF ACOUSTIC EMISSION MEASUREMENTS GENERATED BY PARTIAL DISCHARGES

T. BOCZAR and S. WOLNY

Department of Electrical Engineering and Automatic Control
Technical University of Opole
45-272 Opole, K. Sosnkowskiego 31

The subject matter of this paper deals with the improvement of the acoustic emission (AE) method in diagnostics of insulation systems of power appliances. The paper presents the results of the statistical analysis of the AE pulses generated by the setups modeling basic partial discharge (PD) forms that can occur in oil insulation systems. Especially, the results of parametric and non-parametric tests of quality of fit are presented that were carried out in order to determine the probability distribution of the AE pulses measured, to test the repeatability of the frequency analysis results obtained, and to check the influence of the factors that can disturb this repeatability. The statistical analyses were carried out based on the values of three descriptors, i.e. shape coefficient, peak coefficient and median frequency, which make the identification of basic PD forms occurring in insulation oil possible.

1. 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 the power appliance measured [13, 14].

At present the AE method can be used in two domains connected with power engineering. Firstly, it can be used for detection, location and evaluation of PD intensity occurring in insulation systems of various power appliances. Secondly, it can be used for detection and evaluation of the intensity of material defects that can occur in the welds of welded steam pipelines of a significant thickness installed in power plants. The potential objects in relation to which the AE method could be specialized are: power transformers, power condensers, transformer passes, current and voltage high power transformers and switchgears with SF_6 gas insulation. The current research into the improvement of the AE method refers to the application of the statistical analysis and the methods of digital signal processing to determine the descriptors, the values of which would characterize best the phenomena accompanying the occurrence and development of PDs in insulation systems [1, 2, 8, 10].

In the research carried out so far, the authors concentrated on determining identification possibilities of basic PD forms based on the results of frequency analysis of the AE pulses generated by them. In order to do so, the measurements were taken and frequency analysis of AE pulses generated in setups modeling the following PD forms was carried out: point-plane type discharges in oil, multipoint-plane type discharges in oil, multipoint-plane type with a layer of pressboard discharges in oil, surface discharges in oil, gas bubble discharges in oil, discharges in indeterminate-potential particles moving in oil. Analyzing the research results, the author showed that based on frequency spectrum runs, the ranges of dominant frequency bands, peak factor, shape coefficient and median frequency, compared simultaneously, it is possible to identify the PD forms. The comparative criteria determined make the identification of PDs possible, however, it refers only to a single source, single, one-type discharges, at strictly defined measuring conditions [3, 4].

The aim of the research carried out by the authors of this paper is determining comparative standards, the so-called fingerprints for each of the basic PD form in such a way that by carrying out the comparative analysis of the AE pulses measured generated by PDs in insulation systems of power appliances, it will be possible to identify them uniquely. Apart from determining the place, intensity and size of PDs, it is of basic significance in evaluating the condition of the insulation measured and the time of its further failure-free operation.

The subject matter of this paper refers to the application of the statistical analysis tools to evaluate the repeatability of various PD types generated in spark gaps that model them. In particular, using the parametric tests of goodness of fit, the influence of the construction parameters of the model setups used and the conditions in which PDs were generated on the descriptors characterizing the AE pulses measured in the frequency domain will be determined.

2. Characteristics of the measuring apparatus used and the descriptors making the PD identification possible

The AE signals were generated in the setups modeling the following six partial discharge (PD) forms: point-plane discharges in oil, multipoint-plane type discharges in oil, multipoint-plane type with a layer of pressboard discharges in oil, surface discharges in oil, gas bubble discharges in oil, discharges in indeterminate-potential particles moving in oil. A standard measuring setup, produced by the firm Brüel and Kjær, was used for the measurements of the AE pulses. Detailed characteristics of the model setups, the conditions in which the tests were carried out and the parameters of the measuring apparatus used have been presented in the works [3, 4].

The descriptors used for identification, the values of which were determined for amplitude and energy density spectra separately, taking into account the polarization of the supplying voltage, and which were consecutively tested for their repeatability, were calculated based on the following relationships:

• peak factor $W\{E(f)\}$:

$$W\{E(f)\} = E_{\mathrm{MAX}}/E_{\mathrm{RMS}}, \tag{1}$$

where $E(f)$ – values for amplitude and energy density spectra, respectively, E_{MAX} – maximum value, E_{RMS} – root-mean-square value calculated according to (2):

$$E_{\mathrm{RMS}} = \sqrt{\int_{f_1}^{f_2} E^2(f)df \Big/ \int_{f_1}^{f_2} df}, \tag{2}$$

• shape coefficient $K\{E(f)\}$:

$$K\{E(f)\} = E_{\mathrm{RMS}}/E_{\mathrm{AVG}}, \tag{3}$$

where E_{AVG} – average value calculated from (4):

$$E_{\mathrm{AVG}} = \int_{f_1}^{f_2} E(f)df \Big/ \int_{f_1}^{f_2} df, \tag{4}$$

• median frequency:

$$f_{\mathrm{MED}} = 2\int_{f_1}^{f_{\mathrm{MED}}} E(f)df = \int_{f_1}^{f_2} E(f)df. \tag{5}$$

To process, analyze and visualize the AE pulses registered, numerical procedures written in Mathcad 2001 program by the Mathsoft firm were used. The detailed characteristics of the measuring setup used, its parameters and the way of executing the frequency analysis were presented, among others, in the works [3, 4].

3. Characteristics of the measurement results of PDs taken by the AE method as random variables

In order to carry out a statistical analysis, for each of the six populations of the PD forms under study, samples that represent them, consisting of the randomly selected elements, were created. For the designated random samples, function runs and density probability cumulative distribution functions were determined, where using histograms the empirical distribution of the values measured was presented, and using a continuous line their theoretical distribution was presented. In order to verify the statistical hypothesis of equivalence of the probability density of the AE pulses analyzed with the assumed theoretical probability density, a non-parametric χ^2 test of goodness of fit was used. Within the analyses carried out it was proved that with a 5% tolerance of error making, there are no bases for rejecting the zero H_0 hypothesis which assumes a normal type of distribution of the AE pulses measured, generated by the PD forms considered. The detailed results of the test verifications carried out have been presented, among others, in the works [5]. Moreover, in order to verify graphically the normal distribution probability of the random variables tested, probability diagrams of the normal and semi-normal probability were used.

Figures 1–4 show in order the probability density and cumulative density function, the normal and semi-normal probability diagram for random samples representing the AE pulses generated by PDs of the multipoint-plane type for the positive voltage halftime.

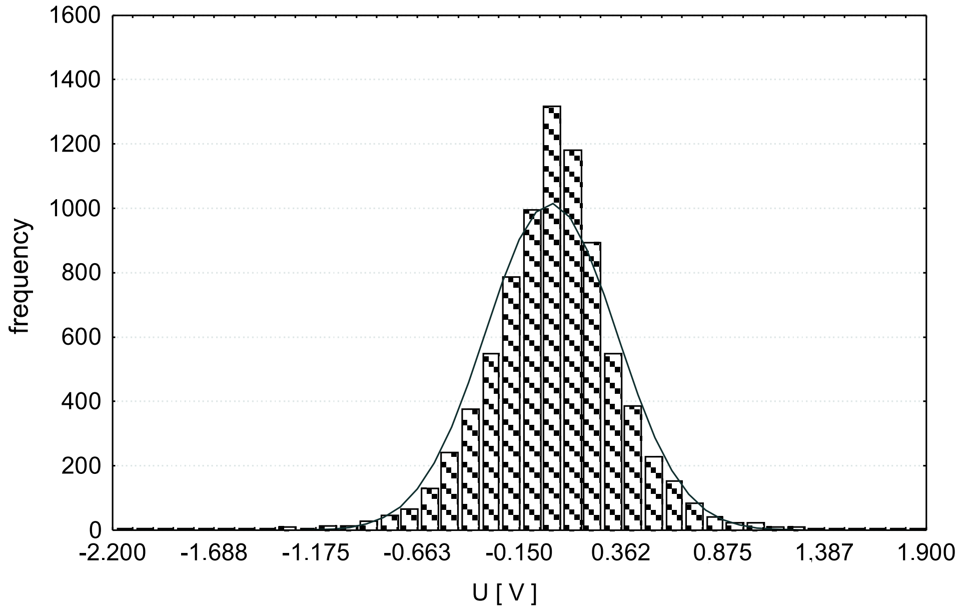

Fig. 1. Probability density functions (PDF) determined for the AE pulses generated by PDs of the multipoint-plane type at the positive voltage polarization.

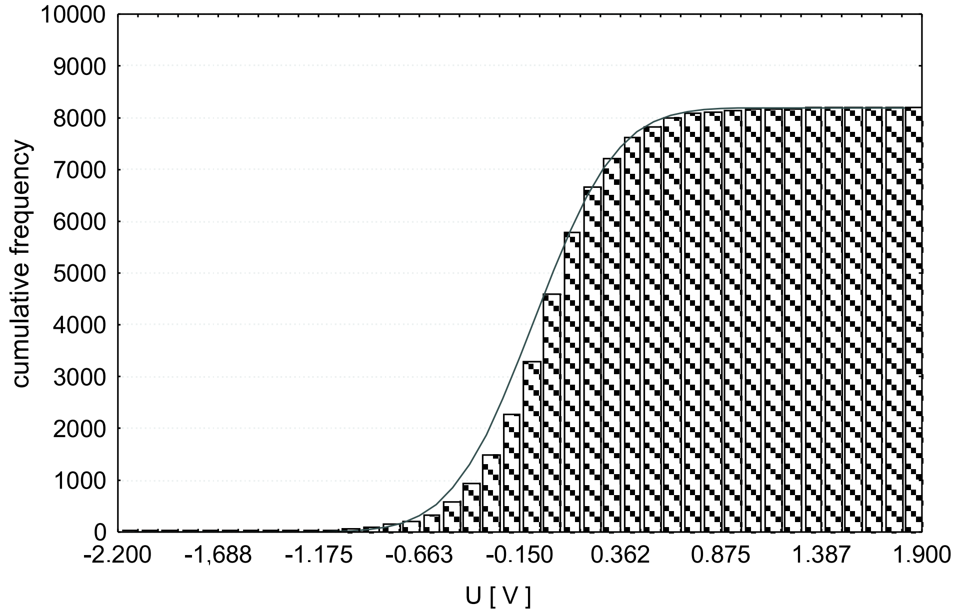

Fig. 2. Cumulative density function determined for the AE pulses generated by PDs of the multipoint-plane type at the positive voltage polarization.

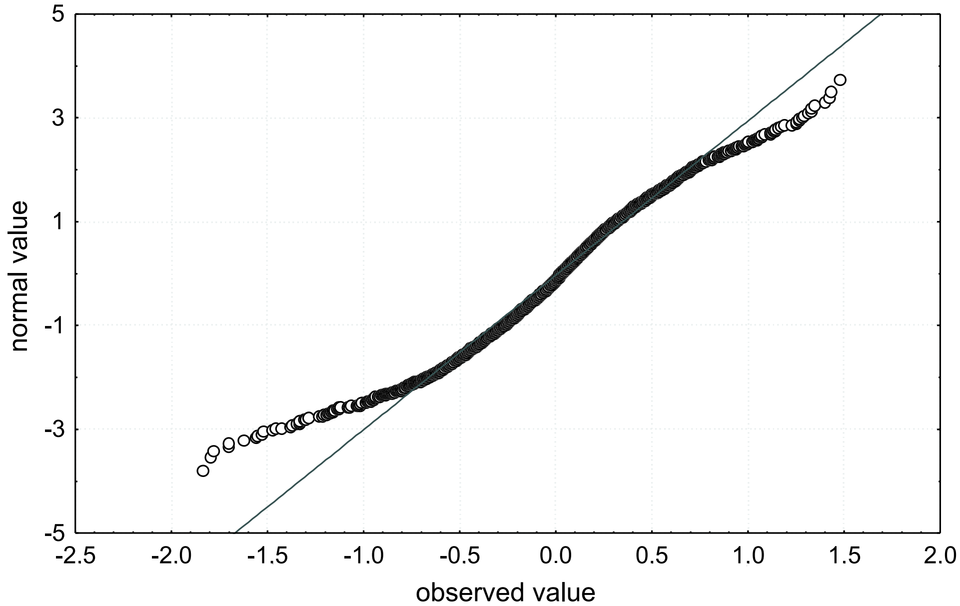

Fig. 3. Normal probability plot determined for the AE pulses generated by PDs of the multipoint-plane type at the positive voltage polarization.

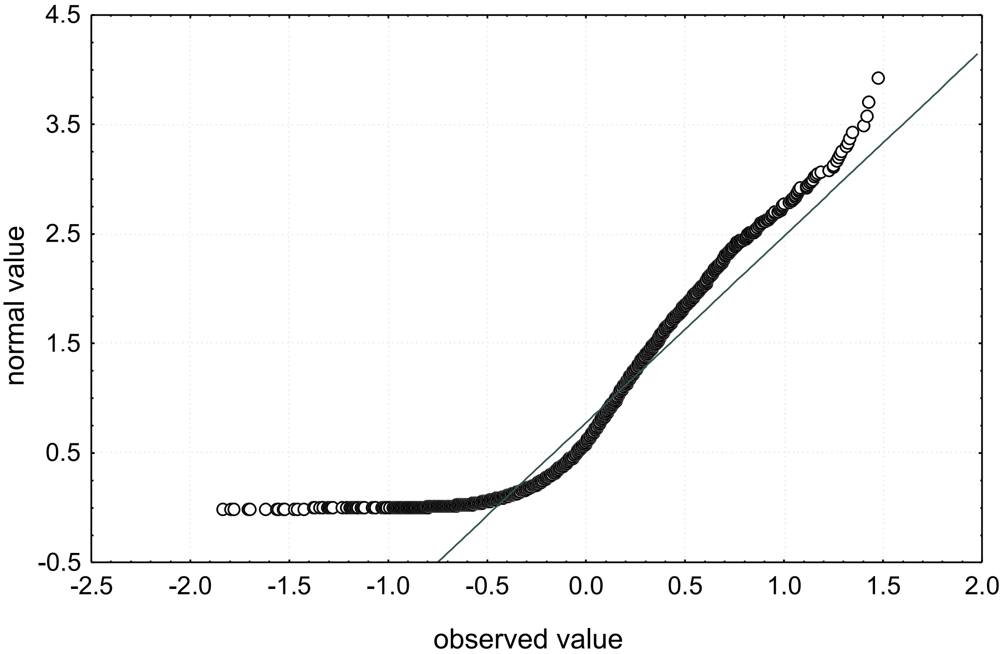

Fig. 4. Semi-normal probability plot determined for the AE pulses generated by PDs of the multipoint-plane type at the positive voltage polarization.

4. Test results of the measurement repeatability

Since the laboratory tests were carried out repeatedly over a long period of time in model setups, it is necessary to verify the repeatability of the measurements which were carried out based on the values of descriptors making it possible to recognize the basic PD forms.

The repeatability tests of the selected descriptors were based on the measurements of PDs generated in indeterminate-potential particles moving in oil, using the acoustic method. They were repeated six times on consecutive measurement-taking days. The measurement cycles took place in similar environmental conditions, e.g. temperature, humidity and air pressure. Similar shapes of frequency spectrum runs and the values of the descriptors that characterize them were obtained for the discharges of the type analyzed, thus the descriptors determined for the positive polarization of the supplying voltage were selected for the repeatability analysis. Figures 5–6 show characteristic runs of the AE pulses generated by PDs of the point – plane type measured in the positive voltage half-time. Figure 5 shows a time run, Fig. 6 amplitude spectra, and Fig. 7 an energy density spectrum.

The conclusions from the analyses carried out were drawn based on the test of significance that follows from the variance analysis for many averages of a single classification [7, 9, 11, 12, 15–17]. This test is based on F – Snedecor distribution and

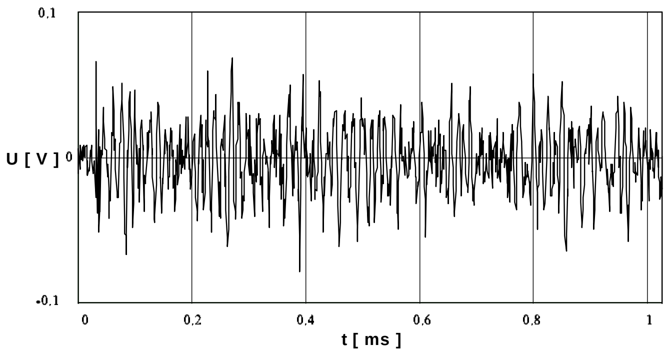

Fig. 5. Time run for AE pulse series generated by PDs in indeterminate-potential particles moving in oil, in the positive voltage half-period discharges.

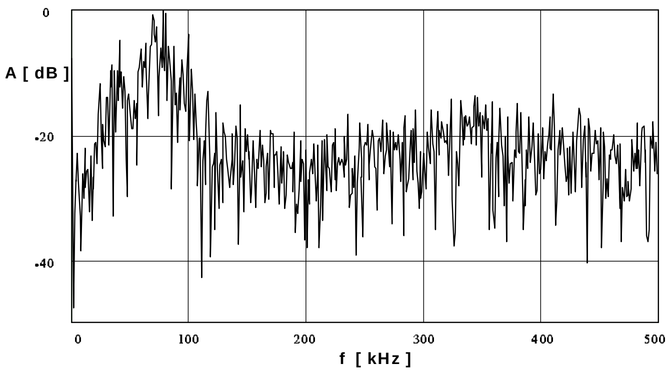

Fig. 6. Amplitude spectrum run for AE pulse series generated by in indeterminate-potential particles moving in oil, in the positive voltage half-period.

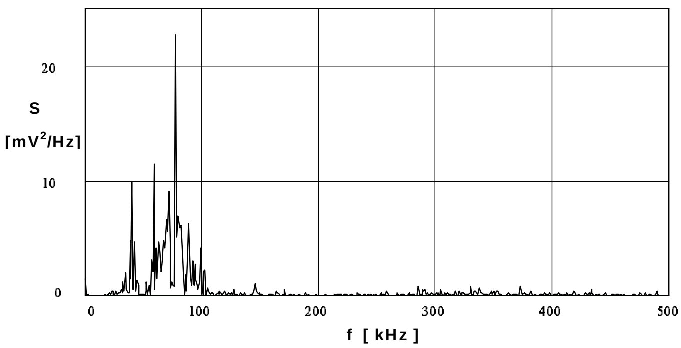

Fig. 7. Energy density spectrum run for AE pulse series generated by PDs in indeterminate-potential particles moving in oil, in the positive voltage half-period.

the assumption that there are given k populations of a normal distribution $N(m_i, \sigma_i)$, where $i = 1, 2, \ldots, k$, or close to a normal distribution, and the variances of all k populations are equal, i.e. $\sigma_1^2 = \sigma_2^2 = \ldots = \sigma_k^2 = \sigma^2$, but they do not have to be known. Hence, in order to begin the test it was necessary to check first whether the data of PDs for a given type were within a normal distribution. Following the earlier research already published [5, 6], it was decided, basing on the assumption of the concord of the data with the distribution of a normal type, to find out whether there also occurs the equality of the variance of the data. A homogeneity test of many variances [7, 9, 11, 12, 15–17] is based on the distribution χ^2 and the assumption that there are k normal populations $N(m_i, \sigma_i)$, where $i = 1, 2, \ldots, k$, of n_i number. The selected measurement data on which the calculations were performed are presented in Table 1.

Table 1. Calculation results of the selected descriptors determined through PD measurements listed in order to carry out the test of measurement repeatability.

Peak coefficient of the energy density spectrum – positive polarization				
Days	Average [V]	Standard Deviation [V]	Test χ^2	Test F
1	14.0377	0.09044	10.15539	0.184141
2	14.0355	0.21231		
3	14.0950	0.25909		
4	14.1048	0.21948		
5	14.1225	0.35854		
6	14.1618	0.41979		
Shape coefficient of the energy density spectrum – positive polarization				
1	3.6622	0.03461	2.04928	1.904208
2	3.6279	0.03627		
3	3.6257	0.0479		
4	3.5891	0.04794		
5	3.6472	0.05712		
6	3.6227	0.03538		
Median frequency of the energy density – positive polarization				
1	76.4147	0.03715	9.230427	1.993989
2	76.3966	0.01748		
3	76.3809	0.02152		
4	76.3672	0.05156		
5	76.4089	0.05452		
6	76.4248	0.0267		

The hypotheses of the test assume, respectively:

H_0: $\sigma_1^2 = \sigma_2^2 = \sigma_3^2 = \sigma_4^2 = \sigma_5^2 = \sigma_6^2$, where σ is a variance of a given population,

H_1: not all variances of results are equal.

The calculated value of χ^2 distribution and the value of the significance level $\alpha = 0.05$ taken from the table are presented in Tables 1 and 2.

Table 2. χ^2_α value readout from the table of distribution for the test of homogeneity of many variances and F_α value for the test of variance analysis for many averages.

α	degrees of freedom	χ^2_α	1 degree of freedom	2 degree of freedom	F_α
0.05	5	11.07048	5	30	2.533554

Since in each case there is the inequality $\chi^2 < \chi_\alpha$, there is no basis for rejecting the H_0 hypothesis which says that all variances of the descriptors determined are equal to one another. It should be added that the limitations of the length of the paper do not allow the presentation of all the calculation results tested, i.e. for the amplitude spectrum and the negative polarization and the other five setups of PD generation. However, homogeneity tests of many variances were performed for all the data collected, and as a result of them it was possible to state that there are no bases for rejecting the H_0 hypothesis.

Because the calculations presented in Table 1 can be described by a normal distribution and their variances are equal, it was possible to carry out a test of variance analysis for many averages in order to determine the repeatability of the test results.

The test hypotheses assume, respectively:

H_0: $m_1 = m_2 = m_3 = m_4 = m_5$, where m is the average of population.

H_1: not all averages are equal to one another.

The calculated value of distribution F and the value taken from the table for the significance level $\alpha = 0.05$ is presented in Tables 1 and 2, respectively. Since in each case the inequality $F < F_\alpha$ takes place, there are no bases for rejecting the H_0 hypothesis which says that all the selected PD descriptors are equal to one another. This statement proves, at the same time, that in the setup under study the repeatability of the experiment results takes place with a 5% error tolerance. Also the tests carried out for peak factors, shape and median frequency in the negative polarization and for the amplitude spectrum and the other five setups of PD generation, ended with identical results.

5. Determining the influence of the factors that could disturb repeatability of the measurement results of the AE pulses generated by PDs

The statistical analysis carried out confirmed the assumed hypotheses of the normal character of the PD population distributions under study and repeatability of the measurement results obtained. The next stage of the research, however, dealt with determining the influence of the factors that can disturb the repeatability of the AE pulses measured. Within the statistical analyses, an evaluation of the influence of the following parameters was performed:

- geometrical configuration and the size of a point electrode for discharges of the point-plane type,
- number of point electrodes for discharges of the multipoint-plane type,
- placement of a pressboard layer between the electrodes of a spark gap which makes the modeling of PDs of the multipoint-plane type possible,
- type of material used for the insulation layer for surface discharges.

Moreover, the influence of the material change and the thickness of insulation layers placed in the propagation path of the AE signals generated by the discharges of the multipoint-plane type on the repeatability of the frequency analysis results was tested. The range of the research carried out also included the evaluation of the influence of the change of insulation oil type and physico-chemical parameters in which discharges of the multipoint-plane type were generated on the repeatability of the selected descriptor values.

In order that the results obtained should be of a general merit and be comparable, the measurements of the AE pulses generated by the PD forms under study were taken at precisely defined experiment conditions concerning the relative value of the PD generation voltage, total amplification value of the signals measured as well as the place of generation and measurement of the AE pulses from PDs. For the comparative analysis were selected, each time through an independent drawing, ten values of a peak coefficient, shape and median frequency determined separately for the amplitude and energy density spectra, taking into account the polarization of the voltage supplying the model setups under study.

The conclusions referring to determining the influence of the constructional and technical conditions as well as metrological conditions under study on the repeatability of the results obtained were drawn at the assumed significance level $\alpha = 0.1$, based on the parametric tests of goodness of fit that are based on the homogeneity analysis of many variances and on the analysis of variances for many averages of a single classification in the case when a few result populations were considered. To determine the repeatability of the results obtained, at the assigned destabilizing parameter change when two populations were compared, a parametric t-Student test was used which makes it possible to verify the thesis of the equality of two average values. Within this paper the results connected with evaluation of repeatability obtained for the change of the point electrode geometry for PDs of the point-plane type and for the changes of the transformer oil type for the AE pulses generated by PDs of the multipoint-plane type will be presented.

In order to evaluate the influence of the point electrode geometry on the repeatability of the results of the frequency analysis of the AE generated in the point-plane setup, measurements were taken for its five various curvature angles and the corresponding five diameters of the point tip. For the test, copper point electrodes were made of the following sizes of the point curvature angles and the diameters of their tips (the values are given in round brackets): 22° $(\phi\, 0.6\ \mathrm{mm})$, 17° $(\phi\, 0.54\ \mathrm{mm})$, 12° $(\phi\, 0.4\ \mathrm{mm})$, 8° $(\phi\, 0.23\ \mathrm{mm})$, 1° $(\phi\ 0.06\ \mathrm{mm})$. The paper presents the results obtained for the shape and peak coefficients and the median frequency calculated for the energy density spectrum at the positive voltage polarization, for two extreme values of the curvature angle 22° and 1°. The results obtained are presented in the table form (Tables 3–4), and the values of the descriptors drawn for ten measurements, their average value, standard deviation (Table 3) and the values obtained for the homogeneity tests of many variances and the equality of two averages (Table 4) are listed separately.

Table 3. Comparative listing of the selected descriptors characterizing the energy density spectrum of the AE pulses generated by PDs of the point-plane type for two curvature angles of the point electrode at the positive voltage polarization.

	Measurement	Descriptor					
		Peak coefficient		Shape coefficient		Median frequency	
		1°	22°	1°	22°	1°	22°
Positive polarization	1	3.34	3.32	1.89	1.79	326.9	326.9
	2	3.32	3.32	1.82	1.83	326.6	327.1
	3	3.34	3.31	1.82	1.78	326.2	326.5
	4	3.29	3.28	1.82	1.87	326.8	326.5
	5	3.38	3.36	1.80	1.84	326.4	326.1
	6	3.29	3.26	1.78	1.75	326.7	326.6
	7	3.39	3.25	1.82	1.75	327.1	326.3
	8	3.29	3.32	1.72	1.79	325.9	326.2
	9	3.35	3.35	1.86	1.73	325.9	327.2
	10	3.31	3.31	1.82	1.75	326.2	327.3
	Average:	3.33	3.31	1.82	1.79	326.5	326.7
	Standard Deviation:	0.03573	0.03553	0.04508	0.04646	0.41647	0.42960

Table 4. The value χ^2_α from the distribution table for the homogeneity test of many variances and t_α value for the analysis test of two averages and the calculated values χ^2 and t for the selected descriptors for PDs of the point-plane type for two curvature angles of the point electrode at the positive voltage polarization.

Descriptor	α	degrees of freedom	χ^2	χ^2_α	degrees of freedom	t	t_α
Peak coefficient	0.1	1	0.000288	0.015791	18	1.374342	1.734063
Shape coefficient			0.007719			1.358036	
Median frequency			0.0082186			-1.057033	-1.734063

The following hypotheses were adopted

- for the homogeneity tests of many variances:
  H_0: $\sigma_1^2 = \sigma_2^2$,
  H_1: $\sigma_1^2 \neq \sigma_2^2$ variances are not equal;
- for the equality test of two average values:
  H_0: $m_1 = m_2$,
  H_1: $m_1 > m_2$.

Figures 8–15 present frequency spectrum runs determined for the AE pulses generated by PDs in the point-plane setup for the two geometric sizes of the point electrode considered. The detailed results of the comparative analysis carried out in the time and frequency domains of the AE pulses generated by PDs of the point-plane type at the changes of the point electrode geometry have been presented in the papers [3, 4].

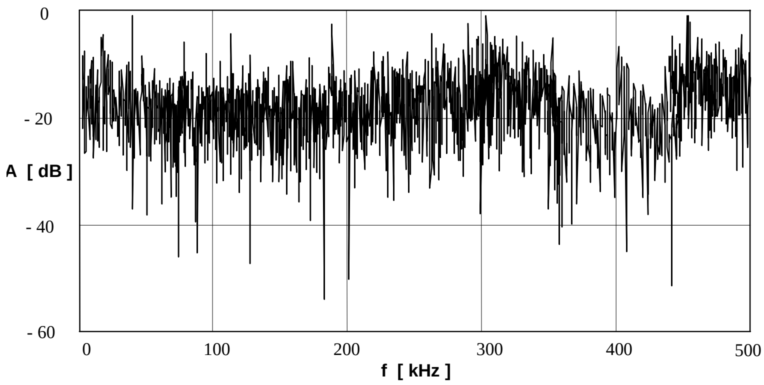

Fig. 8. Amplitude spectrum of a series of AE pulses generated by PD in oil in the "spike-plate" system during the positive voltage half-cycle (1°, ϕ 0.06 mm).

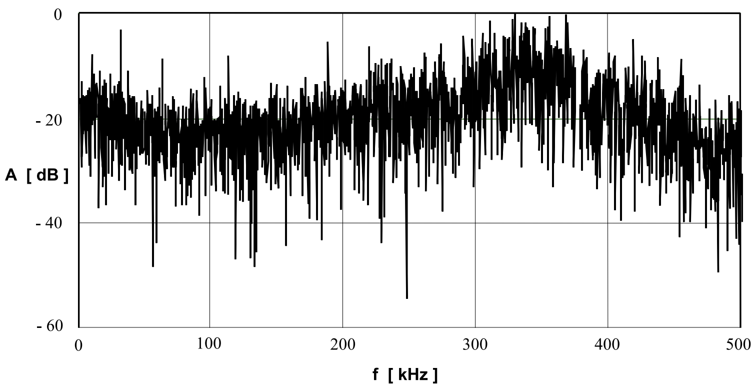

Fig. 9. Amplitude spectrum of a series of AE pulses generated by PD in oil in the "spike-plate" system during the negative voltage half-cycle (1°, ϕ 0.06 mm).

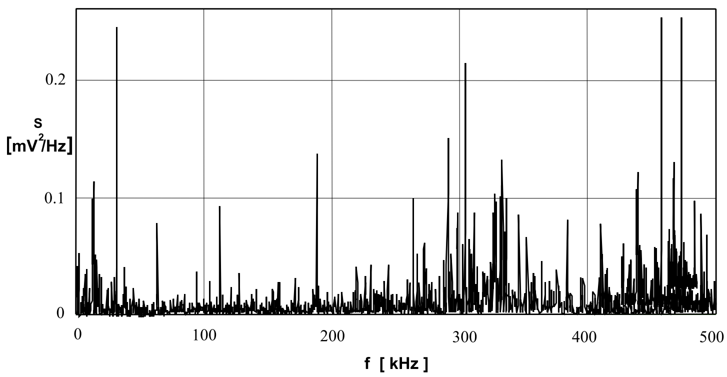

Fig. 10. Energy density spectrum of a series of AE pulses generated by PD in oil in the “spike-plate” system during the positive voltage half-cycle (1°, ϕ 0.06 mm).

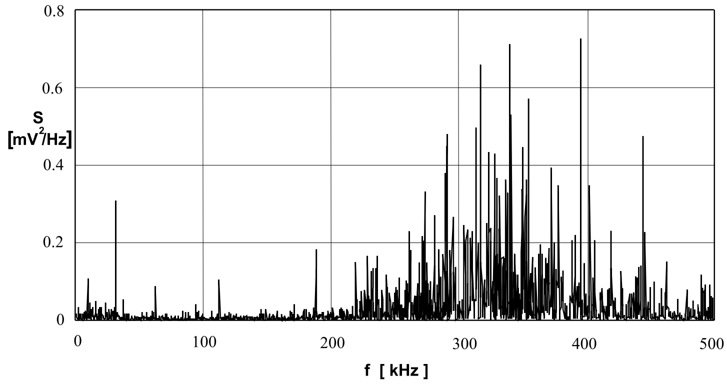

Fig. 11. Energy density spectrum of a series of AE pulses generated by PD in oil in the “spike-plate” system during the negative voltage half-cycle (1°, ϕ 0.06 mm).

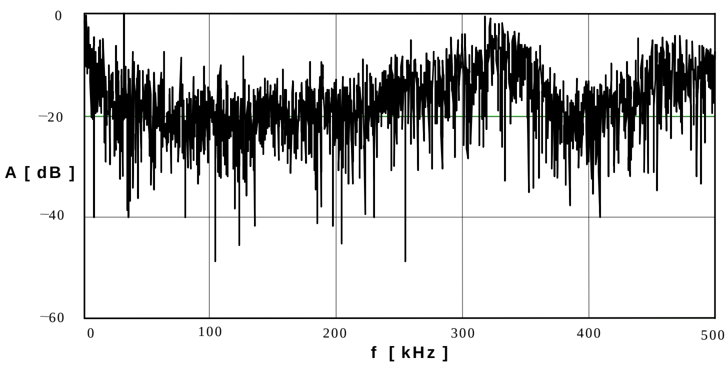

Fig. 12. Amplitude spectrum of a series of AE pulses generated by PD in oil in the “spike-plate” system during the positive voltage half-cycle (22°, ϕ 0.6 mm).

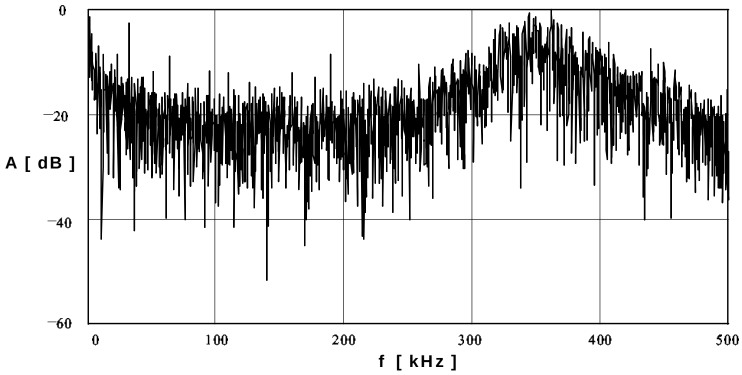

Fig. 13. Amplitude spectrum of a series of AE pulses generated by PD in oil in the “spike-plate” system during the negative voltage half-cycle (22°, ϕ 0.6 mm).

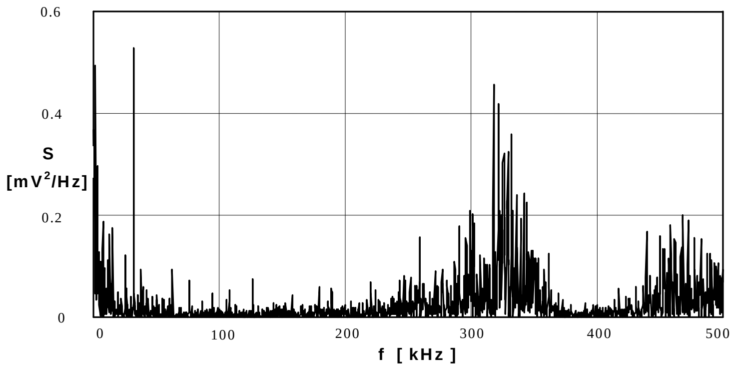

Fig. 14. Energy density spectrum of a series of AE pulses generated by PD in oil in the “spike-plate” system during the positive voltage half-cycle (22°, ϕ 0.6 mm).

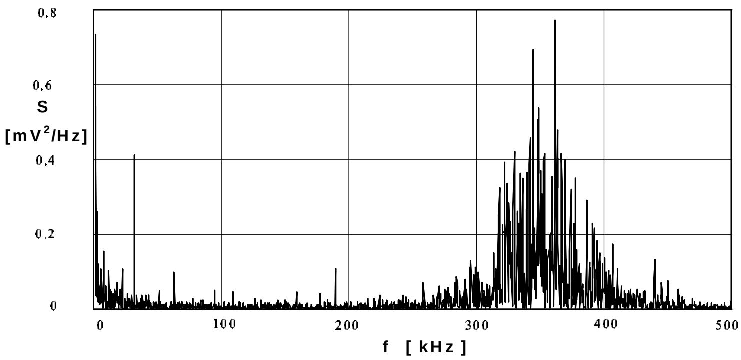

Fig. 15. Energy density spectrum of a series of AE pulses generated by PD in oil in the “spike-plate” system during the negative voltage half-cycle (22°, ϕ 0.6 mm).

In order to determine the influence of the insulation oil type on the repeatability results of the AE pulses generated by PDs of the multipoint-plane type, five transformer oils of various physico-chemical parameters were selected, the values of which are presented in Table 5. The oil samples used in the testing were taken from high-power transformers operating in industrial conditions, of various times of their exploitation. The measurements were taken at a voltage equal to $0.8\,U_p$ (breakdown voltage) and at oil temperature equal to $24°$C. Voltage polarization and the change of the physico-chemical parameters of the transformer oil did not influence the shape of the frequency spectrum runs or the values of the descriptors that characterize them. Detailed characteristics of the influence of the insulation oil type on the frequency analysis results of the AE pulses generated in a spark gap modeling PDs of the multipoint-plane type have been presented in the paper [3, 4].

Table 5. Listing of the selected physical and chemical parameters of the transformer oils studied.

Oil sample number	Breakdown voltage [kV]	Loss factor [-]	Resistivity [m·Ω]	Water contents [ppm]
I	67.5	0.0133	$2.4 \cdot 10^8$	17.5
II	56.1	0.0046	$3.2 \cdot 10^8$	15.8
III	66.3	0.004	$212 \cdot 10^{10}$	12.5
IV	50.2	0.0064	$3.2 \cdot 10^9$	11.8
V	56.4	0.0043	$5.3 \cdot 10^9$	14.6

In order to determine the influence of the oil type change on the measurement repeatability of the AE pulses, the homogeneity test of many variances was used and the following hypotheses were adopted:

H_0: $\sigma_1^2 = \sigma_2^2 = \sigma_3^2 = \sigma_4^2 = \sigma_5^2 = \sigma_6^2$, where σ_i^2 denotes a variance of an i population of the results obtained for a given temperature of insulation oil;
H_1: not all variances of the results are equal.

Next, the analysis test of variances for many averages of a single classification was used, for which the following hypotheses were assumed:

H_0: $m_1 = m_2 = \ldots = m_6$, where m_i is the average value for an i population of the results obtained for a given type of insulation oil;
H_1: variances are not equal.

To present the repeatability results, the value of the peak coefficient was selected that was determined for the peak coefficient in both voltage polarizations. The results are presented in Tables 6–7.

Table 6. Comparative listing of the peak coefficient calculated for the amplitude spectrum of the AE pulses generated by PDs of the multipoint-plane type for five types of insulation oil.

Measurement	Peak coefficient									
	positive polarization					negative polarization				
	oil I	oil II	oil III	oil IV	oil V	oil I	oil II	oil III	oil IV	oil V
1	3.20	3.11	3.77	3.02	2.94	3.23	3.62	3.24	3.26	3.64
2	3.55	2.86	3.99	3.51	3.29	3.13	3.54	3.39	3.45	3.56
3	3.38	3.49	3.10	3.54	3.57	3.67	3.17	3.57	3.69	3.68
4	3.20	3.25	3.22	3.99	3.48	3.45	3.46	3.78	3.52	3.24
5	3.55	3.56	3.54	3.41	3.15	3.68	3.82	3.67	3.68	3.64
6	3.88	3.74	3.22	3.35	3.32	3.55	3.51	3.15	3.74	3.71
7	3.96	3.33	3.28	3.45	3.48	3.25	3.24	3.22	3.44	3.46
8	3.11	3.25	3.41	3.56	3.88	3.33	3.73	3.66	3.48	3.42
9	3.01	3.89	3.01	3.15	3.47	3.64	3.45	3.62	3.5	3.16
10	3.19	3.76	3.88	3.01	3.95	3.55	3.74	3.73	3.16	3.57
Average:	3.40	3.42	3.44	3.40	3.45	3.45	3.53	3.50	3.49	3.51
Standard Deviation:	0.324826	0.322979	0.339732	0.292402	0.306233	0.20071	0.211282	0.232286	0.184258	0.187012

Table 7. The value χ^2_α from the distribution table for the homogeneity test of many variances and F_α value for the test of variance analysis for many averages and the calculated values χ^2 and F for the peak coefficient calculated for the amplitude spectrum of the AE pulses generated by PDs of the multipoint-plane type for five types of insulation oil.

voltage polarization	α	degrees of freedom	χ^2	χ^2_α	1 degree of freedom	2 degree of freedom	F	F_α
positive	0.1	4	0.22953	1.063624	4	45	0.05527	0.26323
negative			0.633811				0.212747	

6. Summary

Comparing the values obtained by parametric tests of goodness of fit for three selected descriptors, with critical values read from the distribution tables at the assigned significance level $\alpha = 0.1$ and a determined number of the freedom degrees depending on the number of measurements and the number of populations considered of the measurement results obtained, it can be stated that:

• The changes concerning the point electrode geometry and the introduction of another point for a spark gap making the generation of PDs of the point-plane type possible, does not influence the repeatability of the results obtained.

• The increase of the number of points in the range from 3 to 12 in the setup for PD generation of the multipoint-plane type did not disturb the repeatability of the results obtained. However, the placement of a pressboard layer between the electrodes of the spark gap used caused a significant change of the determined descriptor values characterizing the amplitude and energy density spectrum runs. The use of the pressboard barrier changed the physical conditions in which PDs are generated and thus such a model setup should be considered as a separate PD form.

• For the setups that enable modeling of PDs of the point-plane and multipoint-plane types, the lack of repeatability of the descriptors compared was pointed out. In such spark gaps, varying analysis results in the time and frequency domains of the AE pulses generated were obtained.

• The application of insulation oils of various physico-chemical parameters and the oil temperature change in the range from $22°$C to $85°$C did not influence the measurement repeatability of the AE pulses generated by PDs of the multipoint-plane type.

• The use of three different types of resin as a layer separating the electrodes in a spark gap for PD generation of the surface type did not influence the repeatability of the measurement results. However, the use of the pressboard layer caused the change of the compared descriptor values obtained and the lack of repeatability of the measurement results.

• The placement of barriers made of various types and of various thickness papers and insulation resins on the propagation path of acoustic waves, between a spark gap for

PD generation of the multipoint-plane type and a wall of a transformer tub on the surface of which a measuring transducer was attached, did not influence the repeatability of the AE pulses registered. Also some experimental works were performed which referred to the evaluation of the effect of the change of the propagation path length of the acoustic signals generated and determining the changes of the transducer placement in relation to the PD generation area, on the repeatability of the AE pulses measured. Also in this case the hypotheses assuming the repeatability of the results obtained were verified, and the results obtained have been presented in the paper [6].

Summing up, the laboratory measurements taken repeatedly of the AE pulses generated in the constructed spark gaps modeling basic PD forms are characterized by their repeatability, and the results obtained are resistant to the influence of the changes of the interfering factors considered. This conclusion is true on condition that a 10% margin of error making possibility is taken into account.

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