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The Influence of Physical-Chemical Parameters of Transformer Oil on the Time-Frequency Analysis Results of the Acoustic Emission Signals Generated by Partial Discharges

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The paper presents the measurement results of the acoustic emission (AE) generated by partial discharges (PDs) in oils of various physical-chemical parameters. The time-frequency analysis of the AE signals measured for PDs generated in the particular oils was carried out. For the AE signals measured, generated by PDs, the descriptors describing a signal in the frequency domain were determined, amplitude spectra were drawn and the spectrograms of the energy and amplitude density spectra were determined.

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Introduction

During PDs part of electric energy is turned into mechanical energy in the form of a medium elastic disturbance. The disturbance is a spherical acoustic wave propagating in all directions. The propagation of an acoustic wave in a medium is connected with the intermolecular interaction, through which the wave movement is transmitted between the molecules. These interrelations depend on the properties of a medium in which PDs occur [4].

In power transformers an acoustic wave generated by PDs propagates in electroinsulation oil. During operation, oil is subject to aging processes therefore its physical-chemical properties change. Also the conditions of the acoustic wave propagation in electroinsulation oil change with the change of physical-chemical properties. Hence it becomes purposeful to determine the influence of the physico-chemical change of electroinsulation oil on the results of the time-frequency analysis of the AE signals generated by PDs. In this paper the descriptor analysis of the AE generated by PDs in oils of various physical-chemical parameters was carried out.

I. Parameters of Electroinsulation Oils Used for Tests

For testing purposes the samples of electroinsulation oils taken from distributive transformers being in operation were used. Nominal parameters of transformers are shown in Table 1.

Table 2 shows a collective listing of physical-chemical parameters of electroinsulation oils under study.

Table 1.

Collective listing of nominal data of transformers from which the samples were taken

	Parameter	Oil No. 1	Oil No. 1	Oil No. 3	Oil No. 4
1	Type	TOC 100/20	T3ZONE 50/20	T3ZONg 100/20	TAOFn 630/20
2	Production year	1957	1970	1965	1985
13	Nominal power [kVa]	100	50	100	630
4	Primary voltage [kV]	15000±5	15750±5	15000±5	15750±5
5	Secondary voltage [V]	400 - 231	400 - 231	400 - 231	400 - 231
6	Type of operation	C	C	C	C
7	Type of cooling	ON-AN	ON-AN	ON-AN	ON-AN
8	Oil mass [kg]	280	195	250	470

Table 2.

Collective listing of physico-chemical parameters of electroinsulation oils

	Parameter	Testing method	Oil No. 1	Oil No. 2	Oil No. 3	Oil No. 4
1	Density in 20ºC [g/ml]	PN – 90/C-04004	0,865	0,878	0,882	0,879
2	Temperature of ignition [ºC]	PN – 75/C-4009	166,1	148,1	145,2	146,1
3	Acid number [mg KOH/g]	PN – 88/C – 04049	0,170	0,063	0,070	0,080
4	Water contents [ppm]	PN – 81/C – 04959	14,7	12,6	16,2	24,8
5	Dielectric loss coefficient tgδ at 50ºC and 50 Hz [%]	PN – 84/E – 04409	0,42	0,22	0,76	1,53
6	Resistivity at 50ºC [Ωm] •10^{10}	PN –84/E - 04409	11,2	38,0	4,68	8,78
7	Breakdown voltage at 20ºC [kV]	PN – 77/E - 04408	66,5	68,3	66,7	62,5

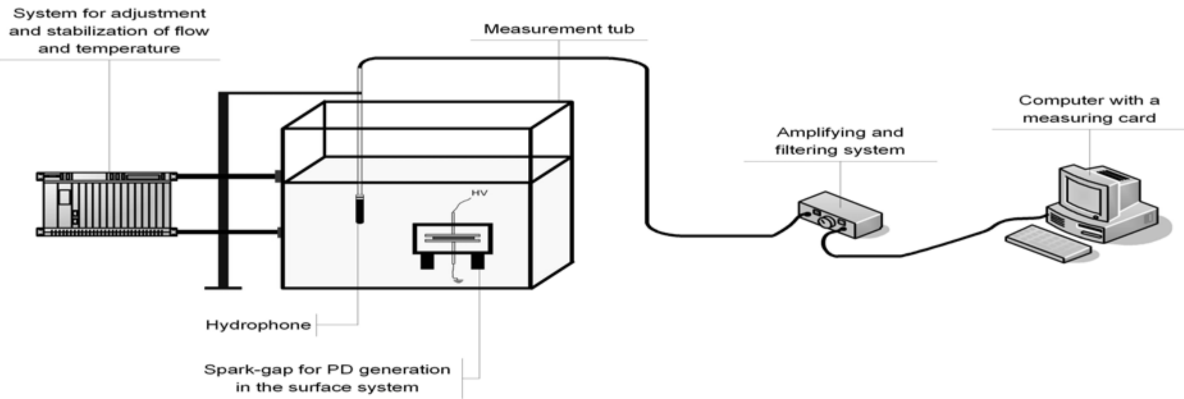

Fig. 1. Diagram of the measuring set-up for the measurement of the AE signals generated by PDs.

II. Measuring Set-up

A diagram of the measuring set-up used for testing is shown in Fig. 1. The main element of the measuring set-up is a tub filled with the electroinsulation oil under study, in which a spark-gap for PD generation in the surface system was placed. The AE signals generated by PDs were registered with a hydrophone type 8103 by the Brüel&Kjær firm, which was immersed in oil. During the measurements the hydrophone was placed on a stand in a fixed position in relation to the spark-gap. Next, a signal was amplified in an amplifying and filtering system and registered with a measuring card in a computer. In the set-up a band-pass filter of a transfer band from 10 to 700 kHz was used. A four-path measuring card Acquitek CH 3160 was used for a signal registration. The AE signals generated by PDs were registered with the frequency of 2.56 MS/s. During the measurements 51200 samples were registered, which made it possible to analyze a signal in the time of 20ms.

During the measurement taking oil was heated up to the temperature of 50ºC. To stabilize temperature the system was equipped with a unit for adjustment and stabilization of flow and temperature. Its main element is a pump which enables a step adjustment of the flow speed, a connection which adjusts the flow in a fluent manner, a flow-meter, a heating system and a thermostat.

III. Methodology of the Reasearch Work Conducted

Each of the electroinsulation oils under study was placed in a measuring set-up and then PDs of the surface type were generated in it. The AE signals generated by PDs were subject to the frequency analysis consisting in determining the spectrum density of amplitude and energy and descriptors describing the AE signals determined for the spectrum density of amplitude and energy. To describe a signal in the frequency domain three descriptors were used: shape coefficient, peak coefficient and median frequency. Then the time-frequency analysis was carried out through determining two- and three-dimensional spectrograms of the spectrum density of energy and three-dimensional spectrograms of the amplitude spectrum.

IV. Analysis of the Results Obtained

Fig. 2 shows amplitude spectra of the AE signals registered, generated by PDs in oils of various physical-chemical parameters and determined by using a numerical procedure written in Mathcad program.

Table 3 shows a collective listing of descriptor values determined for the spectrum density of energy and the spectrum density of amplitude of the AE signal generated by PDs in various electroinsulation oils.

The amplitude spectra shown in Fig. 2, which characterize the AE signals from PDs generated in

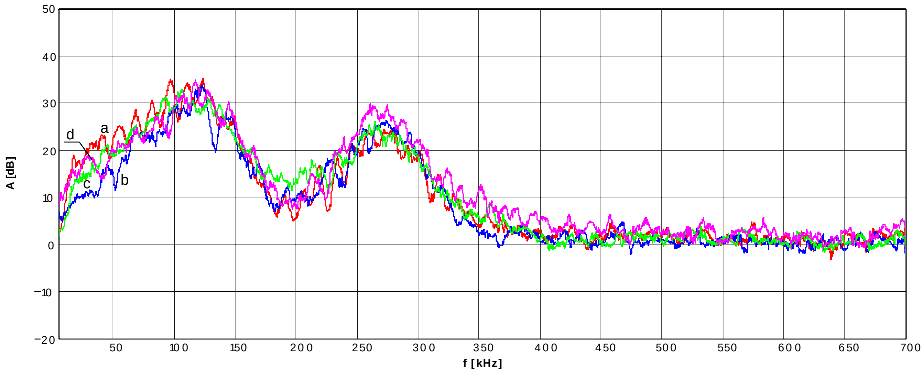

Fig. 2. Amplitude spectra of the AE signal generated by PDs for four electroinsulation oils of various physical-chemical parameters: a) oil no. 1, b) oil no. 2, c) oil no. 3, d) oil no. 4.

Table 3.

Average descriptor values determined for the amplitude spectrum and the power density spectrum.

Kind of descriptor	Spectrum density of energy [mV2/Hz]				Spectrum density of amplitude[mV]			
	Oil 1	Oil 2	Oil 3	Oil 4	Oil 1	Oil 2	Oil 3	Oil 4
Peak coefficient [-]	25,81	23,01	24,63	23,01	11,14	10,69	10,93	10,52
Shape coefficient [-]	4,69	4,71	4,72	4,70	2,75	3,00	2,76	2,79
Median frequency [kHz]	102,05	133,08	110,65	117,14	119,38	141,66	126,20	130,99

Table 4.

Comparative listing of the standard deviation values for the descriptors of the spectrum density of amplitude and power determined for the AE signals generated by PDs in various electroinsulation oils.

Kind of descriptor	Standard deviation for spectrum density of power descriptors [%]	Standard deviation for spectrum density of amplitude descriptors [%]
Peak coefficient	5,66	2,51
Shape coefficient	0,28	4,22
Median frequency	11,33	7,21

various oils, are very similar to one another as far as the shape and the range of dominant frequencies are concerned. In order to compare the values of the descriptors calculated, which describe the AE signals generated by PDs, standard deviation expressed in % of the average value was calculated. Maximum standard deviation for the determined descriptors of the spectrum density of energy does not exceed 12% and for the descriptors of the amplitude spectra – 8%. The analysis of the amplitude spectrum as well as of the descriptors determined proves that the change of physical-chemical parameters of electroinsulation oil does not have a statistically significant influence on the interpretation of the AE signals generated by PDs in the frequency domain.

In order to carry out the time-frequency analysis the AE signals registered, generated by PDs, were subject to a short-time Fourier transform using the Hamming window.

Fig. 3 shows two-dimensional spectrograms of the spectrum density of energy, Fig. 4 shows three-dimensional spectrograms of the spectrum density of energy, and Fig. 5 presents a three-dimensional spectrogram of the amplitude spectrum.

Figs 3, 4, 5 show spectrograms determined while using a threshold function cutting off components of lower amplitude values. The threshold function was used to bring out the coherent structures obtained.

On the two-dimensional spectrogram of the spectrum density of energy we can observe repeated structures contained in two frequency ranges. One of them refers to low frequencies from 30 kHz to 180 kHz, and the other range is contained within the range from 220 to 330 kHz. Such structures occur on each spectrogram presented.

Three-dimensional spectrograms of the spectrum density of energy shown in Fig. 4 confirm the participation of the two above-mentioned frequency bands. It can be observed that PDs are generated in particular oils with different intensity. The difference between the amplitude values in spectrograms for the particular oils is not statistically significant.

Fig. 4 shows spectrograms of the amplitude spectrum, in which bigger participation have frequencies contained within the first range – from 30 to 180 kHz. On the spectrograms presented we can observe repeated structures of a similar shape and character.

Summing-Up

In the result of the research work carried out we can conclude that the change of physical-chemical

a) b) c) d)

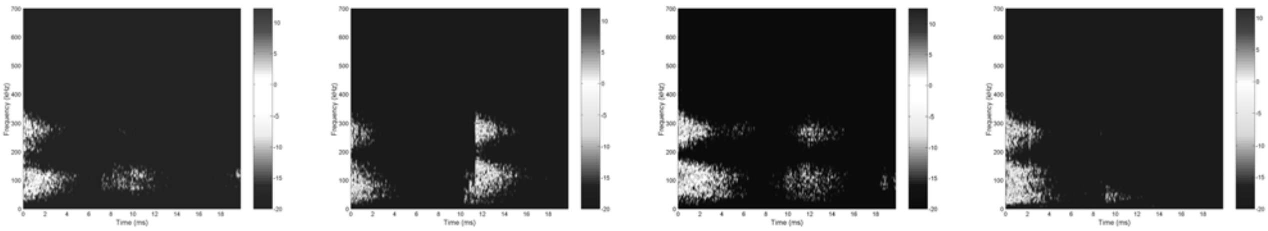

Fig. 3. Two-dimensional spectrograms of the spectrum density of energy determined for the AE signals generated by PDs in oils of various physical-chemical parameters: a) oil no. 1, b) oil no. 2, c) oil no. 3, d) oil no. 4.

a) b) c) d)

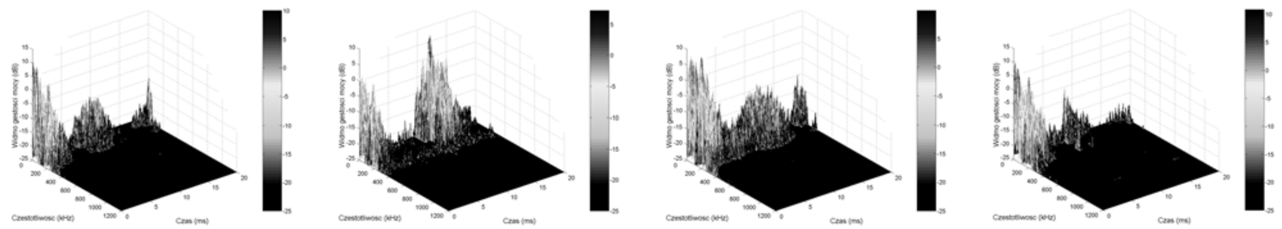

Fig. 4. Three-dimensional spectrograms of the spectrum density of energy determined for the AE signals generated by PDs in oils of various physical-chemical parameters: a) oil no. 1, b) oil no. 2, c) oil no. 3, d) oil no. 4.

a) b) c) d)

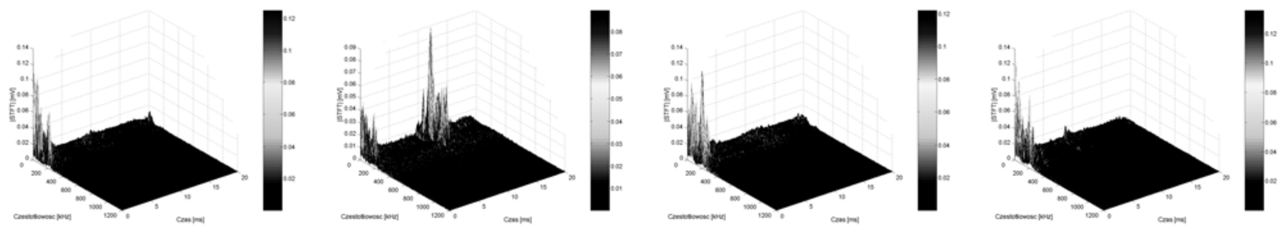

Fig. 5. Three-dimensional spectrograms of the amplitude spectrum determined for the AE signals generated by PDs in oils of various physical-chemical parameters: a) oil no. 1, b) oil no. 2, c) oil no. 3, d) oil no. 4.

parameters such as: density, temperature of ignition, acid number, water contents, dielectric loss coefficient, resistivity and breakdown voltage do not have a statistically significant influence on the time-frequency analysis of the AE signals generated by PDs. This conclusion makes it possible to interpret the registered AE signals generated by PDs irrespective of the type and physical-chemical parameters of oil and the time and conditions of a transformer operation.

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Вплив фізико-хімічних параметрів трансформаторного масла на частотно-часові характеристики акустичних сигналів емісії.

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Стаття представляє результати вимірювання акустичної емісії (AE), що генерується частковими розвантаженнями (PDs) в маслах різних фізико-хімічних параметрів. Проводився частотно-часовий аналіз сигналів AE, виміряних для PDs, що генеруються в специфічних маслах. Для виміряних сигналів були визначені, спектри амплітуди і зняті спектрограми енергії і спектри густини амплітуди.