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Investigation of acoustic emission generated by cavitation in insulating oils

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Absolwent kierunku Informatyka Dwujęzyczna Wydziału Elektrotechniki, Automatyki i Informatyki Politechniki Opolskiej. Słuchacz II roku studiów doktoranckich w dyscyplinie Elektrotechnika w Politechnice Opolskiej. Prowadzi prace badawcze nad zastosowaniem zjawisk optyczno-akustycznych do diagnostyki olejów izolacyjnych w Zakładzie Inżynierii Materiałowej i Elektrycznej Instytutu Elektroenergetyki.

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Abstract

The main aim of this article is the investigation of acoustic emission signals generated by acoustically induced cavitation in oils. The possibility of using the cavitation phenomenon as a principle of a diagnostic tool for monitoring the condition of insulating oils in power transformers is proposed. In this note, the principles of the measurements method are explained, the built and used experimental apparatus is described and representative results of the experimental data taken from the apparatus are shown. The experimental results are presented in form of power spectral densities of acquired acoustic emission signals. An attempt to approximate the relationship between the power spectral density and the oxidation time of the mineral oil according to the PN-EN 61125 norm was executed.

Keywords: acoustic emission, insulating oils, cavitation.

Badanie emisji akustycznej generowanej zjawiskiem kawitacji w olejach izolacyjnych

Streszczenie

Podstawą niniejszego artykułu jest badanie sygnałów emisji akustycznej generowanych podczas zjawiska wymuszonej kawitacji akustycznej w olejach. Zaproponowano możliwość wykorzystania zjawiska do diagnostyki właściwości starzeniowych olejów izolacyjnych. Przedstawiono schemat wykorzystywanego układu pomiarowego oraz uzyskane wyniki w postaci widm gęstości mocy sygnału emisji akustycznej dla różnych wartości amplitud sygnału źródłowego. Ponadto dokonano aproksymacji zależności gęstości widmowej mocy wybranych wartości częstotliwości sygnału w funkcji czasu starzenia mineralnego oleju izolacyjnego.

Słowa kluczowe: emisja akustyczna, oleje izolacyjne, kawitacja.

1. Introduction

The process of rupturing a liquid by decrease in pressure at roughly constant liquid temperature is called cavitation. The behaviour of creation of cavitation voids or bubbles in a liquid is a result of increasing liquid flow in pumps, propellers and a decreasing liquid pressure on a orifice. Ultrasonically induced cavitation is defined as the formation, growth and collapse of gaseous or vaporous bubbles under the influence of ultrasound [1]. One of the most interesting consequence of cavitation is a sonoluminescence phenomenon in form of multi-bubble sonoluminescence [2] and single-bubble sonoluminescence [3]. An acoustic emission signal from working transformer can be used for monitoring of its condition [4] and recognizing the form of partial discharges generated in insulating oil [5]. An imploding gas-vapour bubble during cavitation is a source of broadband acoustic emission signal and consist of fundamental frequency component produced by the direct driving acoustic field and its harmonics, subharmonics and ultraharmonics components [6]. The acoustic emission signal contains also a broadband noise generated by shock waves from collapsing bubbles of a wide range of sizes [7]. The analysis of hydrodynamic cavitation acoustic emission spectrum can be used for on-line diagnostics of a centrifugal pump [8]. In high energy acoustic fields the cavitational effect may be dominated by the characteristics of the entire generated bubble population [9]. Also laser-induced breakdown in liquids is followed by a formation and collapse of cavitation bubbles within the liquid [10].

2. Measurement system

A measurement system needed for generating acoustic cavitation in an oil filled round bottomed glass flask and acoustic emission signal measurements was built. Its schematic diagram is presented in figure 1.

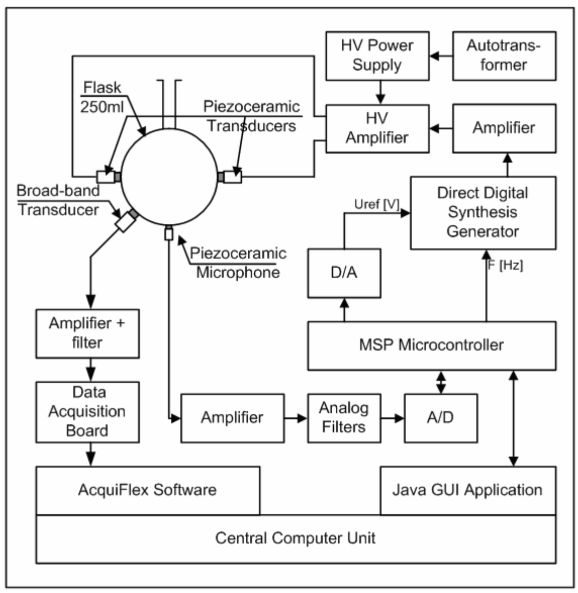

Fig. 1. Schematic diagram of used measurement system
Rys. 1. Schemat blokowy wykorzystywanego systemu pomiarowego

The main part of used measurement system is a high frequency, high voltage sine wave generator based on a Direct Digital Synthesizer AD9833 with 0.1Hz frequency resolution tuning. A used 12-bit resolution TLV5638 digital-to-analog converter connected to REF input of the programmable waveform generator enables signal amplitude tuning. The generated signal drives two piezoceramic transducers (16mm diameter and 6mm thick) glued to the flask in two opposite ends of the flask as showed in figure 2.

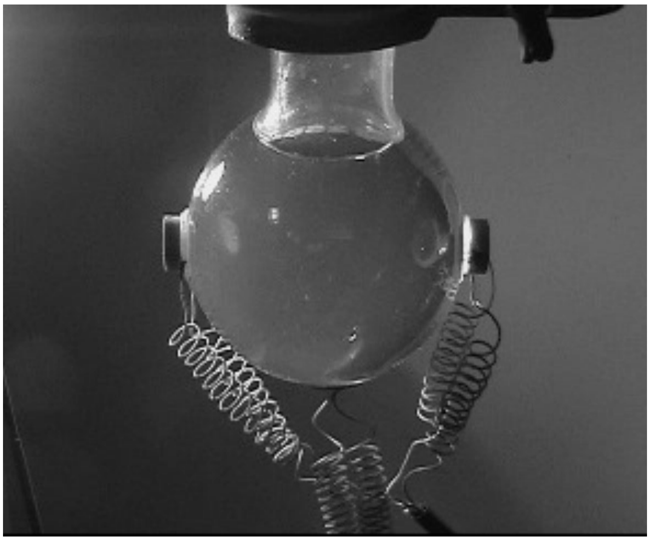

Fig. 2. Used cavitation vessel
Rys. 2. Wykorzystywane naczynie kawitacyjne

The third transducer used as microphone enables to find the optimal driving resonance frequency. A four channel, 40MS/s sample rate and 12-bit resolution data acquisition PCI board CH-3160, an acoustic emission broad-band transducer WD AH 17 and AquiFlex software were used for acoustic emission signal measurements. A Java application performs a graphical user interface role and together with central control microcontroller were used for automate the measurement process.

3. Measurements results

For the measurement purposes four mineral oil samples were prepared according to the PN-EN 61125 norm. The oxidation times of prepared oil samples were 1h, 20h, 48h and 114h. The acoustic cavitation in used insulation oil filled 250ml flask was induced by a generated 133kHz sine signal of different signal amplitudes up to 1200V. All measurements of acoustic emission signal were carried out for period of 1 second with 1048576 S/s sample rate. The estimated power spectral densities of measured acoustic emission using Welch's averaged, modified periodogram method of four oil samples induced with signal of 133kHz frequency and 400V amplitude are presented in figure 3. Presented spectrums show the main frequency component and its harmonics, the differences between spectras are unimportant and there was no cavitation present.

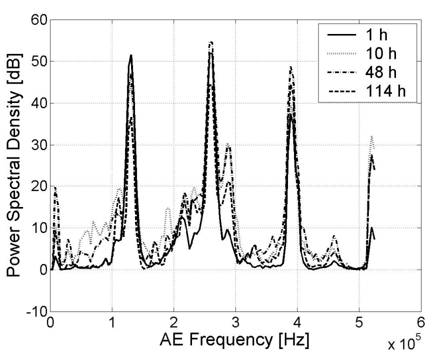

Fig. 3. Power spectral densities of a cavitation generated acoustic emission signal from oils samples with different aging properties for amplitude of 400V
Rys. 3. Gęstości widmowe mocy sygnału emisji akustycznej generowanej podczas kawitacji dla próbek oleju o różnym stopniu zestarzenia przy amplitudzie 400V

The power spectral densities of acoustic emission during inducing with sine signal of 133kHz frequency and 800V amplitude, as showed in figure 4, contain a broad-band noise signal which indicates the existence of collapsing cavitation bubbles generating shock waves. The freshest oil sample of 1h oxidation time is characterised by higher power density for the whole frequency band.

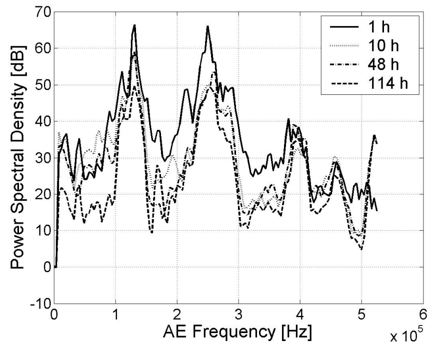

Fig. 4. Power spectral densities of a cavitation generated acoustic emission signal from oils samples with different aging properties for amplitude of 800V
Rys. 4. Gęstości widmowe mocy sygnału emisji akustycznej generowanej podczas kawitacji dla próbek oleju o różnym stopniu zestarzenia przy amplitudzie 800V

The most interesting measurement results are introduced in figure 5 and show a clear relationship between acoustic emission activity and the oxidation time of oil. In the whole measured frequency band a decrease of power spectral density in function of oxidation time can be observed. The cavitation bubbles activity almost disappeared for the two oldest oil samples.

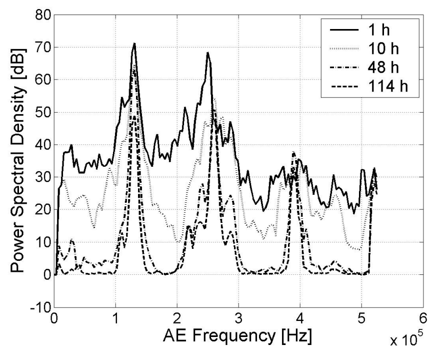

Fig. 5. Power spectral densities of a cavitation generated acoustic emission signal from oils samples with different aging properties for amplitude of 1200V
Rys. 5. Gęstości widmowe mocy sygnału emisji akustycznej generowanej podczas kawitacji dla próbek oleju o różnym stopniu zestarzenia przy amplitudzie 1200V

For graphical presentation purpose of acoustic emission power spectral density dependence on oxidation time of oil, four frequency components of acoustic emission frequency band from figure 5 (100kHz, 240kHz, 350kHz, 420kHz) were selected. Figure 6 shows the extracted values from acoustic spectra and approximated exponential functions described by equation 1. Tab. 1 shows estimated coefficient values of approximated exponential power density functions of acoustic emission during cavitation for selected frequency components.

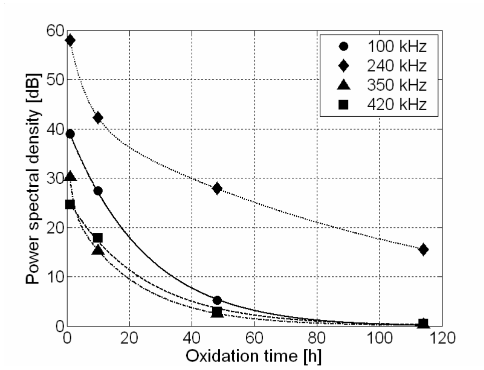

Fig. 6. The dependence between power spectral density of acoustic emission signal generated by cavitation and oxidation time (t_{st}) of oil sample for different frequency components

Rys. 6. Zależność gęstości widmowej mocy sygnału emisji akustycznej generowanej podczas kawitacji od czasu starzenia (t_{st}) próbek oleju dla wybranych częstotliwości składowych

$$G(t_{st}) = A_1 \cdot e^{-\tau_1 \cdot t_{st}} + A_2 \cdot e^{-\tau_2 \cdot t_{st}} \qquad (1)$$

Tab. 1. Estimated coefficient values of approximated exponential power density functions of acoustic emission during cavitation for selected frequency components and the corresponding determination coefficient values of fitting results

Tab. 1. Wartości współczynników aproksymowanej wykładniczej funkcji gęstości mocy sygnału emisji akustycznej zjawiska kawitacji dla wybranych częstotliwości składowych oraz wartości współczynników determinacji wyników dopasowania

Frequency - f [kHz]	A_1	τ_1	A_2	τ_2	R^2
100	-295.80	0.03188	336.4	0.0329	0.9997
240	42.49	0.00880	18.9	0.1725	1
350	24.63	0.04749	13.6	0.6971	1
420	25.99	0.04125	0.0	0.0000	0.9974

4. Conclusion

The objective of this work is to point out the possibility of using acoustic emission signal from cavitation, induced by a high energy acoustic field as a diagnostic tool for power transformer life-time prediction. During the long time of energetic transformer operation the losses of insulation properties of used transformer oils can't be avoided. The essential factor in transformer oil degradation is the amount of chemical compounds i.e. oxygen, nitrogen, hydrogen and simple hydrocarbons. An important factor is the humidity content as a result of insulation paper oxidation. All of the factors have also influence on the bubble dynamics during acoustic cavitation. An imploding cavitation bubble is a source of broad-band acoustic emission signal and this feature is the main point of interest of this paper. The introduced measurement results in form of power spectral densities of detected acoustic emission signal during ultrasound induced cavitation in oil filled vessel can be used for estimation of aging properties of mineral insulating oils. The results from acoustic emission analysis have shown a clear relationship between acoustic emission activity and the oxidation time of oil. The older the insulating oil the smaller the power of specific frequency component of detected AE signal. In conclusion the use of acoustic cavitation can be an essential supplement for existing methods of insulating oil diagnostics.

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Artykuł recenzowany

INFORMACJE

Sprostowanie

W notce biograficznej prof. dr. hab. inż. Wiesława L. Wolińskiego w PAK nr 1/2008 na str. 38 został podany błędnie status Profesora w PAN. Aktualnie prof. Wiesław L. Woliński jest członkiem zwyczajnym PAN. Za pomyłkę przepraszamy.

Redakcja