Optical and Acoustical Methods in Science and Technology

Time-Frequency Analysis of Mechanical Vibrations of the Dry Type Power Transformer Core

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The paper presents research results referring to the development of a non-invasive method of assessment of the power transformer core technical condition based on the analysis of the mechanical vibrations registered. It characterizes the power object under study, the measuring system used and the developed methodology of assessment of the core pressing degree using the vibroacoustic method. The original results of the time–frequency analysis of the vibroacoustic signals presented in the paper were obtained during switching on a real 800 kVA dry type power transformer in laboratory conditions. The analysis of the signals registered was carried out for three states of its operation: the core pressed by the manufacturer, the core with loose screws fixing the upper yoke and the core with separated upper yoke beams.

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1. Introduction

Modern approach to the management of the network property gathered in distribution companies is conditioned, to a large extent, by the rules of the liberated electric energy world market. The legal regulations introduced and the market rules forced the existing power enterprises to increase their competitiveness, which is connected with a dynamic cutting of operational costs of the particular installations of the national electric power system. The ultimate and the most essential aim of such management policy is minimization of the electric energy price [1–4].

At present, a continuing improvement of reliability of the particular installations constituting the electric power system is the measurable effect of the innovative approach to the network resources management. A correct and systematic diagnosis of appliances of a strategic significance is one of the most important procedures leading to the lowering of failure indexes. Undoubtedly, power transformers belong to the group of such appliances and their shut down due to failure may cause a significant economic loss [5–8].

During a regular operation, a power transformer is subjected to the influence of numerous unfavorable factors, which may shorten its life and cause unexpected failures. A gradual loosening of the pressing and its core fastening takes place with the transformer "age" due to loosening of the screws and fastening wedges and falling out of the distance inserts (Fig. 1). Such a situation may lead to the so-called catastrophic failure, which usually results in a total damage of a transformer and nearby appliances.

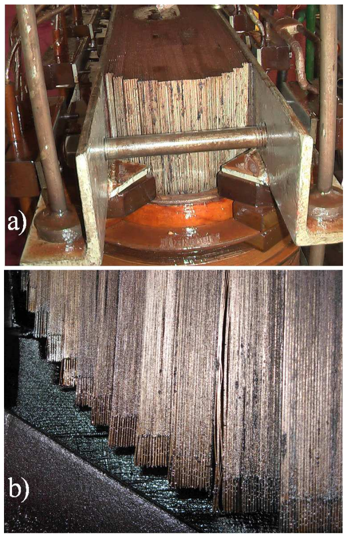

Fig. 1. View of the power transformer core: (a) without damaged packets, (b) with damaged packets.

In the electric power sector, the assessment of the transformer core pressing degree is carried out, first of all, based on the measurements: of magnetizing currents, FRA frequency response and acoustic pressure generated by a working transformer at changing load. Nevertheless, the above-mentioned measurement methods enable identification of only the cases of extreme loosening of the elements of the active part. Currently, the internal in-

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spection is the only and effective way of identification of the loosening of the core and windings but it is a rather complicated and costly procedure [2, 5, 7].

Because it is necessary to maintain the electric energy supply and not possible to shut down the installations for measurements, the works on the improvement and development of the so-called non-invasive measurement methods [1] are becoming of a greater and greater interest of distribution companies and research centers.

The research work carried out in Opole University of Technology, the results of which are presented in this paper, focus on the development of a non-invasive method of diagnosis and assessment of the pressing degree of the transformer unit core. The method proposed by author, the so-called modified vibroacoustic method, is based on the mechanical vibrations measurements of an appliance under study in its transient state — while switching on the unit. The research work aims at developing a modern and, what is most important, non-invasive assessment method of the core technical conditions of power transformers operating in the national electric power system.

2. The object under study and the measuring apparatus used

The research results presented in the paper were obtained through analyses of the vibroacoustic signals registered at the test station, which were measured during switching a real dry type 800 kVA power transformer into idle operation. The transformer under study, the overall view of which is shown in Fig. 2, was characteristic of the following technical parameters: power — 800 kVA, primary voltage — 400 V, secondary voltage — 6300 kV, connection group — Dy5, production year — 1973.

Fig. 2. Overall view of the transformer under study.

Mechanical vibrations of the core of the transformer diagnosed were measured with two accelerometers type 4514-B-001 by Brüel & Kjær attached directly to the core pressing beams. One accelerometer was placed on the upper beam of the pressing yoke and the other one on the lower beam. Next, the signal received by transducers was passed onto the input of the measuring case of PULSE Dyn-XI, type 3050-B-A4 system by Brüel & Kjær, which is used as a specialized equipment for registration of mechanical vibrations (Fig. 3). The analysis of the vibrations measured was carried out based on PULSE LabShop 13.5 professional software.

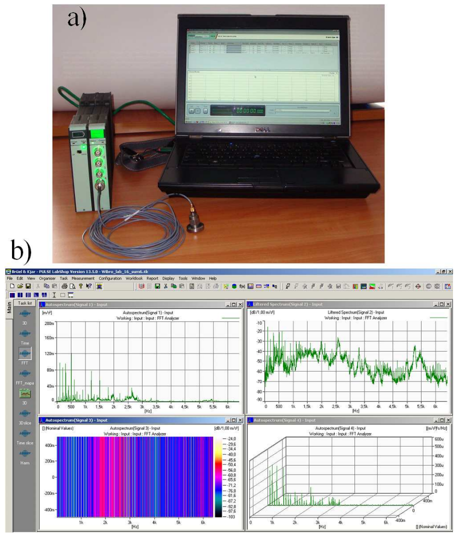

Fig. 3. Overall view of the measuring apparatus used (a) and a graphic window of the software used (b).

3. The analysis of the results obtained

The range of the research experiment presented in this paper included the registration and analysis of the core mechanical vibrations of the power unit under study for three operation cases. One case referred to vibroacoustic measurements taken during switching on a transformer with the core fastened by a manufacturer (the appliance without modeled core defects). The second case was connected with registration of mechanical vibrations during switching on the object under study with loose pressing screws of the upper yoke (1st degree of the core damage modeling). The third stage of vibroacoustic measurements was carried out with a totally unscrewed upper yoke and mechanically slackened core (2nd degree of the core damage modeling).

During the research work carried out, the simulations of the core damage of the appliance diagnosed came down only to slackening of its upper packets. The aim of this methodology was to perform the analysis and assessment of the influence of the modeled damage on the parameters of the vibroacoustic signals registered by accelerometers placed on both upper and lower yoke beams, but the lower beam was not made loose. The analysis of the registered signals of the core mechanical vibrations of the object under study was carried out in the time-frequency domain using root mean square (rms) values of vibration acceleration in relation to dB/1.0 m/s^2. Total registration time of a vibroacoustic signal from the moment of switching on (transient state) to the steady state of the transformer operation on the so-called idle run (with no load) was determined for 10 s, and the range of the frequency band from 0 to 6400 Hz was assumed.

The results of the time–frequency analysis of the vibrations registered for the particular stages of the core damage modeling, obtained through measurement taken on a real transformer, are shown in the figures below.

Figure 4 shows two-dimensional spectrograms of the vibration acceleration rms value for a transformer unit with a properly pressed core. Figure 4a shows a spectrogram of mechanical vibrations of the appliance under study determined based on the measurements taken with accelerometer no. 1 placed in the middle of the upper yoke beam. Figure 4b shows the results of the rms value of the core vibrations registered with accelerometer no. 2 placed in the middle of the lower yoke beam. The analysis of the time–frequency images shows that at the moment of connecting the unit to voltage, the frequency band of vibrations is practically contained within a full range of the frequencies determined, and the amplitude increase in the band $1800 \div 3400$ Hz (Fig. 4b) results, most probably, from natural vibrations of the transformer support construction, which stood on metal wheels. From the point of view of further comparative analysis of the particular core operation cases, the frequency range from the bands $0 \div 1200$ Hz and $3000 \div 6400$ Hz is significant.

Analyzing the spectrograms determined for the transformer with a properly packeted core (Fig. 4), the fact of a gradual fading of the particular frequency components of vibrations in the range from 0 to 1200 Hz with extended operation time of the transformer can be observed. At the same time higher harmonics of component 50 Hz become protruding in this frequency band. This phenomenon occurs for registration with accelerometers no. 1 and no. 2. In the case of the remaining frequency band it can be assumed that the changes of amplitudes of rms values of vibration acceleration, shown in the spectrograms, are insignificant. In the further part of the section, the spectrograms shown in Fig. 4 should be adopted as reference points for further comparative analyses connected with a gradual simulation of the core damage.

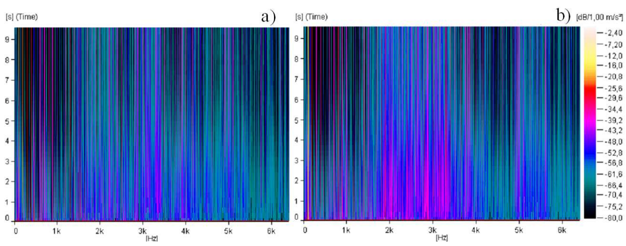

Fig. 4. Exemplary spectrograms of rms value of vibration acceleration of the transformer core without modeled defects of the core damage: (a) accelerometer no. 1 placed on the yoke upper beam, (b) accelerometer no. 2 placed on the yoke lower beam.

Figure 5 shows spectrograms of the rms value of vibration acceleration for the case of switching on and operation of the object diagnosed with loose screws pressing the upper yoke (1st degree of the damage modeling). A natural consequence of loose screws was an unconstrained slackening of the upper part of the core. Figure 5a shows the results of the time-frequency analyses of the vibrations registered on the upper yoke beam (accelerometer no. 1), and Fig. 5b shows the signals measured on the unchanged beam of the lower yoke (accelerometer no. 2).

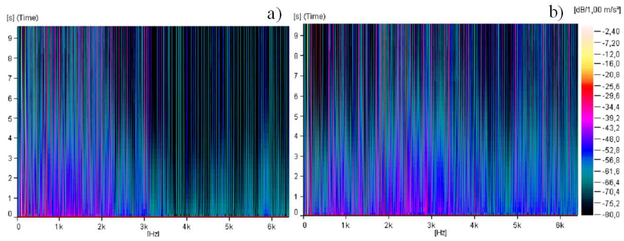

Fig. 5. Exemplary spectrograms of rms value of vibration acceleration of the transformer under study with a 1st degree modeled defect: (a) accelerometer no. 1 placed on the yoke upper beam, (b) accelerometer no. 2 placed on the yoke lower beam.

Based on the comparative analysis of the determined rms value of vibration acceleration for a correct core operation (Fig. 4) with a 1st degree modeled defect (Fig. 5), significant differences in the ranges of dominant frequency bands may be observed. These differences are observable especially in Figs. 4a and 5a, that is for registration carried out on the upper yoke beam, on which there was modeled a core damage. For the operation of the transformer with the depacketed core, the participation of vibrations from the band $0 \div 1200$ Hz is of a constant character and it does not change during the measurement test — quite opposite as in the case of the transformer operation with a packeted core. Also harmonics from the band $3000 \div 6400$ Hz behave in a quite different manner. In the case of the loosened core they disappear gradually in time, practically till their complete disappearance (Fig. 5a).

A separate comparative analysis of the vibroacoustic signals registered measured on the lower yoke beam (Figs. 4b and 5b) showed a relatively close participation of the particular frequency components changes in time. It means that the measurements taken with accelerometer no. 2 do not show unequivocally damage of the upper part of the core. In this case, however, significantly lower amplitude of the rms value of vibration acceleration of the particular harmonics, especially in the band $2000 \div 6400$ Hz, may suggest damage of the core in its upper part.

The final stage of the experiment carried out consisted in a complete loosening of the upper yoke and mechanical slackening of the core. Figure 6 shows in a graphic way the obtained results of the time–frequency analysis of the vibroacoustic signals registered for the core defect simulated in this way (2nd degree).

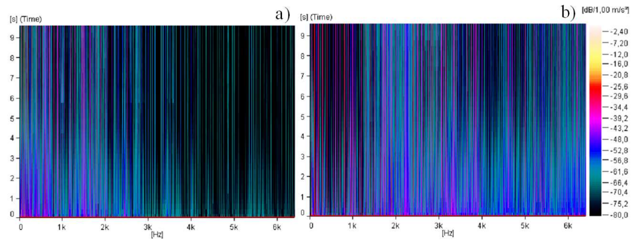

Fig. 6. Exemplary spectrograms of rms value of vibration acceleration of the transformer under study with a 2nd degree modeled defect: (a) accelerometer no. 1 placed on the yoke upper beam, (b) accelerometer no. 2 placed on the yoke lower beam.

Based on the results shown in Fig. 6a and their reference to the spectrograms in Figs. 4a and 5a it can be observed that the process of modeling the 2nd degree damage of the core of the transformer unit under study caused an even more distinct disappearance of the particular frequency components from the range $3000 \div 6400$ Hz, especially in the bands $2800 \div 3300$ Hz and $4500 \div 5300$ Hz. Moreover, based on the comparative analysis of the mechanical vibrations measured on the upper yoke beam for three states of the core operation, it can be inferred that in the case of a complete loosening of the core, an increase of the vibrations amplitude in the range $0 \div 1000$ Hz takes place, especially within the first seconds from switching on the power object under study. The analysis of the results shown in Fig. 6b confirms a relatively close participation of the changes of the particular frequency components in time compared to the results shown in Figs. 4b and 5b. Also in this case, lower amplitude of the rms value of vibration acceleration of the particular harmonics, especially in the band $2000 \div 6400$ Hz, may suggest damage of the core in its upper part.

4. Summing-up

Based on the carried out analysis of the power transformer core vibrations in transient and stable states of operation for three cases of its operation, significant differences of the two-dimensional spectrograms determined (Figs. 4–6) were indicated, which means the vibroacoustic indexes. Tim–frequency images showing rms value of vibrations acceleration in the range $0 \div 6400$ Hz, determined for the simulated core damage of the 1st and 2nd degrees, differ in amplitudes and ranges of the dominant frequencies of the mechanical vibrations of the core. These differences are observable especially for the registration carried out with accelerometer no. 1, which was placed on the upper yoke beam, within which the core defect was modeled (Figs. 4a–6a).

Based on the analyses and results shown in Sect. 3, author presented a potential possibility of using the modified vibroacoustic method for the assessment of the technical condition of the power transformer cores. The original results of the research work carried out within this paper show that it is possible to develop a non-invasive and effective method of assessment of the core technical condition of the transformer units used in the national electric power system.

Acknowledgments

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