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EVALUATION METHODOLOGY OF THE TECHNICAL CONDITION OF A POWER TRANSFORMER BASED ON THE MEASUREMENT RESULTS OF MECHANICAL VIBRATIONS OF ITS TUB

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Abstract

The subject matter of this paper refers to vibroacoustic measurements of high power transformers. The evaluation method of the transformer technical condition, based on the measurements of mechanical vibrations of its tub, is characterized. The elements of the measuring set-up, which were used during the registration of the signals coming from the core and winding vibrations of a given transformer unit, transferred by the tub, are presented. Based on the criterion values of the vibroacoustic parameters measured: root-mean-square value of the vibration acceleration and the vibration spectrum amplitude in the frequency range from 0 to 3000 Hz, the evaluation of the technical condition of the power appliance under study was carried out.

1. INTRODUCTION

High requirements of industrial and individual consumers concerning the supply quality and a competitive market of power energy forced distribution companies to maintain the highest reliability of the particular appliances being parts of the electric power system. This is connected directly with legal and financial consequences that power enterprises are subjected to in the case of failure to ensure an uninterrupted supply of power energy according to binding contracts. Only an effective and systematic diagnostics of appliances of strategic significance can minimize considerable costs incurred during the power object failures and the costs connected with undelivered power or penalties resulting from the violation of contracts. Power transformers are elements of the power system of a great significance for the supply and distribution of electric power. An emergency shut-down of such a unit may cause considerable economic loss, which in extreme conditions may exceed a few times the value of a new appliance [1, 3]. Therefore, an extensive diagnostic research work, the range of which should be correlated with the technical and economic significance of the power object measured, is fully justified.

The research work on developing effective methods of evaluation of the technical condition of power appliances has been carried out for many years. At present research centers focus mainly on the improvement and development of the so-called non-invasive diagnostic methods, which make it possible to take measurements during a regular operation of an appliance. In the sector of professional power engineering there exist a few methods of detecting defects occurring in power transformers. One of them is the vibroacoustic method, which consists in the measurement and analysis of vibrations of the object under study. Its application in diagnostics of high power transformers, first of all, makes the evaluation of the core technical condition possible. Combining the results of vibroacoustic measurements with other methods can provide information on: the degree of the winding deformation, degradation of paper-oil insulation and the technical condition of a mechanic construction [2, 4, 5].

The aim of the vibroacoustic measurement results presented in this paper was determining the level of the tub and core vibrations of the unit transformers under study, and based on them, evaluating the technical condition of the units diagnosed.

2. CRITERIA OF THE TECHNICAL CONDITION EVALUATION OF POWER TRANSFORMERS BASED ON VIBROACOUSTIC MEASUREMENTS

The evaluation of vibroacoustic vibrations was carried out based on the analysis of the measurement results of:

- root-mean-square value of vibration acceleration a_{RMS} in cm/s^2;
- amplitude vibration spectrum in the frequency range from 0 to 3000 Hz.

Based on the laboratory research and on the research on real professional power objects, boundary values of the above-mentioned parameters were determined. Threshold values determined in this way are of a general character and they should not be used mechanically in each case. Interpreting the results it is imperative to take into account individual construction properties of the unit under study and to compare the results obtained with the results obtained through the application of other methods (partial discharge evaluation, gas chromatography). This refers especially to the cases when the decision on shutting down a transformer is taken. The first criterion value of the technical condition evaluation of power transformers is a root-mean-square value of vibration acceleration $a_{sk,}$ which for an efficiently operated unit should not exceed the threshold value of 400 cm/s^2. The occurrence of vibrations of the root-mean-square value of acceleration above this value may indicate a core damage of the appliance under study and the need of its survey or repair.

The other evaluation criterion of a high power transformer core condition is a frequency analysis of the vibrations in the band $0 \div 3000$ Hz. It results from the experiments and investigations carried out that frequency participation of the particular vibrations falls into the following groups:

- vibrations of the component amplitude of up to 500 Hz, which are treated as the components coming from and characterizing magnetostriction vibrations of the core,
- vibrations of the component amplitude from the range ($600 \div 1500$) Hz, which are treated as the components characterizing the work of cooling appliances,
- vibrations of the components above 1500 Hz, which are treated as generated components characterizing the work of the core; their occurrence can indicate the core damage.

Table 1. Boundary values of the vibration spectrum components in the frequency range (1500 ÷ 3000) Hz.

	Core damage free transformers	Possible developing core damage	Possible core damage
Transformers ≤ 200 MV·A	a ≤ 3 cm/s^2	3 cm/s^2 < a ≤ 30 cm/s^2	a > 30 cm/s^2
Transformers > 200 MV·A	a ≤ 10 cm/s^2	10 cm/s^2 < a ≤ 30 cm/s^2	a > 30 cm/s^2

The comparison of the transformer tub vibrations measured with the criteria assumed should make an early detection of the core damage and possibly of other elements of the equipment of the unit under study possible. A correct measurement as well as an analysis and interpretation of the vibroacoustic signals registered can make it possible to determine the technical condition of the appliance under study correctly and to forecast its failure-free operation time.

3. METHODOLOGY OF MEASUREMENT TAKING AND THE MEASURING APPARATUS USED

Three unit transformers operating in power plant were subject to vibroacoustic testing. Table 2 shows the parameters of the units diagnosed.

Table 2. Parameters of the transformer units under study.

Parameter	Transformer 1	Transformer 2	Transformer 3
Type	TNAP 240 000 / 220 PN	TNEPC 270 000 / 220 PN	TWBN 240 000 / 400
Manufacture Year	1985	1995	1998
Power [MV·A]	240	270	240
Transmission [kV/kV]	240/ 15.75	250 / 15.75	420 / 15.75
Coupling group	YNd 11	YNd 11	YNd 11
Manufacturer	Elta	ABB Elta Sp. z o.o.	Elta

During the measurement taking of the vibroacoustic vibrations, in each unit transformer under study, all cooling appliances – pumps and cooler fans – were in operation. Transformer 1 had five oil coolers, which constituted an external set of heat exchangers (not attached to the tub). Units 2 and 3 were equipped with five and four coolers, respectively, attached to the transformer tub. All cooling appliances were in operation due to a high external temperature during the measurements, which was about 30 °C. Transformer 1 was loaded with apparent power S = 210.12 M·VA (87.55 % of rated power), transformer 2 with power S = 228.32 MV·A (84.56 % of rated power), and transformer 3 with power S = 217.16 MV·A (90.48 % of rated power). The photograph of the unit under study is shown in Fig. 1.

Figure 1. View of the unit transformer 3 under study.

Mechanic vibrations of the unit transformers were measured with an accelerometer type 752-10 by the firm Endevco, which was attached to the tub walls. The measuring transducer sensitivity was 1.021 mV/m/s^2 (for 100 Hz). The signal received by the transducer was transferred onto the input of a low-noise measuring amplifier Nexus 2693 by the firm Brüel & Kjær of 20 dB amplification. In order to separate from disturbances transferred by the supply network, the amplifying system was supplied from the external storage cell during measurement taking. A computer equipped with a measuring card type CH 3160 by the firm Acquitek and specialized AcquiFlex software were used for observation and registration of the vibration signals measured.

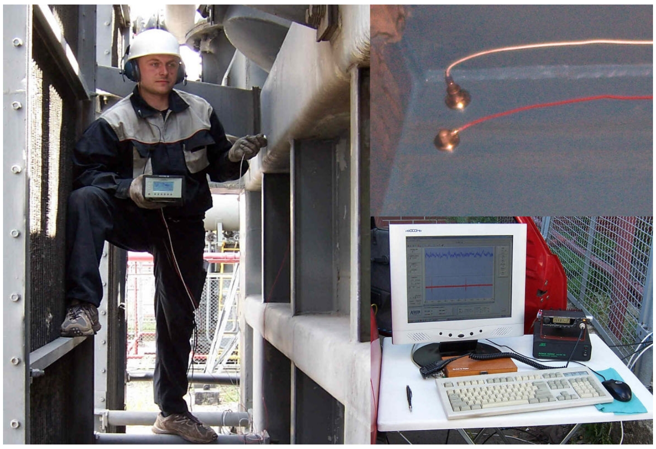

Figure 2. Measuring apparatus used during registration of vibroacoustic vibrations of the unit transformers under study.

During measurement taking the accelerometer was attached to the transformer tub in the following measurement points:

- 4 points on the upper voltage side,

- 4 points on the lower voltage side,
- 2 points on the side wall on phase L1 side,
- 2 points on the side wall on phase L3,
- 1 point on the tub bottom.

The measurement positions obtained in this way make observation of the whole tub and diagnosis of the technical condition of the core of the transformer measured possible. A detailed arrangement of the attachment positions of the measuring transducer is shown in Figs 3 – 5. The same measurement point distribution was adopted for all transformers under study.

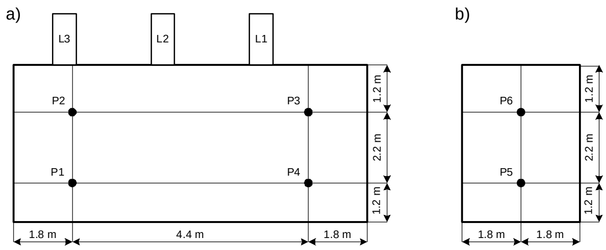

Figure 3. External dimensions of the unit transformer 3 with placement points of the measuring transducer: a) wall from the low voltage side, b) side wall from phase L1 side.

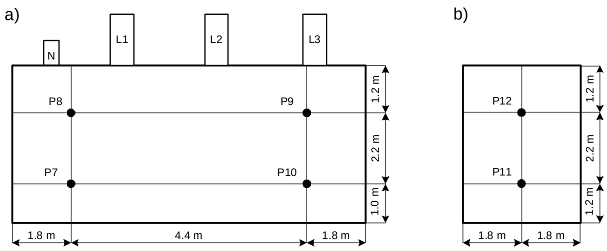

Figure 4. External dimensions of the unit transformer 3 with placement points of the measuring transducer: a) wall from the high voltage side, b) side wall from phase L3 side.

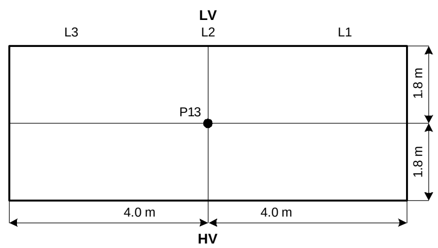

Figure 5. External dimensions of the unit transformer 3 with placement point of the measuring transducer on the tub bottom.

4. MEASUREMENT RESULTS

The results of the measurements and analyses of the technical condition evaluation of the cores of unit transformers 1, 2, 3, obtained through vibroacoustic testing, are shown in Tables 3 and 4. Table 3 lists rms values of vibration acceleration a_{RMS}, which were determined for a total frequency band $(0 \div 3000)$ Hz. Table 4 shows acceleration values a_{MAX} determined for maximum values of vibration amplitudes of the particular components from the band above 1500 Hz, for each measurement point.

Table 3. Root-mean-square value of vibration acceleration a_{RMS}.

Measurement point	Transformer 1 a_{RMS} [cm/s^2]	Transformer 2 a_{RMS} [cm/s^2]	Transformer 3 a_{RMS} [cm/s^2]
P1	137.4	160.0	299.9
P2	208.2	141.2	140.7
P3	180.6	104.1	190.3
P4	157.2	137.1	327.3
P5	255.3	127.3	185.42
P6	226.0	74.3	96.1
P7	179.5	11.5	192.7
P8	315.4	119.3	126.3
P9	339.8	85.2	147.2
P10	146.3	135.1	216.5
P11	216.4	139.2	269.1
P12	317.2	104.1	297.2
P13	249.1	117.8	269.2

Table 4. Value of vibration acceleration a_{MAX}.

Measurement point	Transformer 1 a_{MAX} [cm/s^2]	Transformer 2 a_{MAX} [cm/s^2]	Transformer 3 a_{MAX} [cm/s^2]
P1	9.2	20.9	25.8
P2	17.1	7.8	9.7
P3	28.3	4.4	14.7
P4	12.1	9.7	22.7
P5	11.4	10.6	13.9
P6	9.2	7.8	7.9
P7	19.1	7.9	25.4
P8	22.6	9.9	15.7
P9	20.9	7.2	19.7
P10	9.1	15.9	25.1
P11	16.9	8.9	11.7
P12	10.7	6.8	26.1
P13	17.2	4.9	19.3

Fig. 6 shows exemplary spectrograms of power spectral density of the registered mechanic vibrations of the transformer tubs under study, for a full measurement range ($0 \div 3000$) Hz and time 20 ms.

The spectrograms presented confirm the right choice of the frequency band (0 – 3000) Hz adopted during diagnostics of the power transformer cores using the vibration measurement method. The values of the power spectral density determined indicate that all signals registered on the tub walls are entirely contained in the range analyzed. The dominant role play frequency components from the band (0 – 1500) Hz, for the presence of which magnetostriction vibrations of the core and the vibrations coming from the cooling appliances are responsible. Frequency components have a relatively low amplitude around 3 kHz, which confirms that the upper threshold value of the vibroacoustic signal analyzed was determined properly.

For better visualization and analysis of the participation of the particular frequency components of vibrations, Fig. 7 shows amplitude spectra of the acoustic signals registered.

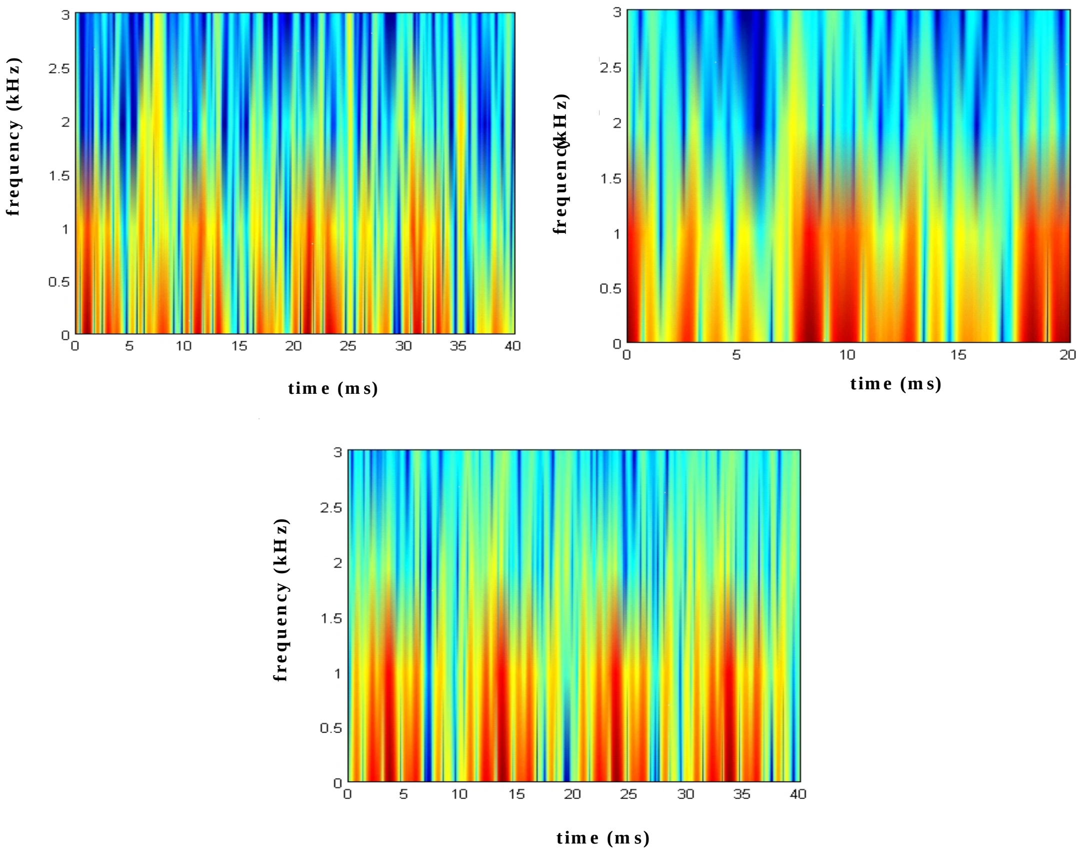

Figure 6. Two-dimensional spectrograms of power spectral density of vibroacoustic vibrations registered in point P4: a) transformer 1, b) transformer 2, c) transformer 3.

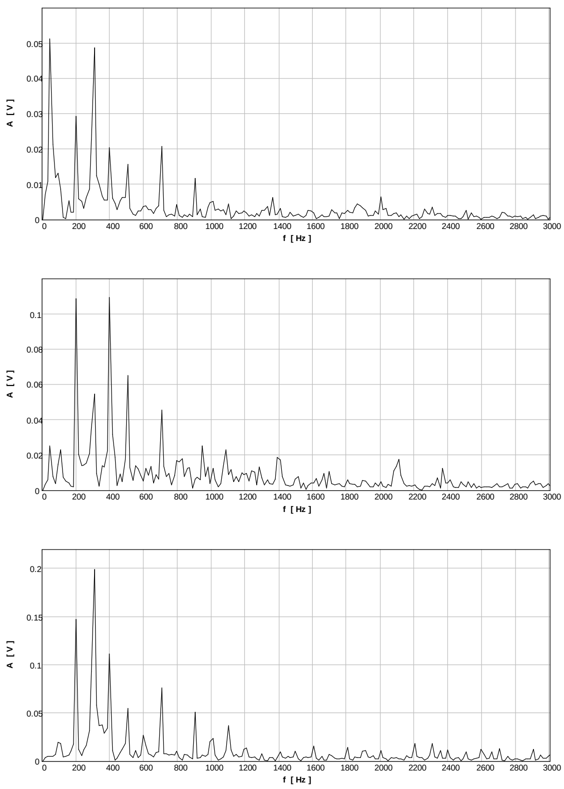

Figure 7. Spectral analysis results of the vibration runs registered in measurement point P4: a) transformer 1, b) transformer 2, c) transformer 3.

5. CONCLUSION

The vibration analysis carried out did not show any value departures of the root-mean-square acceleration (a_{RMS}) from the values measured on similar transformer units. The root-mean-square values of acceleration obtained during measurements also do not exceed the admissible value and are contained within the adopted diagnostic criterion ($a_{RMS} \leq 400$ cm/s^2).The analysis of the maximum amplitude of mechanic vibration acceleration of the transformer under study (a_{MAX}) in the frequency band range ($1500 \div 3000$) Hz showed increased values. Maximum acceleration values of frequency component vibrations (f > 1500 Hz), shown in Table 4, exceed the lower boundary value for this type of transformers in all measurement points. However, they do not exceed the upper criterion value, equal to 30 cm/s^2.

The measurement results of the vibrations of unit transformers 1, 2, 3 may indicate the possibility of existence and gradual development of internal damage to the core. Due to the occurrence of maximum values of vibration acceleration in the vibroacoustic signal spectrum (f > 1500 Hz) above the lower boundary value, the authors of this paper recommend taking verifying measurements (after a year) and applying other diagnostic methods (gas chromatography, the acoustic emission method, the FRA method).

The factor determining the high effectiveness of the vibroacoustic method in the evaluation of the core technical condition is the frequency (periodicity) of diagnostic examinations of high power transformers. This makes it possible to visualize the dynamics of the occurrence changes of the particular frequency components, and not only absolute amplitude values in the spectrum. Therefore the adoption of this methodology will enable an effective diagnostics and observation of the possible vibroacoustic parameter changes of the cores of the transformer units under study.

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