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THE ANALYSIS OF THE LOW-VOLTAGE TRANSFORMER CORE VIBRATIONS BASED ON VIBROACOUSTIC INVESTIGATIONS

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Abstract.

The subject matter of this paper refers to diagnostics and assessment of the technical condition of the transformer core based on the vibroacoustic investigation results. The research results presented in this paper were obtained based on the measurements of the low-voltage transformer core vibrations, in dry work, of the power of 20 KV·A. An accelerometer type 752-10 by Endevco, mating with a low-noise amplifier from the group Nexus 2693 by the firm Brüel&Kjæl, was used for vibroacoustic measurements. During measurement taking the transformer load was changed and attempts to simulate transformer core failures and to relate them to the results of the acceleration rms value and the amplitude spectrum of vibrations were made. The investigations included the registration of mechanical vibrations with an accelerometer placed in four measurement points directly on the transformer core. During the experiment, the influence of the rms value changes of vibration accelerations on the increasing current value of the transformer load and also the power packeting the particular metal plates of the core (yoke twist power) was investigated.

1. Introduction

A widely-understood diagnostics of electric power transformers has been a very important and dynamically developing area of activities of power enterprises and research centers in recent years. Maintaining adequate technical condition of electric power transformers is of great significance in the process of maintaining proper quality standards of customer service, and continuity and reliability of electric power supply belong to most essential aspects.

Electric power transformers are statistically appliances of a high degree of reliability, however their failures have serious technical and economic consequences. Therefore research work on improving diagnostic techniques is fully justified so that the operation, especially of high-power transformer units, may be as long as possible and failure free [3, 4, 6].

The assessment of the transformer core condition is one of the elements of a complex analysis of the technical condition of electric power transformers. The vibroacoustic method, which consists in the measurement and analysis of mechanical vibrations of the object under study, is the one that is commonly used. The advantage of the vibroacoustic method is the possibility of taking measurements

during a regular operation of a transformer, which makes a measuring procedure much easier.
The construction of the transformer core has been subject to significant changes over the recent years, which made it necessary to narrow down the criteria for measurement results interpretation [5, 6].
The paper presents research work results the aim of which was determining vibroacoustic parameters of the model of a low-voltage transformer. The analysis of the results was carried out based on determining a rms value of acceleration a_{sk} and frequency analysis of vibrations in the band (0 ÷ 3000) Hz.

2. Criteria used for the assessment of technical condition of electric power transformers examined by using the vibroacoustic method

In available literature, among others [1, 2, 7, 8], boundary values of the vibroacoustic parameters measured, used for the assessment of the technical condition of electric power transformers, have been determined. These parameters are: rms value of acceleration a_{sk} and frequency analysis of vibrations in the band (0 ÷ 3000) Hz. Threshold values, presented in publications, are of a general character as they refer to a wide group of transformers and they should not be used automatically for each case. Analyzing the measurement results it is necessary to take into account individual constructional properties of the unit under study and to compare the results obtained with the results obtained through other methods. This refers especially to the cases when it is necessary to take decision on disabling a power transformer.
The first assessment criterion of the technical condition of an electric power transformer is the rms value of acceleration a_{sk}, which should not exceed threshold value 400 cm/s^2 for an efficiently operating unit. The occurrence of vibrations of a higher rms value of acceleration may indicate damage to the core of the transformer under study and the necessity of its survey or repair.
The other criterion of the assessment of the core condition of a high-power transformer is a frequency analysis of vibrations in the band (0 ÷ 3000) Hz, and especially an analysis of vibrations of their components above 1500 Hz, which are considered as components characterizing the work of the core. Exceeding the value of vibration acceleration by any component from the frequency range (1500 ÷ 3000) Hz above admissible values, which are shown in Table 1, may indicate the possibility of the core damage.

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

	Transformers without core damage	Possible developing core damage	Possible core damage
Transformers ≤ 200 MV·A	$a \leq 3$ cm/s^2	3 cm/s^2 < $a \leq$ 30 cm/s^2	a > 30 cm/s^2
Transformers > 200 MV·A	$a \leq 10$ cm/s^2	10 cm/s^2 < $a \leq$ 30 cm/s^2	a > 30 cm/s^2

3. Methodology of measurement taking and measuring apparatus used

The research tests were performed on the transformer model the view of which is shown in Fig. 1. The transformer under study was characteristic of the following rated data:

- type: ET3S-20,
- power: 20 kVA,
- rated voltage GN: 3 x 400 V,
- rated voltage DN: 3 x 20 V,
- rated current GN: 17,1 A,
- rated current DN: 333 A,
- work: AN,
- type of work: S1.

During the measurements the transformer load was changed from 0 to 95% of its rated power. The transformer model under study was loaded with a water rheostat which made the current flow in the range from 0 to 320A possible. The research work was carried out in three stages: the first stage included the analysis of the transformer vibrations at a twisted core, the second stage referred to vibroacoustic measurements at an untwisted core, and the third stage referred to determining the dependence of the rms value of vibration acceleration a_{sk} on the power packeting the transformer core. Mechanical vibrations were registered with a transducer placed on the transformer in 4 measurement points shown in Fig. 1 at each load value and power packeting the core.

Fig. 1. Low-voltage transformer model under study with marked measurement points

Mechanical vibrations of the transformer under study were measured with accelerometer type 752-10 by the firm Endevco attached to the core, the view of which is shown in Fig. 2. Sensitivity of the measuring transducer was 1.021 mV/m/s^2 (for 100 Hz). The signal received by the transducer was passed onto the input of a low-noise measuring amplifier of the family Nexus 2693, by the firm Brüel & Kjær. A computer equipped with a measuring card type CH 3160 by the firm Acquitek and specialized software AcquiFlex were used for observation and registration of the vibration signals measured.

Fig.2. View of the measuring transducer type 752-10, by the firm Endevco and measuring amplifier Nexus 2693, by the firm Brüel & Kjær

4. Measurement results

The measurement results obtained through vibroacoustic investigations are shown in Tables 2, 3 and 4. Table 2 lists rms values of vibration acceleration a_{sk} at a packeted core, Table 3 acceleration values corresponding to the signals registered at the unpacketed core, and Table 4 lists the results of the acceleration values measured in dependence on the force packeting the transformer core. Unpacketing and packeting the core was carried out through unbolting the screws clenching the yoke.

Tab. 2. Rms value of vibration acceleration a_{sk} determined for a transformer with a twisted core

No.	Load current [A]	Measurement point			
		P1 [cm/s^2]	P2 [cm/s^2]	P3 [cm/s^2]	P4 [cm/s^2]
1	0	38,15	54,70	27,18	22,28
2	40	34,47	60,24	26,56	22,19
3	80	32,03	59,34	25,42	21,43
4	120	29,34	61,77	25,41	22,30
5	160	28,89	54,89	26,08	21,12
6	200	30,04	58,85	24,68	20,93
7	240	30,37	59,92	24,15	21,24
8	280	28,50	60,28	26,10	21,66

Tab. 3. Rms value of vibration acceleration a_{sk} determined for a transformer with an untwisted core

No.	Load current [A]	Measurement point			
		P1 [cm/s^2]	P2 [cm/s^2]	P3 [cm/s^2]	P4 [cm/s^2]
1	0	62,76	68,26	50,46	57,06
2	40	65,61	68,75	49,84	48,90
3	80	58,71	73,15	42,94	55,37
4	120	54,07	65,07	45,50	49,95
5	160	74,72	61,28	48,51	42,57
6	200	68,61	69,01	43,78	44,37
7	240	72,30	63,86	43,89	41,32
8	280	85,73	89,44	58,15	59,13

Table 4. Rms value of vibration acceleration a_{sk} determined for a transformer loaded with current I = 200A in dependence on the force packeting the core

Lp.	Siła pakietująca [kpm]	Punkt pomiarowy			
		P1 [cm/s^2]	P2 [cm/s^2]	P3 [cm/s^2]	P4 [cm/s^2]
1	1	57,25	61,83	38,87	41,11
2	2	51,45	60,76	34,53	35,29
3	3	46,21	59,62	28,75	29,15
4	4	35,98	57,83	26,12	24,56
5	5	31,44	56,95	25,38	22,63

Fig. 4 shows exemplary spectrograms of the power spectral density of the tub mechanical vibrations registered of the transformer under study for a full measurement range (0÷3000) Hz and measurement time equal to 40 ms.

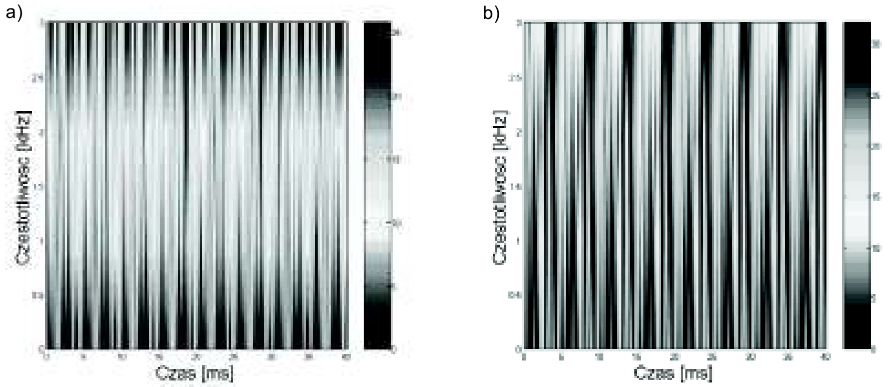

Fig. 4 Two-dimensional spectrograms of power spectral density of vibroacousti vibrations registered in Point P1 for load 280A;

a) packeted core, b) unpacketed core

For a more clear visualization and easier analysis of the participation of the particular frequency components of vibrations, Figs 5 – 8 show amplitude spectra of the acoustic signals registered.

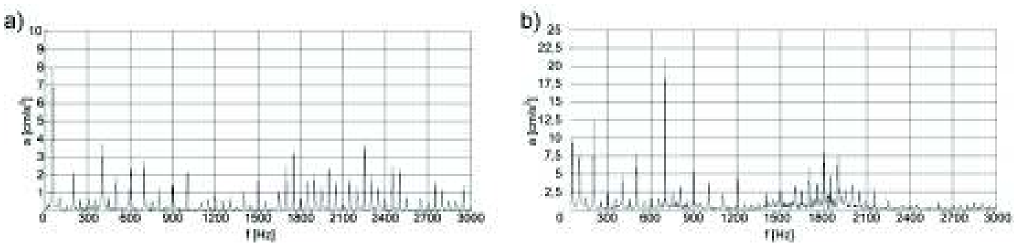

Fig. 5. Frequency spectra of vibrations of the transformer loaded with current 40 A:

a) packeted core, b) unpacketed core

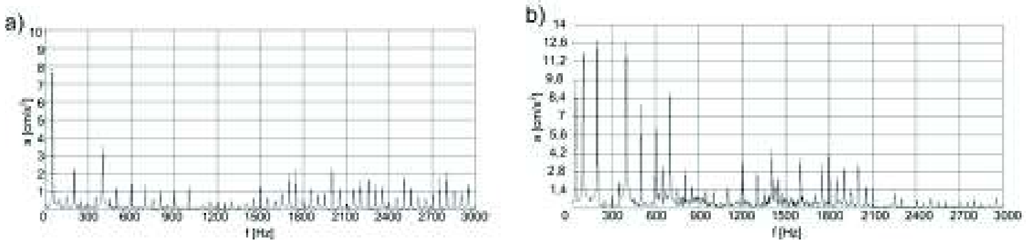

Fig. 6. Frequency spectra of vibrations of the transformer loaded with current 120 A:

a) packeted core, b) unpacketed core

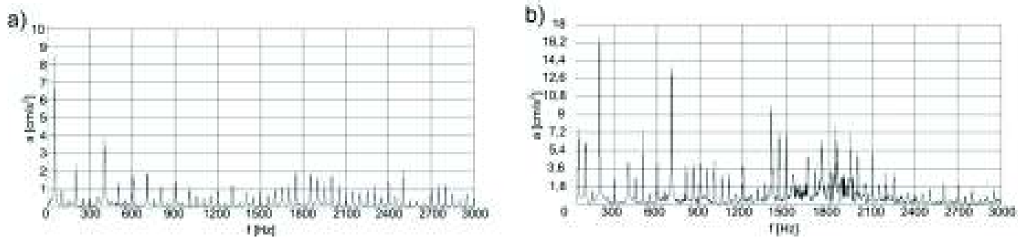

Fig. 7. Frequency spectra of vibrations of the transformer loaded with current 160 A:

a) packeted core, b) unpacketed core

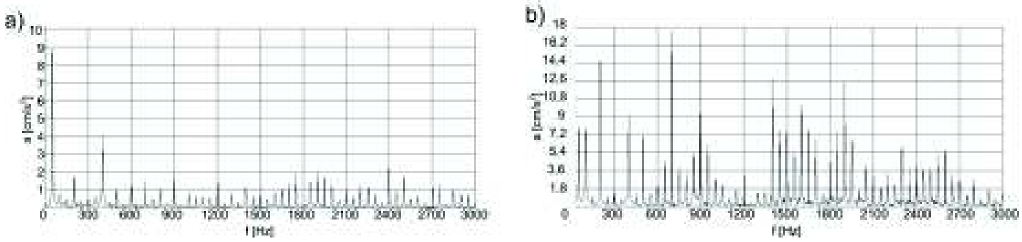

Fig. 8. Frequency spectra of vibrations of the transformer loaded with current 280 A:
a) packeted core, b) unpacketed core

Analyzing rms values of vibration acceleration, determined during this research experiment, it can be observed that these values change insignificantly with the increase of load. The highest a_{sk} values were calculated for Point 2, which was placed in the upper part of the transformer. In the case of the unpacketed core investigation, rms acceleration values assume much higher values in all measurement points than in the case of the packeted core. However, with the changing load the differences between the values determined are bigger than during the analysis of the transformer with a twisted core. It can be also concluded that that increasing the force packeting the core (Table 4) causes a gradual ‘decrease’ of the rms value of vibration acceleration registered. In spite of the modeled core damage in the transformer model under study, no acceleration value determined exceeded criterion value – 400 cm/s^2. Therefore it can be assumed that the adopted criterion values refer to a too large group of transformers and it is necessary to carry out research work aiming at specifying this criterion.

The results of the frequency analysis are shown on the example of the spectra determined for Point 1, at four selected load values, for a transformer with a packeted and unpacketed core. The analysis revealed significant differences between the spectra determined for the transformer in both cases analyzed. These differences are noticeable in the whole frequency band. In the case of the unpacketed core there can be observed a significant participation of components from the band above 1500 Hz, which, according to the criteria assumed, indicates the core damage. Nevertheless, none of the registered frequency components of the spectrum (1500 – 3000) Hz did not exceed the upper criterion value, equal to 30 cm/s^2.

5. Conclusion

The research work carried out showed the need of additional investigations aiming at specifying measuring criteria presently used. Frequency (periodicity) of diagnostic examinations of high-power transformers is the factor determining high efficiency of the vibroacoustic method in the assessment of the technical condition of the core. It makes it possible to visualize the dynamics of occurrence changes of the particular frequency components and not only absolute values of an amplitude in the spectrum. Therefore adopting this methodology will make an effective diagnostics and observation of the possible changes of vibroacoustic parameters of the core of the transformer units under study possible.

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