Vibration Diagnostics System of Power Transformers

DR. KÁROLY VESZPRÉMI[1], DR. ISTVÁN ERDÉLYI[1], SÁNDOR JANKA[1],
[1]Budapest University of Technology and Economics,
Department of Electric Power Engineering,
Egry J. u. 18. H-1111 Budapest
veszpremi.karoly@vet.bme.hu, erdelyi.istvan@vet.bme.hu,
janka.sandor@vet.bme.hu

ABSTRACT

The power transformers are the major parts of power systems, thus their condition is a significant information about the operational reliability. As they are complicated systems (electrical, magnetic, mechanical, thermal, control, chemical), they must be assessed in many different ways. One important condition, determining the reliability is the mechanical condition. Degradation of the mechanical condition affects the condition of the isolation as well, decreasing the reliability of the transformers. By regular condition monitoring the breakdown of the transformers can be prevented (or at least their frequency can be decreased).

Key words: transformer, mechanical condition, vibration, diagnostics, accelerometer

1. INTRODUCTION

The motivation of the investigations is the fact, as the power transformers are the major parts of power systems, thus their condition is a significant information about the operational reliability. The power transformers are extremely complicated equipments: they include electrical (coils), magnetic (iron core), mechanical (fixing, tank), thermal (cooling system), control (on-load tap changer) and chemical (oil) components. These components and the corresponding stresses react with each other [2]. The diagnostics, monitoring, maintenance and life-time management of transformers must include all these: a complex condition assessment system must be developed and used regularly.

One important condition determining the reliability is the mechanical condition. Degradation of the mechanical condition affects the condition of the isolation as well, decreasing the reliability of the transformers. By regular condition monitoring the breakdown of the transformers can be prevented (or at least their frequency can be decreased). This paper focuses on the investigation of the mechanical condition of the power transformers.

There are many methods to diagnose the mechanical condition of transformers. One group of methods includes investigations, based on identifying the modification of electrical parameters or behaviour caused by the changing of mechanical condition (indirect methods) [1]. The other group contains more direct method for identification: the vibration diagnosis, which has more close relation to the mechanical condition (direct method) [3]-[9].

There are different ways to investigate the vibration of power transformers. One difference can be the place of measurement: measuring on the oil drain cock (only at one point) or with more sensors on the tank. The second way is more complicated, but provides more complex information about the mechanical condition. This paper discusses this method describing a special case study.

2. THE VIBRATION DIAGNOSTICS OF POWER TRANSFORMERS

The aims of the diagnostics are the following:

- Early recognition of faults. As a result decreasing the number of unexpected breakdowns.
- Operation fitted to the condition of the transformer, providing optimal life-time.
- Decision about the necessary measures (repair, renewal, etc.)

The general properties of this diagnostic tool are:

- Can be made during operation.
- Not only the coils and clamping systems are diagnosed but the iron core also.

The sources of the vibrations are:

- Coil vibrations: electrodynamic forces, in axial and radial directions. Proportional to the current square (100Hz)
- Core vibrations: magnetostriction and other magnetic forces. Proportional to the voltage square (100Hz).

Our previous works in this filed are started by investigating the diagnostics of transformers generally. The next step was selecting the vibration diagnostics as the part of our competence. Vibration diagnostics were done on operating transformers. The problem was the lack of validation:

The validation of the diagnostics method is absolutely necessary. The validation has different levels:

The first (practical) level is based on a typical research loop:

- Transformers to be repaired are investigated by the diagnostics system. The results can be used for PREDICTION of the fault.
- During repairing it is possible to check the mechanical condition visually (FEEDBACK, VALIDATE).
- Measuring again on the repaired transformer can also VALIDATE the diagnosis and the effect of repairing.

The second (theoretical) level of validation needs model based investigations:

- Different depth models should be developed for this complicated system.
- The model can be fine-tuned by using the results of the first level validation.

The aim of this paper is to discuss the application of the practical level of validation by presenting well selected measurement results.

3. THE MEASURING SYSTEM

As a result of more years research in this filed, we have been developing a transformer vibration diagnostics system. The system uses vibration sensors fastened outside on the transformer's tank. Many considerations affect the measurements:

- **The number of sensors:** to locate more accurately the fault, more sensors are necessary. First we were using four sensors. The number of sensors is limited by the capacity of the data acquisition equipment. Theoretically all sides of the transformer must be measured, the longer ones with two sensors. It needs six sensors. By four sensors it is solved with measuring two subsequent times, moving two sensors (X2, Y1) to the other side (mainly steady-state operation point are investigated, the simultaneous measurement is not a strict must), see Fig.1.
- **The location of the sensors:** well selected locations are necessary to identify the fault. The selections are determined and can be limited by the construction. The scheme of the sensors' locations is presented in Fig.1. They are at approx. 1.5m height.
- **The way of the fastening:** two methods are investigated and evaluated, the magnetic and the screwed fastening (Fig.2.).

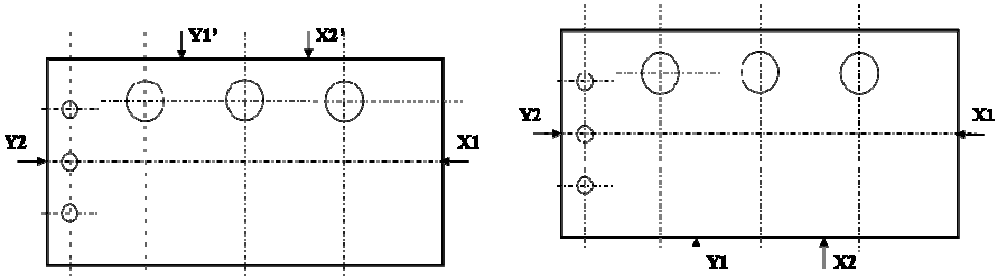

Fig.1. The scheme of the sensors' locations.

Fig.2. The fastening of sensors. (Left: screwed; Right: magnetic)

3.1. The components of the measuring system

First version:

- Brüel & Kjaer 4-chanel data acquisition and processing system 8516 typ.
- Brüel & Kjaer data display 2035 typ.
- Four accelerometers (magnetic fastening)
  - X1, Y2: 4370 typ. (9,89pC/(m/s^2)),
  - X2: 4333 typ. (2,45pC/(m/s^2)),
  - Y1: 4332 typ. (5,65pC/(m/s^2)).

Second version: (more sensors, better parameters)

- To control the measurements and data acquisitions a LabView (7.1) based measuring system is developed.
- Data acquisition card (NI PCI 4472):
  - 8-chanel charge amplifier card
  - 24 bite resolution
  - 50kHz max. sampling frequency.
- Sensors: IMI SENSORS 608A11, 99mV/g, screwed fastening.

4. MEASUREMENT RESULTS (CASE STUDY)

The presented data representing the vibration of the transformer are:

- In 100Hz..1000Hz frequency range in steps 100Hz the acceleration, in relative value also (related to the fundamental harmonic)
- The 100Hz fundamental value is emphasized as essential value: A_1.
- The weighted Total Harmonic Distortion (THD) related to the fundamental component p_1:

$$THD_{weighted} = \frac{1}{p_1 A_1} S_v = \frac{1}{p_1 A_1} \sqrt{\sum_{i=2}^{N} (p_i A_i)^2} \qquad (1)$$

- The squareroot of the weighted square sum of the harmonics: S_v (it is related to the fundamental component).

The presented data are recorded in the following operating conditions:

- No-load.
- Load: 13MVA in Kaposvár (before repair), 9MVA in Paks (after repair). Both can be considered small, comparing with the nominal.
- Switch on.

4.1. Measurements before repair

A complete measurement was done at Kaposvár on an operating transformer with the following name-plate-data:

Type: DHTSV 25001/120
No./year: 107686/1977
Nominal voltages: 120±15% / 22 kV Y_0y_06 (+d)
Nominal power: 25 MVA

Only the most characteristic results are presented:

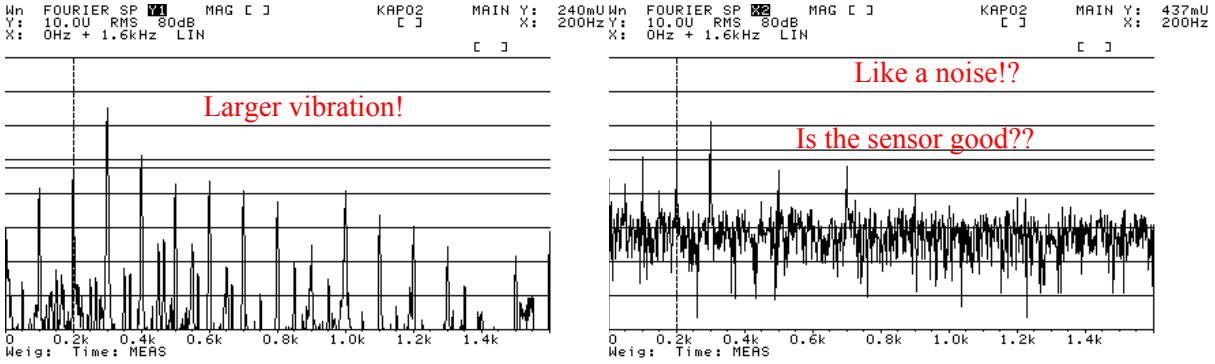

Fig.3. Load (small) operation, spectra (the suspicious sensors are around the middle phase). The sensors are on the low voltage side. (before repair)

Without previous measurements on this transformer, the spectra can be compared only with the other sensors. Two of them are considered to be suspicious (Fig.3.). One of them is so strange (X2), that the applicability of the sensor is even a question. It was checked, the sensor is good, the vibration spectrum came from the transformer. We were lucky, so large anomaly should be visible during disassembly of the transformer. The numerical data of the measurement are given in Table I.

Table I. The numerical data of the measurement. (before repair)

	X1		X2		Y1		Y2	
Hz	**m/s²**	**dB**	**m/s²**	**dB**	**m/s²**	**dB**	**m/s²**	**dB**
100	0.57900	0.00	0.35000	0.00	0.12300	0.00	0.57100	0.00
200	0.19100	-9.63	0.43700	1.93	0.24000	5.81	0.27700	-6.28
300	0.99100	4.67	1.14000	10.26	1.79000	23.26	0.30300	-5.50
400	0.23200	-7.94	0.05850	-15.54	0.35600	9.23	0.09150	-15.90
500	0.08520	-16.64	0.21700	-4.15	0.13900	1.06	0.04560	-21.95
600	0.00956	-35.64	0.03390	-20.28	0.14900	1.67	0.10000	-15.13
700	0.05410	-20.59	0.25100	-2.89	0.11000	-0.97	0.14100	-12.15
800	0.00993	-35.31	0.03980	-18.88	0.07700	-4.07	0.07210	-17.97
900	0.03150	-25.29	0.09470	-11.35	0.01750	-16.94	0.09970	-15.16
1000	0.02890	-26.04	0.06680	-14.39	0.11100	-0.89	0.02210	-28.24
THD	**5.55482**		**12.15367**		**47.82713**		**3.43186**	
A_1	**0.57900**		**0.35000**		**0.12300**		**0.57100**	
S_v	**3.21624**		**4.25379**		**5.88274**		**1.95959**	

4.2. Observations at the repair workshop

Disassembling the transformer in the repairing workshop, the active part of the transformer can be visually investigated.

The suspects of the first measurements (PREDICTIONS) are VALIDATED:

- The coils are deflected, collapsed significantly. It can be seen even before disassembling the coils (Fig.4a).
- After disassembling the coils, large deterioration can be detected (Fig.4b).

a) First view. b) Disassembling the coil.

Fig.4. The disassembled transformer, the suspicious middle phase.

4.3. Measurements after repair

A complete measurement was done at Paks (the new installation place) on the same transformer during operation.

4.3.1. The effect of the repair

The effect of the repair can be evaluated (VALIDATED) by investigating the graphical results (Fig.5.).

- Instead of the noise-like spectrum a regular one is recorded (X2). The noise-like behaviour is surely caused by the large deterioration of the coils.
- The vibration is significantly decreased near Y1.

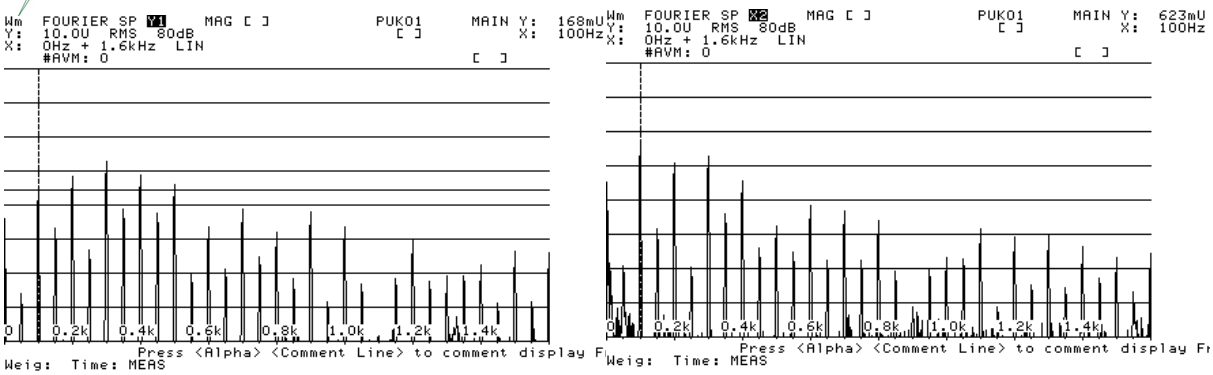

Fig.5. No-load operation, spectra. The sensors are on the low voltage side. (after repair)

4.3.2. The effect of the fastening

The slight effect of the fastening can be evaluated by the numerical data (Table II. and III.).

Table II. The numerical data after repair. Magnetic fastening.
(no-load, low voltage side)

	X1m		X2m		Y1m		Y2m	
Hz	**m/s²**	**dB**	**m/s²**	**dB**	**m/s²**	**dB**	**m/s²**	**dB**
100	0.39500	0.00	0.62300	0.00	0.16800	0.00	0.76400	0.00
200	0.14200	-8.89	0.34500	-5.13	0.25800	3.73	0.12400	-15.79
300	0.46000	1.32	0.43700	-3.08	0.43900	8.34	0.38000	-6.07
400	0.12000	-10.35	0.18900	-10.36	0.27500	4.28	0.13900	-14.80
500	0.09900	-12.02	0.04110	-23.61	0.19700	1.38	0.02100	-31.22
600	0.03810	-20.31	0.08350	-17.46	0.04680	-11.10	0.29300	-8.32
700	0.11000	-11.10	0.06960	-19.04	0.08790	-5.63	0.11100	-16.76
800	0.08290	-13.56	0.04960	-21.98	0.03950	-12.57	0.06280	-21.70
900	0.01880	-26.45	0.00263	-47.49	0.07990	-6.46	0.04840	-23.96
1000	0.01650	-27.58	0.01450	-32.66	0.04890	-10.72	0.04930	-23.80
THD	**4.80434**		**2.99262**		**13.95258**		**3.22233**	
A_1	**0.39500**		**0.62300**		**0.16800**		**0.76400**	
S_v	**1.89772**		**1.86440**		**2.34403**		**2.46186**	

Table III. The numerical data after repair. Screwed fastening.
(no-load, low voltage side)

PUK02	X1c		X2c		Y1c		Y2c	
Hz	**m/s²**	**dB**	**m/s²**	**dB**	**m/s²**	**dB**	**m/s²**	**dB**
100	0.36900	0.00	1.01000	0.00	0.25200	0.00	0.94600	0.00
200	0.17800	-6.33	0.38100	-8.47	0.26100	0.30	0.21000	-13.07
300	0.38900	0.46	0.53800	-5.47	0.65200	8.26	0.33600	-8.99
400	0.13100	-9.00	0.32700	-9.80	0.31400	1.91	0.08540	-20.89
500	0.05100	-17.19	0.06390	-23.98	0.17100	-3.37	0.09240	-20.20
600	0.04390	-18.49	0.09260	-20.75	0.06650	-11.57	0.13200	-17.11
700	0.02430	-23.63	0.04220	-27.58	0.08820	-9.12	0.05270	-25.08
800	0.01460	-28.05	0.01950	-34.29	0.03530	-17.07	0.04010	-27.45
900	0.02970	-21.89	0.02130	-33.52	0.07470	-10.56	0.03560	-28.49
1000	0.02350	-23.92	0.03920	-28.22	0.04600	-14.77	0.02180	-32.75
THD	**3.89609**		**2.34494**		**11.00481**		**1.68439**	
A_1	**0.36900**		**1.01000**		**0.25200**		**0.94600**	
S_v	**1.43766**		**2.36839**		**2.77321**		**1.59344**	

Evaluation:

- The magnetic fastening is slightly damping (less harmonics, mainly at the lower frequency range)
- The screwed fastening is stronger, and safer.

The screwed fastening proposed for the future measurements. An advantageous side effect of this method is the possibility of using the same position for later measurements.

One more comparison is done: the second (PC based) version of the measuring system is tried, used simultaneously, making possible to compare the two systems. The result of the comparison is the validation of the new, better, more simple to use system. It is proposed for later measurements.

5. CONCLUSION

The significance of the proposed investigations is emphasized by the fact, as the very bad mechanical condition could not be recognized from the operation behaviour of the transformer. Possibly, without repairing a serious breakdown would have happened.

The diagnostics method is validated:

- Transformers to be repaired are investigated by the diagnostics system. The results can be used for PREDICTION of the fault.
- During repairing it is possible to check the mechanical condition visually (FEEDBACK, VALIDATE).
- Measuring again on the repaired transformer can also VALIDATE the diagnosis and the effect of repairing.

The main results are:

- The used and proposed measuring method is capable to recognize degradation of the mechanical condition of the transformer.
- The screwed fixing method is proposed for the further investigations. An advantageous side effect of this method is the possibility of using the same position for later measurements.
- The PC based system is validated. It is proposed (better technical properties and simpler usage)

6. REFERENCES

[1] Gusztáv Csépes, István Kispál: Case stories of FRA results used to detect the winding movement and geometric changes in power transformers (Hungarian experience), CIGRE SC A2 2003 Merida Colloquium

[2] Ch. Krause: The Variation of the Clamping Pressure of Power Transformers due to Operational Temperature Cycles and the Loss of Pressure with Time, CIGRE Study Committee A2 Transformers Colloquium, Merida, 2003.

[3] Belén García, Juan Carlos Burgos and Ángel Matías Alonso: Transformer Tank Vibration Modeling as a Method of Detecting Winding Deformations—Part I: Theoretical Foundation, IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 21, NO. 1, JANUARY 2006. pp.157-163.

[4] Belén García, Juan Carlos Burgos and Ángel Matías Alonso: Transformer Tank Vibration Modeling as a Method of Detecting Winding Deformations—Part II: Experimental Verification, IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 21, NO. 1, JANUARY 2006. pp.164-169.

[5] Belén García, Juan Carlos Burgos and Ángel Matías Alonso: Experiences in using thermal and vibration models as a diagnostic method of power transformers, CIGRE Transformer Committee 2003 June 2-4. Merida Colloquium (Mexico)

[6] Z. Berler, I. Blokhintsev, V. Rashkes, V. Tsvetkov, V. Rusov: PRACTICAL EXPERIENCE IN FIELD VIBRO-ACOUSTIC MEASUREMENTS ON POWER TRANSFORMERS, EPRI Substation Equipment Diagnostic Conference VIII ,February 20-23, 2000, New Orleans, LA

[7] Zalya Berler, Alexander Golubev, Valery Rusov, Vladimir Tsvetkov and Cal Patterson: Vibro-Acoustic Method of Transformer Clamping Pressure Monitoring, Conference Record of the 2000 IEEE Intemational Symposium on Electrical Insulation, Anaheim, CA USA, April 2-5,2000. pp263-266.

[8] Cipriano Bartoletti, Maurizio Desiderio, Danilo Di Carlo, Giuseppe Fazio, Francesco Muzi, Giancarlo Sacerdoti, and Fabio Salvatori: Vibro-Acoustic Techniques to Diagnose Power Transformers, IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 19, NO. 1, JANUARY 2004. pp221-229.

[9] Horatio Lamela Rivera, Jose A. García-Souto, and J. Sanz: Measurements of Mechanical Vibrations at Magnetic Cores of Power Transformers with Fiber-Optic Interferometric Intrinsic Sensor, IEEE JOURNAL ON SELECTED TOPICS IN QUANTUM ELECTRONICS, VOL. 6, NO. 5, SEPTEMBER/OCTOBER 2000. pp788-797.