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# NOISE MEASUREMENTS OF THE POWER TRANSFORMERS

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***Abstract*** *- International standards related to functional characteristics of power transformers, very precisely prescribe permitted noise level of transformers in use. Transformer's noise depends on the power, and a number of numerous factors based on the quality of transformer sheet, cooling mode, the magnetic core construction design and technology of the windings. Final laboratory testing of transformers, which are obligatory at each transformer's delivery to the customer, includes noise measurements as well.*

*This paper presents the methodology of noise measurements of power transformers in ABS Minel Transformers factory in Ripanj, thus confirming high technological level and product's quality, both in terms of transformation of electrical energy, and from the aspect of environmental protection.*

## 1. INTRODUCTION

High power transformers are installed on hydro power plants, thermal power plants and high-voltage substations and as such fall under the category of capital equipment for the electric power utility of each public power system. There are many types of power transformers that determine their application: single-phase and three-phase transformers, control transformers with and without regulation, step at generator transformers and distribution transformers, transformers for voltage levels of 110 - 400 kV, the power of 8-725 MVA. The highest levels of power in the distribution networks in the EMS in Serbia are up to 400 kV, although in Russia and China there are the power levels of the distribution networks over 1000 kV where are used transformers with power over 1000 MVA. Max power of block transformers which are installed on the facilities of EPS in Serbia is 725 MVA in Thermal Power Plant TENT B in Obrenovac. Large transformers, depending on the power, cost up to 4 million, but their price is recalculated according to the energy loss that occurs during their work. In addition, the termination of the power transformer stops working the whole block or hydroelectric power plants. Cost of blocks delay get huge until a new transformer is produced, so that each hydro or thermal power plant has spare step at transformer for a quick replacement in case of failure. Currently in the implementation phase is the largest project in the field of electric power in Serbia [1], the design for revitalization of HPP "Bajina Bašta" that executes the Austrian company Andritz Hydro. In the revitalization of all four hydroelectric generators, the two 112 MVA power transformers, voltage level of 242/15.65 kV, which were designed and manufactured in the factory in Ripanj Minel Transformers have already been installed and the remaining two are in the production phase (Figure 1).

**Fig. 1** *Step up transformer 112 MVA*

112 MVA transformers for HPP "Bajina Bašta" were examined by Electrical Engineering Institute "Nikola Tesla" in Belgrade, with the participation of several European institutions accredited for high voltage tests, with all the functional characteristics verified by international standards. One of the important characteristics of power transformer which is checked in final testing is allowed noise level of transformers in use under voltage.

## 2. PERMITTED NOISE LEVEL OF TRANSFORMER

For power transformers the main sources of noise are the magnetic core of transformer, coils and forced cooling systems, which can be carried out with fans for air cooling method or with pumps for water cooling method.

Noise level is very important operational characteristic of transformer, which is measured at each final test using methods prescribed by standards [2] IEC 60076-10 (2001) and IEEE Std C57.12.90 (2006). Measured values must meet the recommended values of permitted noise level according to NEMA - National Electrical Manufacturers Association Standards TR1 (1998) or special requests according to the regulations of the national electric power distribution networks. Recommended values of permitted noise of power transformer are defined depending on the power of transformer, test voltage and cooling modes. With increasing stress levels, allowed noise level of power transformer is increasing as well. For small distribution transformers up to 1000 kVA which are installed in distribution substations in urban areas, the level of allowed noise is up to 64 dB. Most national standards and European countries have stricter requirements regarding permitted noise level than international standards which prescribe the approximate values for transformer manufacturers. For example, requirements of the German, Austrian and Czech power generation industry, in which permissible noise of the distribution transformers of power 50 kVA is 42 dB, and the permissible noise of the distribution power transformers of power 1000 kVA is 48 dB (requirements prescribed by RWE Rheinisch Westfälisches Elektrizitätswerk - 1990), are significantly more stringent requirements than in the most other national electric power systems in the world. For certification of transformer in terms of permitted noise levels, the American National Standards Institute ANSI Standard C89.2 prescribes for distribution transformers up to 9 kVA maximum noise level of 40 dB, and for the power of 301-500 kVA maximum noise level of 60 dB.

According to the recommendations for smaller energy transformers with power of 10 MVA and measured voltage of 350 kV with cooling by mineral oil, transformers allowed noise level according to NEMA recommendation is 68 dB. For the largest power transformers power of 1000 MVA and the measured voltage level over 1300 kV, with combined forced cooling with mineral oil and air, the maximum noise level of transformers is 95 dB. Since the noise level depends directly on the induction or magnetic flux, designer and manufacturer of transformers use the recommended values according to NEMA standard that are commonly given according to method of cooling the active part of the transformer.

The primary source of acoustic noise generation in a transformer is the periodic mechanical deformation of the transformer core and the winding coils, under the influence of fluctuating electromagnetic flux associated with these parts [3]. The physical phenomena associated with this tonal noise generation can be classified as follows:

- The material of a transformer core exhibits magnetostrictive properties. The vibration of the core is due to its magnetostrictive strain varying at twice the frequency of the alternating magnetic flux. The frequencies of the magnetic flux is equal to the power system supply frequency and its harmonics.
- When there are residual gaps between laminations of the core, the periodic magneto-motive force may cause the core laminations to strike against each other and produce noise. Also, the periodic mutual forces between the current-carrying coil windings can induce vibrations if there are any loose turns of the coil.

Some of the other sources of noise in a transformer, such as the cooling fans and the pumps, are considered to be negligible contributors to the far-field noise [4].

## 3. TRANSFORMERS COOLING SYSTEMS

Type and method of cooling the transformers is very important in terms of reducing temperature and reducing noise of transformer at the same time. Since power transformers can be cooled in different ways, the IEEE 571 200 (2011) standard prescribes a specific system of describing types of cooling.

System of marking and describing the cooling of the transformer is the drive letter with four capital letters, with the first two letters indicate the type and method of cooling fluid circulation which is in contact with magnetic core and windings, and the third and fourth letters indicate the type and method of coolant circulation that is in contact with the external cooler (Figure 2).

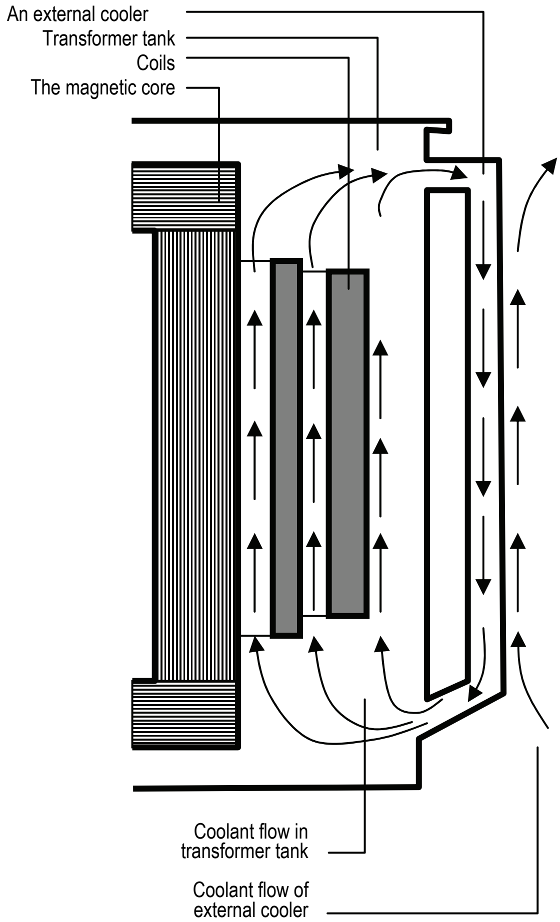


**Fig. 2** *Transformers cooling system*

According to the IEEE 571 200 (2011) for the cooling fluid which is in contact with windings the following codes are adopted: A - oil, L - liquid and A - air, and for the method of fluid flow are adopted the following codes: N - natural and F - forced..

For coolant that is in contact with the outside cooler are adopted the following codes: A - air, G - gas, W - water. The most commonly used cooling systems for power transformers are:

- AN - dry transformer without protective housing,
- ANAN - dry transformer with protective housing
- ONAN - oil transformers with the natural flow of oil in the transformer tank and with the air outside,
- ONAF - oil transformers with the natural flow of oil in the transformer tank and with the fan outside,

- OFAF - oil transformers with forced flow of oil in the transformer tank driven by pumps permanently turned on and the outside with the fan,
- ONWF - oil transformers with the natural flow of oil in the transformer tank and with a water cooling pump outside,
- OFWF - oil transformers with forced flow of oil in the transformer tank driven by pumps permanently turned on, and outside with a water cooling pump.

Codes of mode and the cooling type of transformers are constantly supplemented through periodic changes to the standards, due to the development of cooling systems.

## 4. NOISE MEASUREMENT OF TRANSFORMER 112 MVA

The test procedure is in accordance with IEC Standard 60076-10. At first, the background noise level shall be measured [5]. Then, the transformer shall be powered at rated voltage and frequency under no-load conditions (with the tap-changer selected on the principal tapping), in order to carry out transformer noise level measurements. They shall be performed in several points located around the transformer, placed at a distance of 0,3 m from the machine unless, due to safety reasons or following agreement between supplier and purchaser, the distance is increased to 1 m. Measuring positions shall be spaced at a distance of at most 1 metre one from another; anyway, a minimum of 6 positions is required. The measurements shall be carried out at half the equipment height, if this does not exceed 2,5 m; otherwise, they shall be performed at 1/3 and 2/3 of the component height. After performing transformer sound level measurement, the machine is de-energised and background noise level is measured again; At the end, the final transformer sound level shall result by applying a correction by taking into account the lower background noise level. In case there is a high difference between the transformer and background noise level (>8 dB) no correction shall be applied [6].

Measurement of noise level on power transformers according to IEC 60076-10 (2001-05) can be realized by using three methods [7]:

- Sound power level method ($L_W$),
- Sound pressure level method ($L_p$) and
- Sound intensity method ($L_I$).

Measurement of noise level at the factory ABS Holdings Transformers in Ripanj [8], was performed on the generator step up transformer for block H3 of hydropower plant "Bajina Bašta" in Perućac, with the following characteristics (Figure 3)

- Power of transformer 112 MVA
- High Voltage 242 kV
- Low Voltage 15.65 kV
- Connestion YNd5
- Curent HV 267.20 A
- Curent LV 4131.84 A
- Type of cooling OFWF
- Insulation class A
- Oil weight 25.5 t
- Total weight 124.0 t

Details of measuring instruments:

- Measuring instrument make Bruel&Kjaer, type 2236
- Microphone make Bruel&Kjaer, type 4188
- Acustical Calibrator Bruel&Kjaer, type 4231 (94 dB SPL-1000 Hz)

Test conditions:

- Exitation voltage 15.65 kV
- Frequency 50 Hz
- Temperature ambient 20 $^0$C
- Humidity 60 %
- Preassure 998 mbara

Physical measures of the transformer:

- Length of the transformer A = 5.860 m
- Width of the transformer B = 3.710 m
- Height of the transformer H = 4.640 m
- Contour length $L_m$ = 29000 mm
- Number of measuring the position of the microphone M(N) = 29
- Total area of the surface of the test room $S_v = 10360$ m$^2$
- Average acustic absorption coefficient a = 0.200
- Medium acustic absorption coefficient $A = a\ S_v = 2072$ m$^2$
- Area of the measurment surface $S = (H+2)\ L_m = 192.560$ m$^2$
- Ratio A/S = 10.760
- Reference area $S_0 = 1.000$ m$^2$

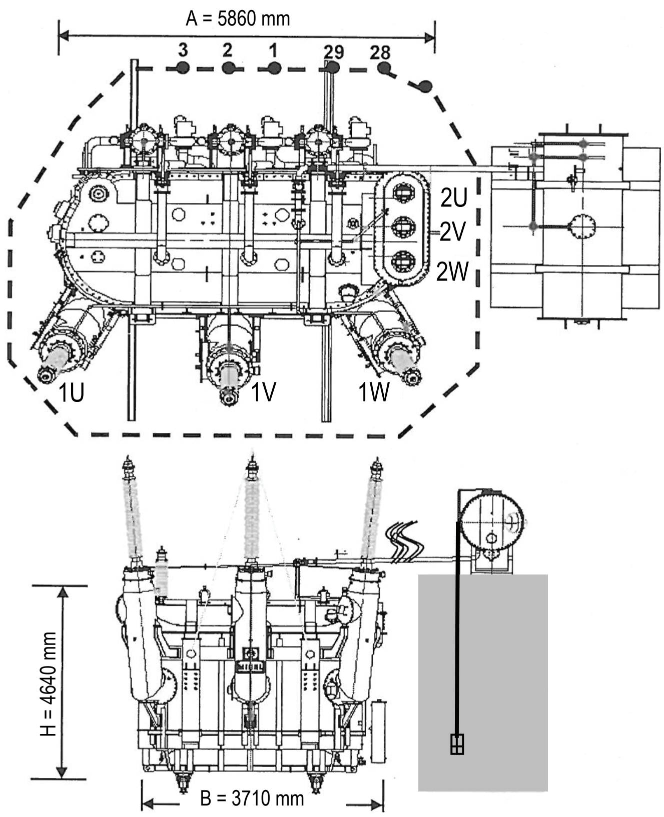


**Fig. 3** *Noise measurement zone and layout of measuring points*

The uncorrected average A – weighted sound pressure level $L_{pA0}$, shall be calculated from the A - weighted sound pressure level $L_{pAi}$, measured with the test object energized by using equation:

$$L_{pA0} = 10 \lg \left\{ \frac{1}{N} \sum_{i=1}^{N} 10^{0.1 L_{pAi}} \right\} \qquad (1)$$

where N is the total number of measuring positions.

The average A – weighted background noise pressure level $L_{bgA}$, shall be calculated separately before and after the test sequence using equation

$$L_{bgA} = 10 \lg \left\{ \frac{1}{M} \sum_{i=1}^{M} 10^{0.1 L_{bgAi}} \right\} \qquad (2)$$

where M is the total number of measuring positions and $L_{bgAi}$ is the measured A – weighted background noise pressure level at the ith measuring position.

The corrected average A – weighted sound pressure level $L_{pA}$ shall be calculated by using equation

$$L_{pA} = 10 \lg \left\{ 10^{0.1 L_{pA0}} - 10^{0.1 L_{bgA}} \right\} - K \qquad (3)$$

where $L_{bgA}$ is the lower of the two calculated average A - weighted background noise pressure levels and K is environmental corrected factor.

The environmental correction K accounts for the influence of undesired sound reflections from room boundaries and/or reflecting objects near the test object. The magnitude of K depends principally on the ratio of the sound absorption area of the test room (A), to the area of the measurement surface (S). The calculated magnitude of K does not depend strongly on the location of the test object in the test room. K shall be obtained from equation by entering the abscissa with the appropriate value (A/S)

$$K = 10 \lg \left\{ 1 + \frac{4}{A/S} \right\} \qquad (4)$$

Since the transformer has OFWF cooling system, at first we measured the noise level with the transformer cooling system pumps on (Figure 4). It is measured:

- A-Weighted sound pressure levels of the backgraund noise $L_{bgAi}$ (ambient sound pressure level when the transformer is switched off, the sound pressure level when the transformer is switched on and ambient sound pressure level at the end of the testing when the transformer is switched off),
- A-Weighted sound pressure levels $L_{pAi}$ in position H/3m and 2H/3m.

Based on the measured noise values of power transformer 112 MVA (LPAI and LbgAi) with pumps on, values LpA0 = 67.1 dB and 48.2 dB = LbgA were calculated. If there is a large difference (greater than 8 dB) between the LpA0 and measured maximum value $LbgA_{(max)}$ it is necessary to perform the correction. Since the maximum measured value $L_{bgA(max)}$ = 42.2 dB, than $\Delta L_{pAi} = L_{pA0} - L_{bgA(max)}$ = 67.1 – 42.2 = 24.9 dB, indicating the necessity of correction. The value of the correction factor K = 10 lg (1 + 4/10.760) = 1.4 dB, a corrected pressure level $L_{pA}$ = 65.7 dB, while guaranteed values for power transformers 112 MVA is 80 dB. Calculated A - weighted sound power level $L_{WA} = L_{pA} - 10 \lg (S/S_0)$ = 88.5 dB, a guaranteed values for power transformers 112 MVA is 102.0 dB.

| ABS MINEL TRAFO AD Transformer factory Mladenovac SRBIJA | SOUND LEVEL MEASURMENT (no-load loss with pumps) | Test Report No B 12U/11 | |
|---|---|---|---|
| | | Sheets | 2 |
| | | Sheet No | 4 |

| Plan position | A - weighted sound pressure levels of the backgraund noise $L_{bgAi}$ | | | Plan position | A-weighted sound pressure levels, $L_{pAi}$ | |
|---|---|---|---|---|---|---|
| | | | | | Measurments the height of the tank | |
| | At start I | Ambient + pumps II | At end III | | H/3m | 2*H/3m |
| 1 | 40.6 | 51.9 | 41.3 | 1 | 69.9 | 67.3 |
| 2 | | | | 2 | 66.0 | 64.1 |
| 3 | | | | 3 | 69.2 | 62.5 |
| 4 | | | | 4 | 68.9 | 65.9 |
| 5 | 39.6 | 49.7 | 39.2 | 5 | 66.9 | 67.1 |
| 6 | | | | 6 | 65.9 | 70.1 |
| 7 | | | | 7 | 69.6 | 64.7 |
| 8 | | | | 8 | 66.9 | 69.0 |
| 9 | 39.8 | 43.9 | 39.9 | 9 | 65.4 | 65.0 |
| 10 | | | | 10 | 62.4 | 62.9 |
| 11 | | | | 11 | 64.4 | 62.8 |
| 12 | 39.9 | 43.9 | 39.0 | 12 | 68.0 | 64.9 |
| 13 | | | | 13 | 68.1 | 67.3 |
| 14 | | | | 14 | 67.6 | 64.6 |
| 15 | | | | 15 | 71.9 | 66.7 |
| 16 | 40.6 | 45.1 | 40.6 | 16 | 69.1 | 67.7 |
| 17 | | | | 17 | 65.4 | 65.9 |
| 18 | | | | 18 | 68.3 | 63.7 |
| 19 | | | | 19 | 65.3 | 62.5 |
| 20 | 41.8 | 48.2 | 42.0 | 20 | 66.3 | 69.7 |
| 21 | | | | 21 | 68.2 | 70.0 |
| 22 | | | | 22 | 67.1 | 67.2 |
| 23 | | | | 23 | 68.6 | 66.8 |
| 24 | 42.2 | 51.6 | 41.2 | 24 | 65.4 | 66.6 |
| 25 | | | | 25 | 69.7 | 68.0 |
| 26 | | | | 26 | 69.3 | 68.9 |
| 27 | | | | 27 | 70.7 | 67.5 |
| 28 | 40.6 | 51.6 | 40.1 | 28 | 70.2 | 69.9 |
| 29 | | | | 29 | 70.0 | 68.9 |

**Fig. 4** *The results of noise measurements of transformers with power of 112 MVA with pumps on*

Then the noise level with transformer cooling system pumps switched off was measured following the same procedure (Figure 5). With the pumps off following values were calculated: $L_{pA0}$ = 67.4 dB and $L_{bgA}$ = 40.5 dB. Since the maximum measured value is $L_{bgA(max)}$ = 42.2 dB, than $\Delta L_{pAi} = L_{pA0} - L_{bgA(max)}$ = 67.4 – 42.2 = 25.2 dB, indicating the necessity of correction. The value of the correction factor is K = 1.4 dB, a corrected pressure level $L_{pA}$ = 66.1 dB, while guaranteed values for power transformer 112 MVA is 75 dB. Calculated A - weighted sound power level $L_{WA}$ = 88.9 dB, while guaranteed values for power transformers 112 MVA is 98.0 dB.

| ABS MINEL TRAFO AD Transformer factory Mladenovac SRBIJA | SOUND LEVEL MEASURMENT (no-load loss without pumps) | Test Report No B 12U/11 | |
|---|---|---|---|
| | | Sheets | 4 |
| | | Sheet No | 4 |

| Plan position | A - weighted sound pressure levels of the backgraund noise $L_{bgAi}$ | | | Plan position | A-weighted sound pressure levels, $L_{pAi}$ | |
|---|---|---|---|---|---|---|
| | | | | | Measurments the height of the tank | |
| | At start I | Ambient + pumps II | At end III | | H/3m | 2*H/3m |
| 1 | 40.6 | 51.9 | 41.3 | 1 | 70.9 | 71.0 |
| 2 | | | | 2 | 65.3 | 64.9 |
| 3 | | | | 3 | 68.7 | 64.2 |
| 4 | | | | 4 | 68.4 | 66.6 |
| 5 | 39.6 | 49.7 | 39.2 | 5 | 67.6 | 66.4 |
| 6 | | | | 6 | 69.6 | 69.4 |
| 7 | | | | 7 | 69.2 | 66.7 |
| 8 | | | | 8 | 69.5 | 64.7 |
| 9 | 39.8 | 43.9 | 39.9 | 9 | 65.6 | 66.2 |
| 10 | | | | 10 | 67.9 | 63.5 |
| 11 | | | | 11 | 66.3 | 63.3 |
| 12 | 39.9 | 43.9 | 39.0 | 12 | 68.1 | 64.0 |
| 13 | | | | 13 | 68.1 | 68.0 |
| 14 | | | | 14 | 65.9 | 66.0 |
| 15 | | | | 15 | 69.9 | 66.2 |
| 16 | 40.6 | 45.1 | 40.6 | 16 | 70.1 | 67.0 |
| 17 | | | | 17 | 66.7 | 67.2 |
| 18 | | | | 18 | 66.4 | 66.3 |
| 19 | | | | 19 | 68.2 | 64.1 |
| 20 | 41.8 | 48.2 | 42.0 | 20 | 67.0 | 69.5 |
| 21 | | | | 21 | 66.9 | 69.7 |
| 22 | | | | 22 | 67.8 | 68.0 |
| 23 | | | | 23 | 67.7 | 65.0 |
| 24 | 42.2 | 51.6 | 41.2 | 24 | 66.0 | 65.4 |
| 25 | | | | 25 | 70.6 | 69.4 |
| 26 | | | | 26 | 69.2 | 68.4 |
| 27 | | | | 27 | 66.7 | 69.7 |
| 28 | 40.6 | 51.6 | 40.1 | 28 | 67.7 | 68.3 |
| 29 | | | | 29 | 69.2 | 71.2 |

**Fig. 5** *The results of noise measurements with pumps off*

The results of measurements at the acceptance tests show a satisfactory noise level of step up power transformer 112 MVA at block H3 of hydropower plant "Bajina Bašta."

## 5. IMPACT OF TRANSFORMER POWER AND TRANSFORMER PLATE TO THE NOISE LEVEL

Analyzing of the measured values of sound pressure level ($L_{pA}$) at last 30 power transformers with power from 12.5 to 63 MVA, 110 kV, produced at the factory ABS Minel Transformers in Ripanj, it can be confidently concluded that the increase of transformers power linearly increases the level of sound pressure (Figure 6).

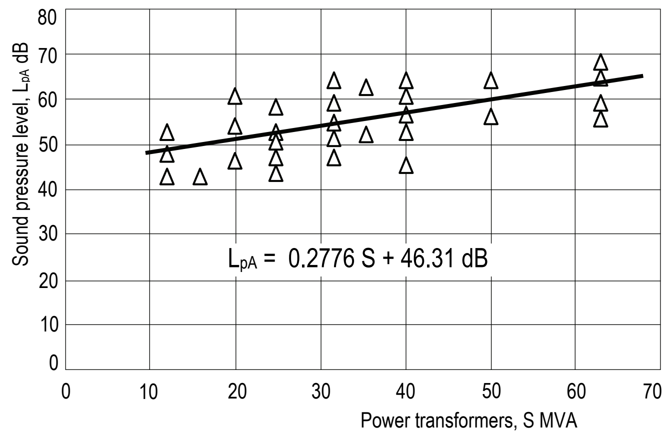


**Fig. 6** *Noise measurement zone and layout of measuring points*

Better quality of transformer plate has a higher resistance to impact of magnetostriction, and therefore provides a lower level of magnetic core noise. Analyzing the noise level for a particular value of induction and built-in types of transformer sheet, at transformers with power of 31.5 MVA produced at the factory ABS Minel Transformers in Ripanj, it can be concluded that the lowest noise level insures transformer plate produced by Nippon Steel, ZDKH type (Figure 7).

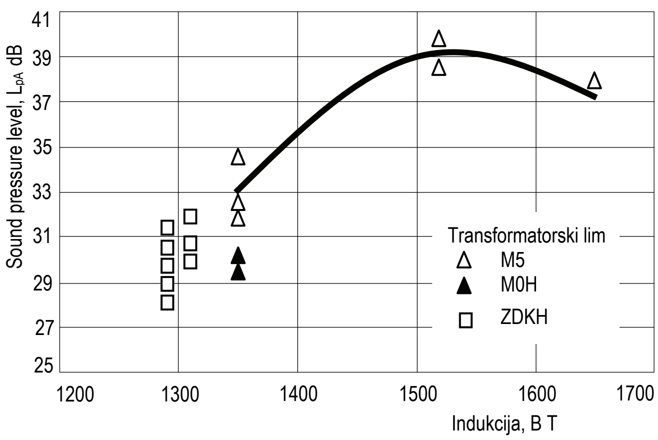


**Fig. 6** *The dependence of sound pressure level on the type of transformer plate of magnetic core*

There are conventional type transformer plates and transformer plates that were treated with laser technologies to reduce losses in the iron. Transformer plate M5 is conventional type of transformer plate which is manufactured by Tysen and has a loss about 1.30 W/kg with induction of 1.7 T at 50 Hz. Transformer plates ZDKH and M0H are laser treated sheets with losses 1:03 to 1:05 W / kg. Application of high quality transformer plate, allows a magnetic core construction with a reduced induction for a specific size and power of transformer with reduced losses and low levels of noise, but also increases the cost of the transformer.

## 6. CONCLUSION

In order to improve aspects of living and working environment protection of power facilities, scientists have developed dry transformers, which don't have transformer tank and don't use any transformer oil, but have an air cooling system or a windings sealed with epoxy materials that absorb heat during heating of magnetic cores. Dry transformers are increasingly used in urban areas because they are environmentally favorable, and have significantly lower noise level compared to oil transformers. Comparative tests show that in the dry transformers up to 1000 kVA noise level is for about 10 - 12 dB lower than for the oil transformers of same power.

Development and improvement of methods of measuring noise at oil power transformers with large power, contribute to the improvement of design methods and manufacturing technology of transformers, and competitiveness in meeting the permissible noise level which modern market of electric power equipment and systems requires today.

## REFERENCES


[1] Lj. Lukic, N. Pejcic, "A New Generation of Transformers with Wound Core Patented by ABS Minel Trafo Serbia", Paper on call, *Proc. 7th International Symposium Nikola Tesla,* pp. 51-56, 23. November 2011, Belgrade, 2011.

[2] International Standard IEC 60076-10, Power transformers – Part 10: Determination of sound levels, 2001 – 05.

[3] R. S. Masti, W. Desmet, W. Heylen, *On the influence of core laminations upon power transformer noise*, Proceedings of ISMA, Vibro-Acoustic Modeling and Prediction, 3851- 3862, 2004.

[4] T. Yanada, S. Mmowa, O. Ichinokura, S. Kuchi, Design and Analysis of Noise - Reduction Transformer Based on Equivalent Circuit, EEE Transactions on Magnetics, pp.1351-1353, Vol.34, No4, 1998.

[5] W. M. Zawieska: A Power Transformer as a Source of Noise*, International Journal of Occupational Safety and Ergonomics (JOSE),* pp. 381–389, Vol 13, No 4, 2007.

[6] R.S.Girgis, K.Garner, M.Bernesjo, J.Anger: Measuring No – Load and Load noise of Power Transformers using the Sound Pressure and Sound Intensity Methods – Part – I: Outdoors measurements, *Scientific Conference "Power and Energy Society General Meeting*", 20-24 July 2008, Pittsburgh, 2008.

[7] K.Garner, M.Bernesjo, J.Anger, D.Chu: Measuring No – Load and Load noise of Power Transformers using the Sound Pressure and Sound Intensity Methods – Part – II: Indoors measurements, *Scientific Conference "Power and Energy Society General Meeting",* 20-24 July 2008, Pittsburgh, 2008.

[8] ABS Minel Transformatori – Project and Tehnical documentation, Belgrade, 2012.


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