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# Low noise transformer technology

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**SUMMARY**

Power transformers are often located near populated areas or even inside cities. In these cases a low noise power transformer is inevitable. Producing one is a complex task demanding a deep knowledge of multiphysics governing the noise levels. In this paper an overview is shown of procedures involved in producing a low noise transformer. First procedures used in design phase are presented, then manufacturing and finally noise measurement phase. Furthermore, at the end also a comparison is given between a standard and a low noise transformer design.

**KEYWORDS**

Transformer noise, Magnetostriction, No-load noise, Load noise, Winding

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## INTRODUCTION

It is well known that high noise levels have a negative effect on people mood and health, therefore, in most countries legislation exists, which prescribes maximum allowable noise levels. These facts are taken into consideration when a customer is preparing demands for a new transformer. Because cities are expanding the transformer substations are closer and closer to residential areas where low noise transformers are necessity. Furthermore, low noise transformers will need to become even quieter.

Transformer noise and vibration was subject of many scientific articles [1-4]. In general it consists of no-load noise, load noise and cooling equipment noise. No-load noise is mainly due to magnetostriction [5, 6] in electrical steel when core is magnetized at nominal induction. Load noise is caused by magnetic forces [7, 8] between conductors in windings at nominal current. Cooling equipment noise consists of fan noise, oil pump noise, etc.

In this paper some procedures will be presented, which we use during different phases of low noise transformer production. First is design phase, then manufacturing and at the end noise measurements in our high-voltage laboratory. At the end general results and conclusions are given.

## DESIGN

Design phase is very important, because mistakes made here are very difficult and expensive to correct in later phases. We use custom program called TrafoS [4, 9] which Kolektor Etra developed in cooperation with local university. This program is used in feedback loop to electrical designers and enables us to check electrical design from noise point of view as shown in Figure 1. Electrical design may require specific core dimensions, which are not optimal and may cause noise problems. In that case new dimension of the core are proposed to electrical designers, which update their electrical design.

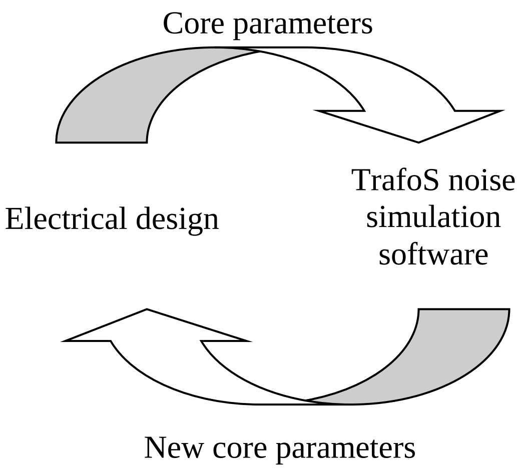


**Figure 1 : Feedback loop between electrical designers and low noise simulation software.**

Correct dimensions are important in order to avoid core and coil resonances which can considerably increase noise levels. In Figure 2 one of the many calculated core and coil resonances are shown.

a) b)

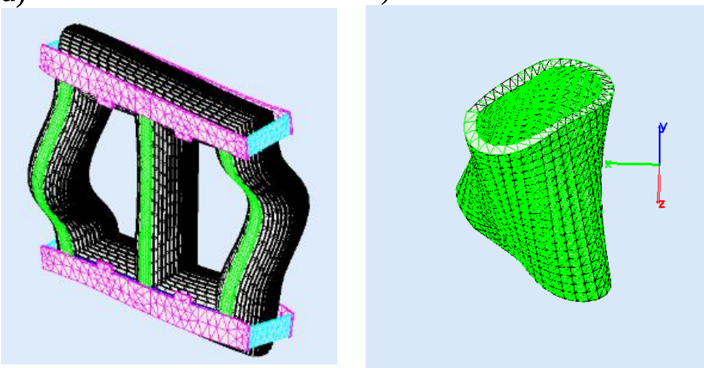

**Figure 2 : a) Core mode shape, b) coil mode shape.**

Core and coil vibrations are transmitted to transformer tank mainly through oil. This is why active part (core and coils) needs to be analysed together with tank in order to obtain tank wall displacement field. In Figure 3 a result of tank harmonic analysis is shown, where as an excitation source active part is used.

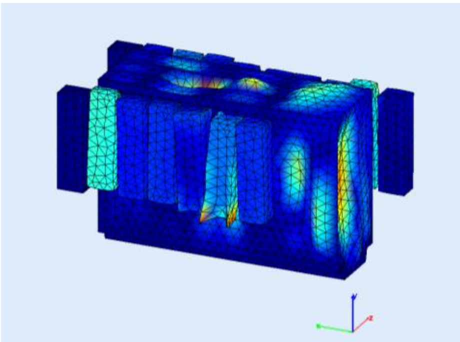

**Figure 3 : Results of tank harmonic analysis.**

The resulting tank wall displacement field is then used as input for boundary element method (BEM), which is in many ways superior to finite element method (FEM) for solving acoustic radiation problems [10]. Using BEM we can determine sound pressure at prescribed contour where it will be actually measured later in the laboratory. In Figure 4 typical results from BEM are shown.

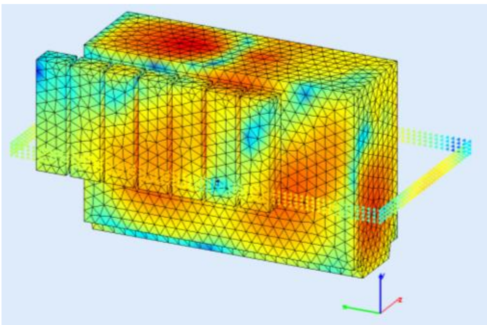

**Figure 4 : Sound pressure field around transformer.**

Once the numerical results regarding noise are satisfying the electrical design is approved and the manufacturing phase can start.

## MANUFACTURING

Manufacturing phase is critical as many parts and materials need to be checked for correct characteristics in order to achieve low noise levels demanded by the customers.

One of the first things, which are checked, are magnetostriction levels of electrical steel. As mentioned before the magnetostriction is one of the main causes for no-load noise. The magnetostriction is a highly nonlinear phenomenon where dimensions of electrical steel change due to changing magnetic flux. These changes in electrical steel dimensions are in the order of microstrains and are difficult to measure. Kolektor Etra has a custom designed device for measuring magnetostriction [11, 12], which is used to check electrical steel before cutting process. The device is shown in Figure 5 and typical measurement results in Figure 6.

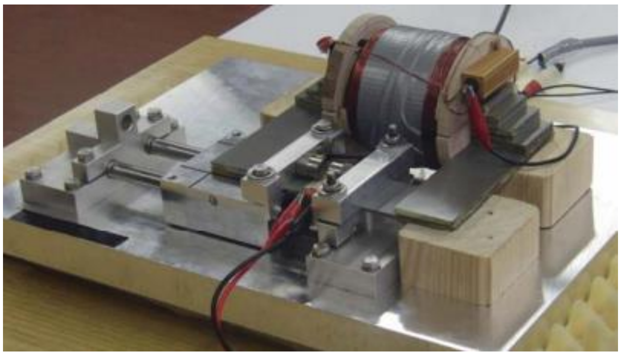

**Figure 5 : Device for measuring electrical steel magnetostriction.**

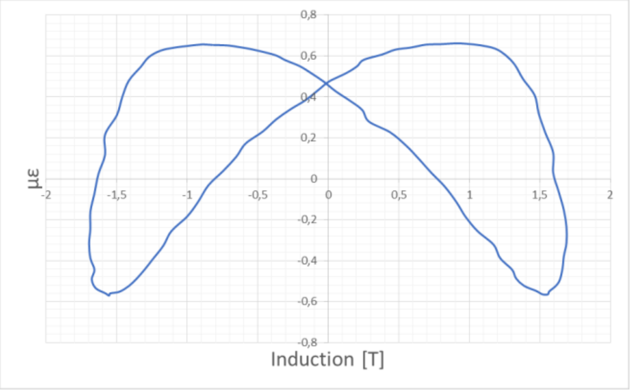


**Figure 6 : Typical magnetostriction curve.**

Once the core is assembled the natural frequencies can be measured using experimental modal analysis [13, 14] as shown in Figure 7a. The results are checked against numerical model. If there are deviations some measures can be taken to move them to desired frequencies, however, these shifts are limited in size. In Figure 7b one of the measured mode shapes is shown.

a) b)

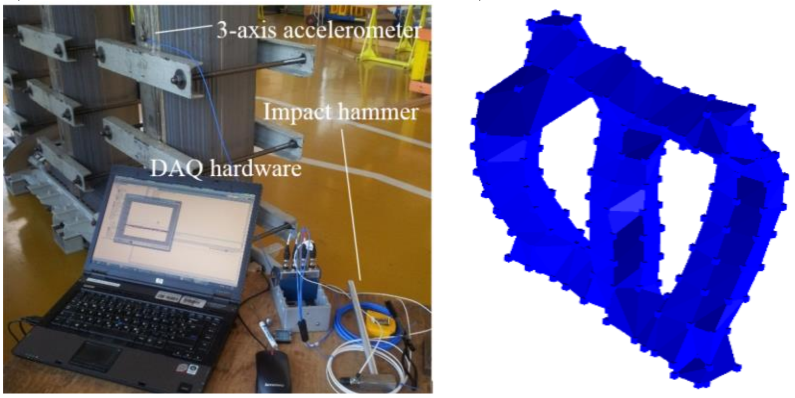


**Figure 7 : a) Experimental modal analysis measurement setup, b) measured core mode shape.**

Regarding load-noise, where Lorentz forces in the windings are the main source of vibrations, several tests are made to ensure correct low noise characteristics of the windings. For example transformerboard material used for winding spacers is checked for correct mechanical properties. Testing is done on a special custom built press, which is shown in Figure 8.

**Figure 8 : Transformerboard press.**

When separate windings are dried and stabilised the natural frequencies and mode shapes are measured. The measurements are done for all windings and the results are again checked against the numerical data calculated in the design phase. One of the measured mode shapes is shown in Figure 9.

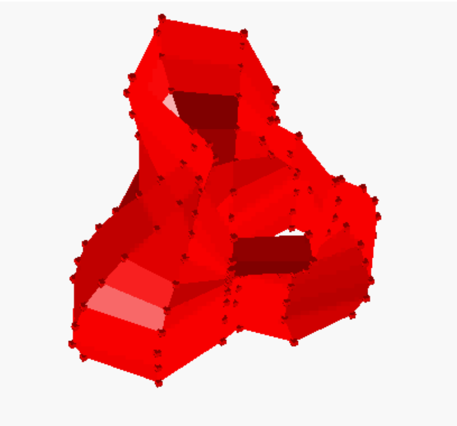

**Figure 9 : Measured winding mode shape.**

Once the active part is assembled it is time for last measurements and minor modifications in order to fine tune the mechanical properties. Additionally appropriate vibroinsulation elements are installed in the joints between active part and transformer tank. These inhibit structural born noise and further reduce overall transformer noise levels.

## NOISE MEASUREMENTS

Noise measurements are the final step on the path to low noise transformer. The measurements need to be conducted in an acoustically appropriate space using correct procedure and calibrated equipment as specified in standard IEC 60076-10 [15]. Example of conducting noise measurements is shown in Figure 10.

Our high-voltage laboratory is equipped with acoustic panels on the walls and double sliding doors which ensure low reverberation times and prevent the noise from production hall interfering with noise measurements.

**Figure 10 : Noise measurements in laboratory.**

Typically the sound pressure method is used, however, the acoustic intensity is the preferred option as the negative effects due to nearfield, reflections and background noise are reduced. In this way the measured sound power of the transformer is more accurate. We encourage our customers to prescribe sound power levels and not sound pressure levels as the first is property of the transformer and is not affected by the surroundings.

## RESULT

The presented procedures are a part of our low noise transformer technology, which results in high quality transformers with low noise. Typical results are presented in Table 1.

| Sound power | Standard design | Low noise design |
|---|---|---|
| **At rated voltage** | X | X – 11 dBA |
| **At rated current** | Y | Y – 7 dBA |

**Table 1 : Comparison of standard and low noise design.**

Results presented in Table 1 are achieved without any additional sound proofing on the transformer tank.

## CONCLUSION

Producing a low noise transformer is a complex multi-physics task demanding additional time and resources in all phases of production. A custom software was presented, which is used during design phase of the transformer in order to obtain optimal design regarding noise. Then procedures used during manufacturing were presented. A device for measuring electrical steel magnetostriction was shown, then measuring core mode shapes using experimental modal analysis, special press for obtaining mechanical properties of transformerboard and measuring winding mode shapes. At the end some details are given regarding noise measurements in our high-voltage laboratory and also typical results, which are achievable using shown low noise transformer technology.

## BIBLIOGRAPHY


[1] R.S. Girgis, M.S. Bernesjö, S. Thomas, J. Anger, D. Chu and H.R. Moore "Development of ultra-low-noise transformer technology" (IEEE Transactions on Power Delivery, 26, 228-234, 2011)

[2] W. Kubiak and P. Witczak "Vibration analysis of small power transformer" (COMPEL - The international journal for computation and mathematics in electrical and electronic engineering, 29, 1116-1124, 2010)

[3] Moses, A.J., Anderson P.I. "Contribution of magnetostriction to transformer noise" (Universities Power Engineering Conference (UPEC) 2010 45th International , pp.1,5, Aug. 31 2010-Sept. 3 2010)

[4] Pirnat, M., Tarman, P., Nastran, M. "A comparison between numerical and experimental modal parameters of transformer core" (Proceedings of International Conference on Engineering Vibration (ICoEV15), Ljubljana, 2015)

[5] Weiser, B., Pfützner, H. "Relevance of magnetostriction and forces for the generation of audible noise of transformer cores" (IEEE Transactions on magnetics, vol 36, no. 5, p. 3759-3777, 2000)

[6] R. Haettel, M. Kavasoglu, A. Daneryd and C. Ploetner "Prediction of transformer core noise" (Proceedings of the COMSOL Conference 2010, Cambridge)

[7] Rausch, M., Kaltenbacher, M., Landes, H., Lerch, R. , Anger, J. , Gerth, J. ,Boss, P. "Combination of finite and boundary element methods in investigation and prediction of load-controlled noise of power transformers" (Journal of Sound and Vibration, vol. 250, no. 2, p. 323-338, 2001)

[8] Ertl, M., Landes, H. "Investigation of load noise generation of large power transformer by means of coupled 3D FEM analysis" (The International Journal for Computation and Mathematics in Electrical and Electronic Engineering, vol 26, p. 788-799, 2007)

[9] Pirnat, M., Čepon, G., Boltežar, M. "Introduction of the linear contact model in the dynamic model of laminated structure dynamics: an experimental and numerical identification" (Mech. mach. theory, vol. 64, pp. 144-154, 2013)

[10] Beer, G., Smith, I., Duenser, C. "The boundary element method with programming" (Springer, 2008)

[11] Javorski, M., Čepon, G., Slavič, J., Boltežar, M. "A Generalized Magnetostrictive-Forces Approach to the Computation of the Magnetostriction-Induced Vibration of Laminated Steel Structures" (IEEE Transactions on Magnetics, vol 49, no. 11, p. 5446-5453, 2013)

[12] Javorski, M., Slavič, J., Boltežar, M. "Frequency Characteristics of Magnetostriction in Electrical Steel Related to the Structural Vibrations" (IEEE Transactions on Magnetics, vol 48, no. 12, p. 4727-4734, 2012)

[13] Ewins, D.J. "Modal testing: theory, practice and application" (Research studies press ltd, 2000)

[14] OpenModal webpage: www.openmodal.com

[15] IEC 60076-10-1 "Power transformers – Part 10 – 1: Determination of sound levels"