Multiphysical electro-vibroacoustics approach for the simulation of transformer noise taking into account the magnetostrictive effects

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Abstract :

This paper presents a multiphysical approach that aims at simulating the noise radiated by a transformer under electromagnetic excitations. This is a 3-step methodology. The first one is about the calculation of the flux density all over the magnetic core. Excitations related to magnetostriction are applied through a thermal analogy and dynamic responses are computed. Then, the noise radiation can be estimated with the aid of an acoustic model (finite/boundary elements or analytical). Experimental Modal Analyses and Operating response measurements strengthen the simulation approach reliability.

Key words : Transformer noise, Magnetostriction, Multiphysics, Finite Elements, Thermal analogy

1 Introduction

The radiated noise by a transformer is due to the vibrations of its structure as response to the excitations which are applied. These excitations can be of different characteristics and origins but the phenomenon of magnetostriction has been identified as the principal noise source. The magnetostriction is characterized by an elongation of the magnetostrictive material under effect of magnetic induction. This dynamic elongation causes vibrations. The vibrations induced by this mechanism are further on transferred to the external hull of the transformer which can also radiate noise.

2 Methodology of simulation

The modeling strategy needs a multiphysics approach in form of a loose coupling between an electromagnetic and a vibro-acoustic model. The principal steps are:

1. Electromagnetic model: this step allows estimation of the induction into the magnetic system and around the windings. A solver of electromagnetic finite elements can be used.
2. Structure model: modelization of the structure of the transformer with mechanical couplings by finite elements:
   a. Extraction of the modal basis and computation of the model (homogenic material equivalent to the magnetic system). Experimental modal analyses (figure 1) allowing computation of the mechanical models of the different components and further on of the complete transformer.
   b. Application of the excitation data.
   c. Calculation of the dynamic response and extraction of the displacement on the outer side of the transformer.
3. Acoustic model: estimation of the radiated acoustic power by a method as finite elements, border elements or analytic model.

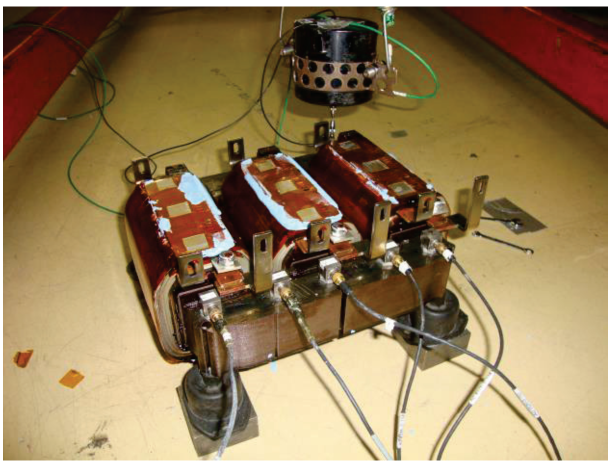
3 Prediction of the excitements which are relative to the magnetostriction

The magnetostriction causes an elongation of the material which can be explained by the law of Hooke [1] :

$$\{\sigma\} = [C]\left(\{\varepsilon\} - \{\lambda^{MS}\}\right)$$

where $\{\sigma\}$ and $\{\varepsilon\}$are the tensors of restraint and deformation, [C] is la matrix of the material stiffness and $\{\lambda^{MS}\}$ the magnetostrictive elongation.

The magnetostrictive elongation depends on the degree of the magnetic induction, determined due to an simulation implement of electromagnetic finite elements (figure 2) and of magnetostrictive properties of the ferromagnetic material: the bends λ-B characteristics are defined by experiments (figure 3).



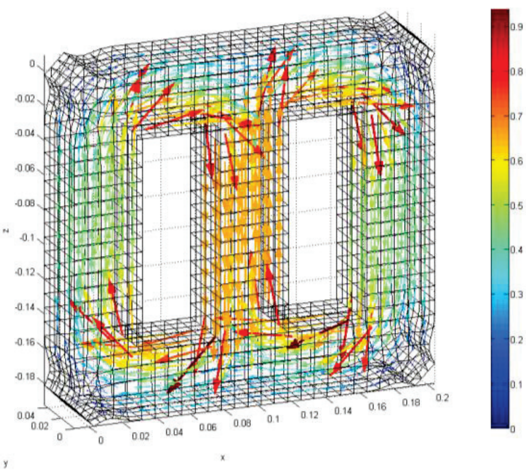


Figure 1 : Figure 1: Experimental modal analysis of the magnetic system of the transformer

Figure 2 : Calculation of the induction into the magnetic system of the transformer

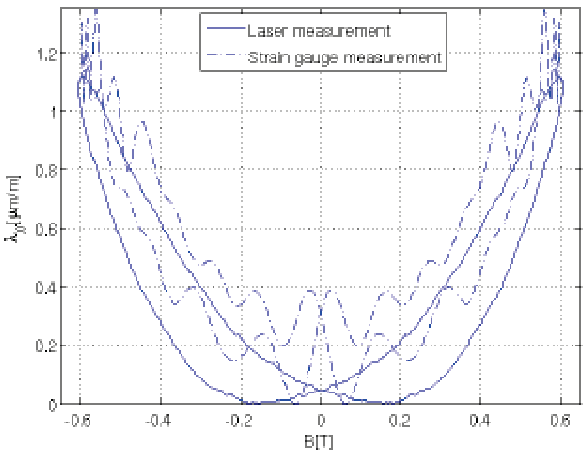


Figure 3 : Characteristics of the λ-B bends [2]

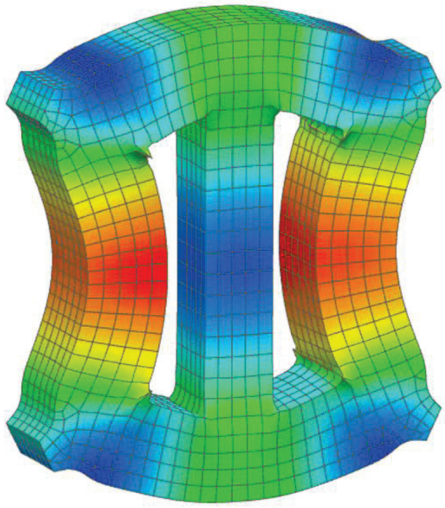


Figure 4 : Dynamic response example of a magnetic system of the transformer with excitement by magnetostriction

4 Vibroacoustic model

4.1 Structure model and strategy of homogenisation

A finite element model of the structure is built. The magnetic circuit is composed of a stacking of sheet metal which is isolated electrically by resin sheets; this multisheet structure will not be represented in detail, therefore the homogenization strategy suggested by Millithaler et al. is applied.

4.2 Loading applications relative to the magnetostriction

In order to use the marketplace solvers (MSC.Nastran for example) for the simulation of the dynamic responses, an analogy between the magnetostriction and thermal phenomena is developed. It is based on the law of Hooke with inclusion of the thermal effects:

$$\{\sigma\} = [C](\{\varepsilon\} - \{A\}(T - T_{ref}))$$

The effects of the magnetostriction can be taken into account for a model with significant size, resolved by a performant solver. The dynamic response of the structure is therefore calculated for the different harmonics of the power streaming the transformer (figure 4). One classic method (acoustic finite elements for example) is used to define the original electromagnetic noise radiated by the transformer.

This simulation method allows anticipating the noise problems caused by the transformers. It also permits to optimize their design as well as their implementation. The development of the thermal analogy is avoiding the development of a new finite elements tool. An experimental validation of this simulation will be realized on the existing transformers for guarantee of the model relevance which can be used afterwards for the concept of a new transformer generation.

Références

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