Numerical and experimental analysis of equivalent magnetostriction forces

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The vibratory behaviour of a single-phase magnetic core made of thermobonded grain-oriented electrical steel (GOES) sheets is analysed experimentally and numerically, considering magnetostriction (MS) effects. To isolate them, the stack has no joints and the laminations are stacked with parallel rolling directions (RDs), preventing flux between layers and eliminating Maxwell forces. The thermobonded core gives a structural stability and makes easier the model calibration to determine its mechanical parameters. Finite element analyses (FEM) are used to quantify equivalent MS forces and their deformations. Experimental deformation measurements are used to determine the forces through inverse methods.

Keywords: Magnetostriction; grain-oriented electrical steel; noise; transformers

1. Introduction

Transformer noise is a key commercial concern, often restricting its use in urban areas. Concerning the noise sources, magnetostriction induces periodic core deformations due to magnetization variations [1]. While many studies have numerically modelled its effect as an equivalent force [2], this work aims to quantify MS forces from experimental deformation data. The obtained forces are then compared with FE simulations on JMAG, providing a rigorous validation of magnetostriction-induced vibrations.

2. Experimental and Numerical approaches

To isolate the contribution of Maxwell forces to transformer noise, a jointless magnetic core consisting of 50 thermo-bonded steel sheets is made with laser-cut laminations, forming a square in one piece with a window. Thermo-bonding ensures structural stability for noise analysis. Without any joints in the corners by aligning the RDs, Maxwell forces in the normal direction do not exist, and magnetic flux remains confined within each sheet. Under these conditions, the noise generated by the core can be attributed solely to MS. Modal analyses allow to identify resonance frequencies, and model calibration methods are applied to adjust the numerical resonance frequencies to match those of the homogenized core. Global deformations of the magnetic core are then studied using a vibrometer to obtain experimental deformation measurements.

Numerical modelling consists in two main steps. First, magnetic modelling is performed using a magneto-harmonic analysis to evaluate the flux density distribution in the jointless core while considering material anisotropy. Next, MS forces are computed (Figure 1) based on the magneto-mechanical decoupled model (1), where M and K represent the magnetic and mechanical stiffness matrices where A and a denote the magnetic field and deformation, T and R the magnetic sources and external forces and F_{ms} the MS forces. These forces are then coupled with a mechanical FE analysis ANSYS to determine the resulting deformations through a harmonic response analysis, incorporating the core resonance frequencies obtained from prior calibration. Finally, experimental deformations are compared with numerical results to determine the equivalent MS forces using reverse methods.

$$\begin{bmatrix} M & 0 \\ 0 & K \end{bmatrix} \begin{bmatrix} A \\ a \end{bmatrix} = \begin{bmatrix} T \\ R + F_{ms} \end{bmatrix} \quad (1)$$

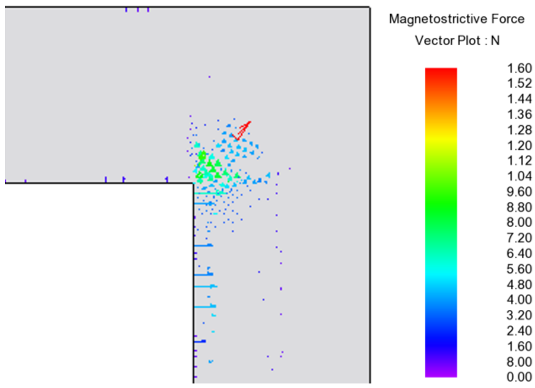

Figure 1: Distribution of MS forces in a jointless magnetic core

3. Conclusion

In this paper, the authors discuss the magnetic and mechanical behaviour of the magnetic core, and they determine the equivalent MS forces using numerical simulations and experimental measurements, applying inverse methods to enable their prediction. The novelty of this work lies in extracting equivalent MS forces directly from experimental deformations.

References

[1] Somkun, S., Moses, A. J., & Anderson, P. I. (2016). Magnetostriction in grain-oriented electrical steels under AC magnetisation at angles to the rolling direction. IET Electric Power Applications, 10(9), 932-938.

[2] L. Vandevelde and J. A. A. Melkebeek, "Magnetic forces and magnetostriction in electrical machines and transformer cores," in IEEE Transactions on Magnetics, vol. 39, no. 3, pp. 1618-1621, May 2003.