Magnetostriction measurement and the contribution of magnetostriction to the noise of a one-phase transformer

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Summary

Deformation of magnetised electrical steel samples, known as magnetostriction, is a main contributor to the noise of electrical machines and especially transformers. In this work, the magnetostriction strains of such samples are measured by using a heterodyne laser vibrometer setup. The results are used to model the data and perform a Finite Element (FE) calculation for one-phase transformer test geometry. To validate the FE data, a transformer test model is built with the same geometry as of that of the FE model. A comparison of the FE data with the measured vibrations of the magnetised test transformer will be reported later.

Introduction

Electrical steel is widely used in the production of the magnetic cores of transformers and electrical machines. Such material has a high magnetic permeability and thus can induce relatively a high magnetic induction B [T] for a medium applied magnetic field H [A/m]. As a result, the machine has an efficient magnetic functionality which increases the total efficiency. In grain-oriented electrical steel, where all the grains are developed in one direction, the material offers even larger magnetic induction B[T] than a nonoriented electrical steel, where the grains are randomly aligned in different directions. To design the electrical device, based on the application, a suitable electrical steel type is selected. In the case of transformers, the grain-oriented material is a common choice. However, for the electrical machines with a rotating magnetic field the nonoriented electrical steel has more advantages and can create a magnetic flux evenly distributed in every direction.
The magnetised laminations of the electrical steel in the cores of the aforementioned devices vibrate and follow some deformation. Such deformation is known as magnetostriction and is ensued by a noise radiation. The deformation of the electrical steel is in the order of micro meter per meter. Transformers and electrical machines are widely used in the industrial applications. However, due to the environmental concerns noise reduction has recently gained more and more attention. The audible

noise of these devices is generated from different sources such as the assembly of the machine, the cooling system and the magnetic cores. Studies have been reported on the noise sources and the design improvement, e.g. on the transformer [1], [2].

Looking at the magnetic sources, the rather complex behaviour of the magnetostriction urges a need to properly measure it and consequently calculate its noise contribution to the total noise. In this work the magnetostriction strain measurement of the samples of electrical steel are measured by using a heterodyne laser interferometer setup which has been recently developed. The magnetostrictive behaviour of the samples of grain-oriented and nonoriented electrical steel are measured under sinusoidal magnetisations with 50Hz frequency. Magnetostriction is a three-dimensional deformation and mostly without any volume change of the material. By using this laser setup, a two-dimensional behaviour of the sample in the parallel and perpendicular direction to the applied magnetic field is measured.

For the vibrations study, a one-phase transformer core with nonoriented electrical steel laminations is built in our lab. This test transformer has no lap joints and the laminations are in one piece. The lap joint design will add some extra noise source due to the air gap between the laminations. However, we would like to study only the magnetostrictive noise and therefore the lap joint geometry is not suitable. The magnetostriction strain measurement data for the same nonoriented material is used to model the vibrations of this transformer test model in FE software. The real vibration measurement of the transformer test will be measured by using a scanning laser vibrometer. A comparison of the FE results and the laser vibration results will be reported later.

In the next section, the measurement setup will be explained. After that the measurement data modelling in FE and validation for a test transformer test setup will be presented.

Magnetostriction measurement setup

The magnetostriction strain measurements of electrical steel samples, in two-dimensions, are performed by using a heterodyne laser vibrometer setup (Polytec IVS200). The magnetostriction strains of the samples in parallel and perpendicular direction to the magnetisation direction are measured. The setup is steered by using a PC and using a LabView program. The single sheet tester technique is applied to measure the magnetic properties of the sample. The magnetisation signal is generated in the LabView program and sent to the amplifier and the excitation coil which is wrapped around the sample. Two heterodyne vibrometer lasers measure the vibrations of two small aluminum mirrors which are glued on the sample. The laser signals are then sent back to the PC, along with the measured magnetic induction B[T] and the magnetic field H[A/m]. In the LabView program, the average velocities of the two laser signals and consequently the relative length change of the sample, compared with the original length of the sample (in the case of non-magnetised) is calculated. A schematic of this setup is presented in Fig.1. The sample size is 17 cm by 8cm. The magnetostriction strain measurements are then post-processed in the LabView program. The early design of this setup and the improvements are reported in [3], [4].

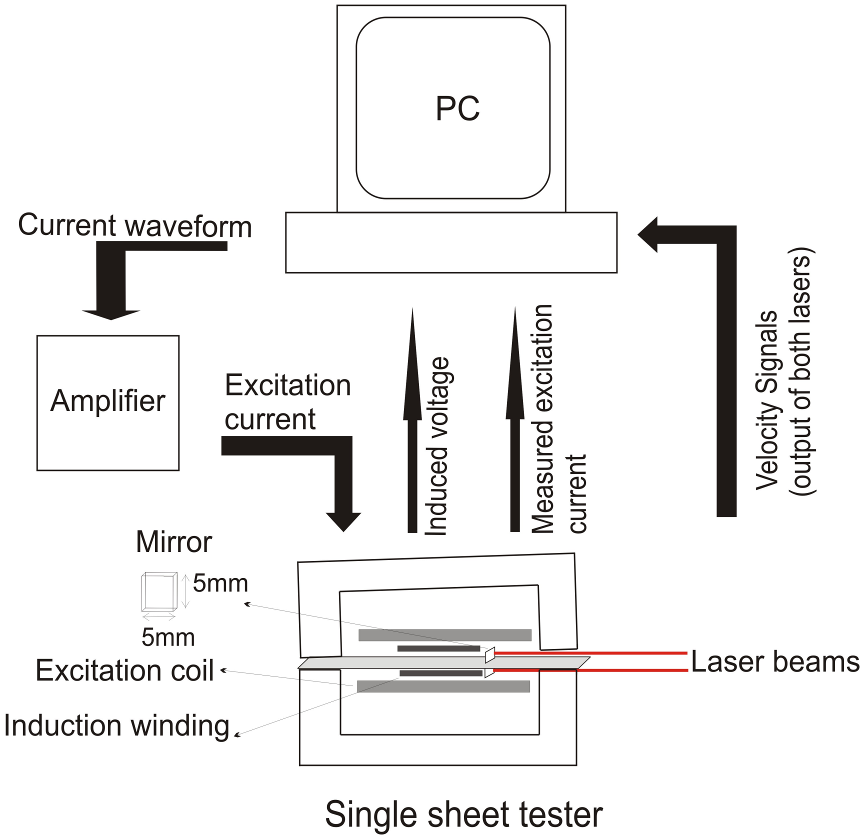
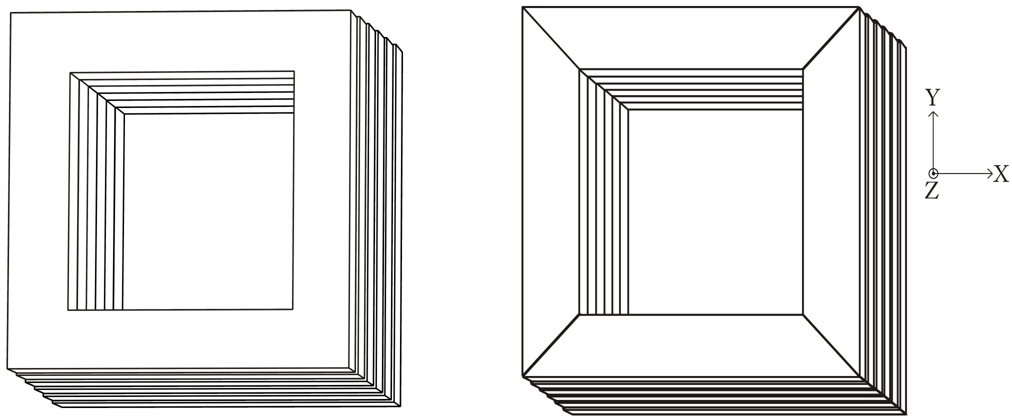


Fig.1: A schematic of the magnetostriction measurement setup by using dual heterodyne laser vibrometer

Modelling and results validation

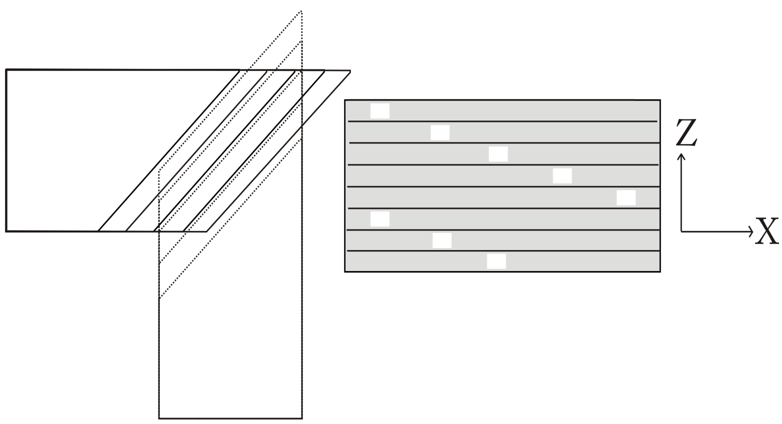
The measurement data for a nonoriented material is used to model the vibrations of a one-phase transformer in FE software. To validate such results, a similar test transformer is built in our lab. In a real transformer, mostly grain oriented materials are used and since such material is strongly developed in one direction, the transformer cores are then built out of lap joint assembly. Such assembly is shown in Fig.2 a. In this way the flux is almost always passing through the rolling direction of material which increases the efficiency of the transformer. However, with this assembly, the flux path that goes from one lamination to another one passes through the very small air gap between two laminations in the z direction, as shown in Fig.3 b. Therefore in addition to the magnetostrictive noise, a noise due to the clapping of the joint regions of the laminations is generated as well. Fig.3 shows overlap design of a lap assembly in a top and a side view. The air gaps are shown with white spaces. Since for the validation of the magnetostriction strain measurement data, only the magnetostriction noise needs to be measured, a simpler assembly without any lap joints is considered for the test transformer. To this end, the laminations are cut out of one piece, by using the spark erosion technique to avoid any harm to the magnetic properties of the material due to cutting, shown in Fig.2 b. However, using a grain-oriented material, with such assembly was not a suitable choice, since the magnetic properties of this material type is significantly different in the rolling direction

compared with the other directions. This would have resulted in a transformer with large different magnetic properties in each leg. To avoid it, a nonoriented material with more uniform magnetic properties in every direction was preferred.
The vibration and noise measurement for such transformer test setup will be performed by using a laser scanning vibrometer. Such vibrometer can determine the operational deflection shapes and Eigen-modes of the specimen. Entire surfaces can be scanned and probed automatically using flexible and interactive measurement grids. The calculated noise by the FE model shows only the magnetostriction noise, The measured noise by using the scanning vibrometer is mainly a result of the magnetostriction noise and perhaps some other small noise e.g. vibrations of the magnetization windings. A comparison of the two data, the FE modeled data and the vibration measurement data of the transformer test setup, will be reported later.



a) *b)*

Fig.2: Transformer test core a) assembly with laminations out of one piece (the transformer test setup design) b) a lap joint assembly and the coordinate system



a) *b)*

Fig.3: Overlap design in joint region for a multiple lap assembly a) top view b) side view and the coordinate system

Conclusion

Magnetostriction deformation of the electrical steel laminations used in the core of transformers and electrical machines cause some vibrations and noise. A setup has been developed to measure such deformation for grain-oriented and nonoriented electrical steel types. By using a non-contact approach, two heterodyne laser vibrometer measure the vibrational velocity of the sample. Based on the average velocities, the relative length change of the sample, magnetostriction strains, are calculated. A model of the measured data for a nonoriented material type is made. For a one-phase transformer with no lap joints FE calculation is applied. The same transformer test setup is built for the validation of the data. The vibrations measurement of the magnetised transformer test core and a comparison with the FE calculation will be reported later.

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