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Noise variation by compressive stress on the model core of power transformers

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ABSTRACT

The reduction of audible noise generated by cores for power transformers has been required due to environmental concern. It is known that compressive stress in the rolling direction of electrical steel affects magnetostriction and it can result in an increase in noise level. In this research, the effect of compressive stress to noise was investigated on a 3-phase 3-limb model core. Compressive stress was applied in the rolling direction of the limbs from the outside of the core. It increased the sound pressure levels and the slope of the rise was about 2 dBA/MPa. Magnetostriction on single sheet samples was also measured under compressive stress and the harmonic components of the magnetostriction were compared with those of noise. It revealed that the variation in magnetostriction with compressive stress did not entirely correspond to that in noise. In one of the experiments, localized bending happened on one limb during compressing the core. While deformation of the core had not been intended, the noise was measured. The deformation increased the noise by more than 10 dBA and it occurred on most of the harmonic components.

1. Introduction

Since audible noise generated by transformers is often restricted by ordinances which are applied to the areas where the transformers are installed [1], the development of technology to reduce and control the noise has been pursued. One of the causes of the noise is vibration on a transformer core, and one of the causes of the vibration is the magnetostriction of grain-oriented electrical steel used for the core [2,3]. The magnetostriction is a phenomenon by which the dimensions of electrical steel slightly change with ac magnetization, and it is often affected by some extrinsic factors. Stress, especially in the rolling direction of electrical steel, is a significant factor. In addition, tensile stress in the transverse direction and bending of steel are also the factors. Since they increase the magnitude of magnetostriction [4–6], there is concern over noise increase. In a previous study, the stresses occurring in a core were measured [7], however, there is no investigation in which the compressive stress was directly related to noise. In this investigation, magnetostriction variation with increasing compressive stress in the rolling direction was measured firstly. Then, the noise levels of a model core were measured under the compressive stress in the rolling direction, and the correlation between the noise and the magnetostriction is discussed. Additionally, the influence of core deformation on noise was investigated.

2. Experimental

2.1. Magnetostriction measurement

The sample size for magnetostriction measurement was 100 mm × 500 mm. The values measured on ten samples were averaged. A magnetostriction measuring system using a laser vibration meter has been used [8]. In the system, a pneumatic mechanism allows application of compressive stress to the sample. Magnetostriction measurement was carried out in the rolling direction. Compressive stress was also applied in the rolling direction of the sample. Excitation was at frequency of 50 Hz and at inductions of 1.3 and 1.7 T. Compressive stress was varied from 0 to 3 MPa in 0.5 MPa steps.

2.2. Model core

Fig. 1 shows a model core for noise evaluation. It is a 3-phase 3-limb stacked core having 6-steplap joints. The core material was grain-oriented electrical steel in 0.30 mm thickness. The stacking thickness was about 41 mm. For tightening the core, wood plates were put on both the sides of the core, and c-shaped clamps were attached on the plates to apply clamping forces to the core. The

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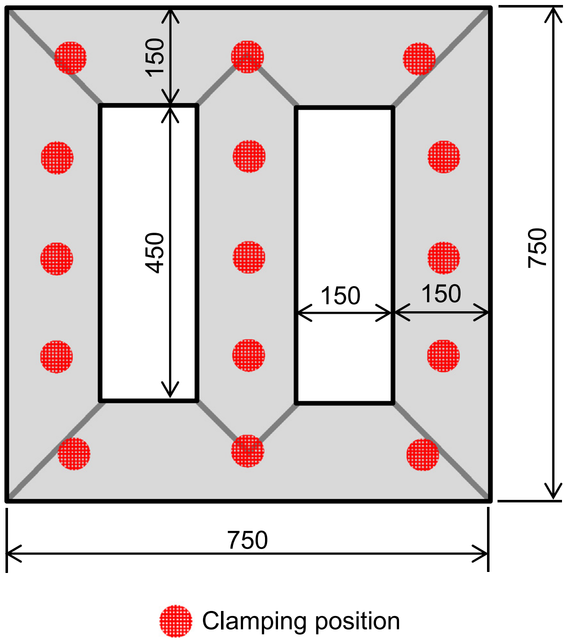

Fig. 1. Dimensions of the model core and clamping positions for c-clamps.

numbers of the clamping positions were 15 as indicated in Fig. 1. The mean clamping pressure was 0.3 MPa. The core was set in an upright position. A couple of windings for excitation and flux density measurement were set on each limb.

Compressive stress was introduced in the longitudinal direction of each limb, i.e. in the rolling direction, from the outside of the core. Figs. 2 and 3 show the mechanism. The compressive forces were applied on the areas which were defined by projecting the cross sections of the limbs onto the top and bottom surfaces of the core, i.e. the dimensions were 150 mm × 41 mm. Firstly, rubber sheets in 5 mm thickness were put on the areas. Then steel plates with the same size as the rubber sheets were put. After that, crossbars were set on them. The upper and lower crossbars were connected by rods, and force was given by nuts through springs. Since the wood plates were tightly fixed on the core, the wood plates would have been loaded by a certain part of the compressive forces, and it would have resulted in the error of the levels of the compressive stress in the core. To avoid the error, the wood plates were cut into several parts, and small gaps were made between the clamping positions as can be seen in Fig. 3.

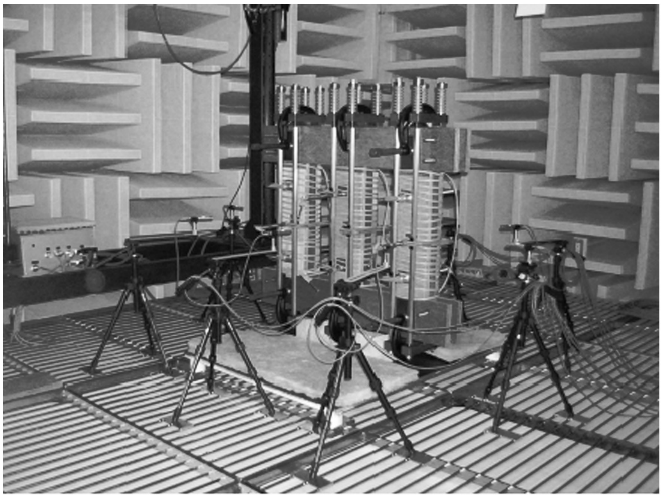

Fig. 2. Model core and microphones set in the anechoic room.

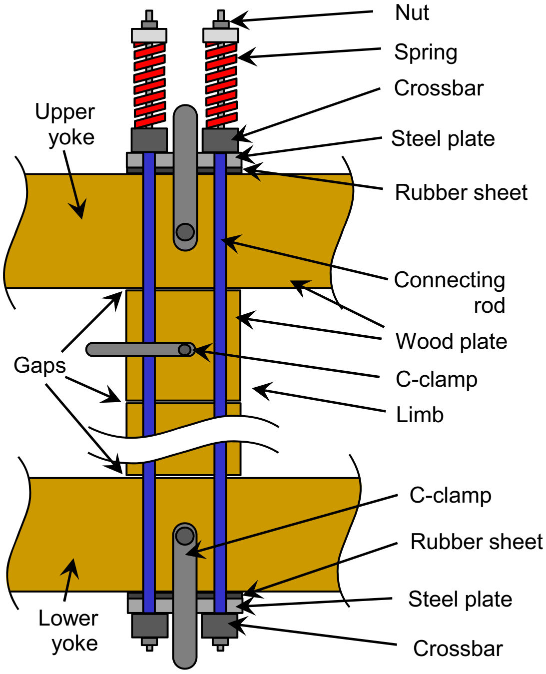

Fig. 3. Schematic of the mechanism for applying compression to a limb of the model core.

The compressive forces were calculated from the spring constant and the displacement of the springs. The nuts were carefully tightened to avoid bending of the limbs. Noise measurement was begun at a stage without stress, and continued up to compressive stress of 3 MPa in 0.5 MPa steps. After the measurement of 3 MPa, the nuts were completely loosened, and the noise was measured to evaluate residual effect of the compression.

2.3. *Noise measurement*

IEC standard for the determination of sound levels on power transformers [9] was basically referred for sound pressure measurement. Fig. 2 shows a scene of the noise measurement. Eight microphones were arranged to surround the model core in equal separations. The microphones were put on the positions by 30 cm apart from the core surface and at a half of the core height.

A computer-based system has been used to make automated measurement. The microphones are switched in predetermined order by a multiplexer which provides a sound signal to a sound level meter. The ac output of the sound level meter is used for harmonic analysis of sound pressure waveforms by an FFT analyzer. Time-synchronous method [9] is adopted for waveform averaging. The data are transferred to a computer, and the data of the microphones are averaged and recorded. The computer also controls both the frequency and the output voltage of an oscillator which provides sinusoidal signals to a 3-phase power amplifier for core excitation. In an automated measuring procedure, firstly, background noise is measured, and then, the core is demagnetized, after that, noise is measured at flux densities of 1.3, 1.5 and 1.7 T, of 50 Hz. After the noise measurements, compressive stress is adjusted to the next value.

The measurements were carried out in an anechoic room. Average A-weighted background noise pressure levels L_{bgA} measured before and after changing stress ranged from 15.8 to 16.0 dBA, namely, the maximum variation was 0.2 dBA. Since the minimum of uncorrected average A-weighted sound pressure levels L_{pA0} was 21.3 dBA, the difference between L_{bgA} and L_{pA0} was more than 5.3 dBA. Background noise correction was applied for