

The Impact of Third-Harmonic Vibrations on the Electricity Grid and the Detection of Vibrations in Transformer Cores

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Abstract

The vibrations and deformation of a test transformer core are measured using an experimental approach in this paper. Because the grid voltage contains some higher harmonics, the occurrence of a third harmonic is investigated in addition to a simply sinusoidal core magnetisation. The surface scan of the leg and the vibrations of the transformer core for points reveal higher deformation in the corners of the leg than in the centre. In the corners of the leg, the impact of the higher harmonic of the magnetisation on the core deformation is likewise more substantial. A sinusoidal magnetisation with a higher harmonic produces a more wavy and variable core deformation shape than a simply sinusoidal magnetization.

Keywords: *Vibrations, Electrical Devices, Electricity Grid, Transformer Cores, Deformation Shape*

INTRODUCTION

Many research, such as [1], [2], have focused on the noise and vibrations of electrical devices and transformers. In this paper, some data on transformer vibrations that are similar to those of electrical devices will be provided. Noise creation is complicated in general since it is created

by several sources. The transformer assembly and mechanical construction, for example, have a direct impact on noise radiation. The winding forces and deformations of the device's core are the primary sources of magnetic noise. The Lorentz force acting on the winding conductors causes winding noise, which is

proportional to the vector product of magnetic induction and current in the conductors. The deformation and vibrations of the transformer core, on which this research focuses, are, however, more difficult. Electromagnetic forces and magnetostriction in the core generate this deformation [3].

The electromagnetic contribution is frequently stated as the impact of an external magnetic source on magnetic material. Magnetostriction deformation, on the other hand, is caused by the core material's interatomic interactions in the presence of a magnetic field. For a more detailed discussion of various noise sources, see [1]. Both events occur simultaneously, resulting in pulsing core vibrations. These vibrations produce audible acoustic noise due to the mechanical nature of the core.

Computational approaches may be used to calculate the deformation and vibrations of transformer cores [4]. However, in this paper, an experimental way to measuring core vibrations using a laser technology will be given. Furthermore, the suggested approach enables us to visualise the core deformation. For the vibration measurements, a test transformer core is created.

Higher harmonics are always present in grid voltage.

Visualizing the core deformation is particularly beneficial for seeing the influence of higher harmonics on the magnetisation voltage, which will be discussed later.

The following is a breakdown of the manuscript's structure. The test transformer core will be discussed in the next section. The technique for measuring vibrations and deformation will be presented next. At the conclusion, the measurement results under various magnetic excitation voltages will be shown, followed by a discussion.

TEST TRANSFORMER CORE

It has previously been noted that the lap assembly of a transformer core impacts the flux route, potentially resulting in an additional noise and vibration source in addition to the magnetic sources [3]. The flux passes from one lamination to the next in the out-of-plane direction through the little air gap between them in the joint corners. This causes a clamping noise by creating an attractive interlaminar force in the corners. Only the contribution of magnetic forces and magnetostriction will be measured in this study.

To this end, the vibrations measurement transformer core does not have any lap joint assemblies [5]. It's a straightforward single-phase transformer with single-piece laminations. Because grain oriented electrical steel is substantially isotropic, it was not a good choice for the core material.

A nonoriented material type M350-50A was used for this. At 1.5T and 50Hz magnetisation, this material has a thickness of 0.5mm and 3.50W/kg losses. To avoid any damage to the magnetic characteristics of the material, the laminations were cut using the spark erosion process. The centre is 30cm by 30cm and the legs are 5cm wide. It's coiled

around three legs to distribute the flux evenly throughout the core and prevent local magnetization. As indicated in Fig. 1, the fourth leg is left open for vibration measurements.

VIBROMETER WITH LASER SCANNING

A laser scanning vibrometer was used to measure the vibrations of the test transformer core. The scanner was a Polytec laser PSV-400 vibrometer. The resolution of the scanner has been set at 0.2 mm/s/V. A PC-based software sends a magnetic excitation voltage to an amplifier, which is subsequently transferred to the excitation coil around the core.

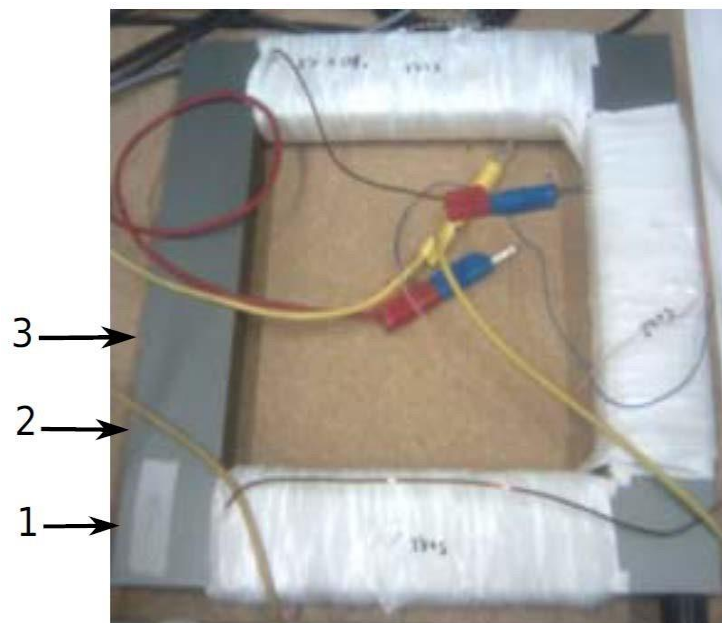


Fig. 1. Depiction of the single-phase test transformer core with only the primary excitation winding where one leg is left free for the vibration measurements.

The voltage provided to the core is adjusted to get the desired magnetic induction. The scanning vibrometer was used to measure the core's vibration, which was then processed to determine the displacements. The laser measured the selected spots of the core for pre-determined time intervals, based on a user modification, and then recorded the average data of the observed velocities. The deformation of the core was computed using average velocity signals.

Furthermore, the scanner can do an autonomous surface scan for a grid pattern of points and present the findings in a 3-dimensional (3D) animation. The scanner then uses an interactive measuring grid to automatically probe the whole grid. The results of this will be presented further on.

MAGNETIC EXCITATION VOLTAGE

The voltage waveform of the electrical power grid is not strictly sinusoidal in practise. Higher harmonics are always present, as a result of the nonlinear voltage-current characteristics of the grid-connected loads [6]. Power converters (rectifiers) and variable speed drives are two well-known examples of nonlinear industrial loads. The third harmonic's influence on the magnetostrictive

behaviour of electrical steel has previously been documented [7]. The results revealed that the amplitude and, in particular, the phase delay of the third harmonic had a considerable impact on the magnetostriction strain harmonics. As a consequence, vibrational measurements of the core were done under a simply sinusoidal applied magnetic voltage and a sinusoidal voltage containing a third harmonic component to explore the influence of higher harmonics. Combinations of the third harmonic's amplitude percentage and phase delay relative to the fundamental were used to achieve this.

MEASUREMENT RESULTS

The transformer core was hung from a frame in a horizontal plane parallel to the ground to avoid any friction with the surrounding surface. As illustrated in Fig. 2, the core weight is likewise equally distributed throughout the plane. The laser head was aimed at the transformer's free leg. A completely sinusoidal magnetic induction and a sinusoidal magnetic induction containing a third harmonic component were used to detect the core's deformation. The amplitude of the magnetic induction was designated as

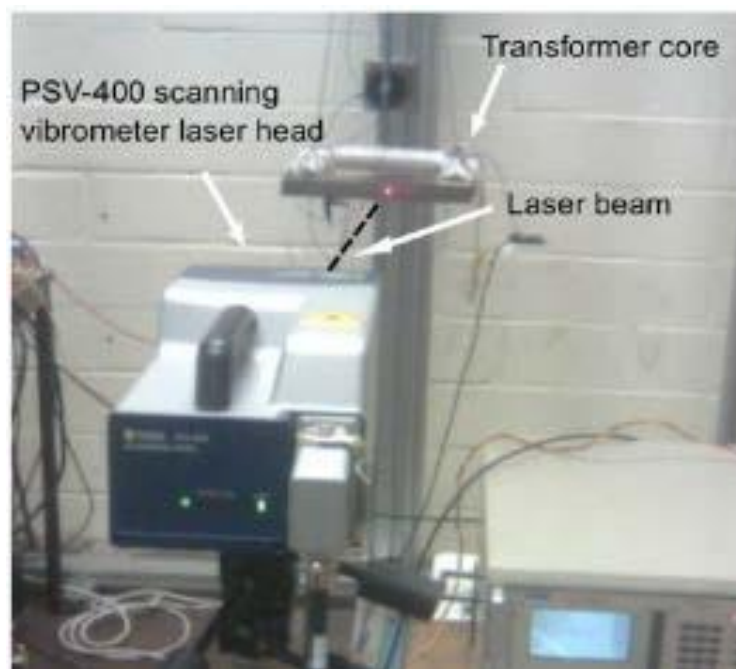


Fig. 2. The test transformer core placement for the vibrations and deformation measurements

1.2T with a frequency of 50Hz for experiments under solely magnetisation. The knee of the B-H loop characteristic of the material, which is a common magnetisation level for transformers, corresponds to this value. The amplitude of the third harmonic component was chosen as 6%, 8%, and 10%, with a phase delay of 00, 900, and 1800, respectively, for measurements with a third harmonic component.

As shown in Fig. 1, the deformation at three sites along the free leg of the transformer core was measured.

In transformers, the contribution of magnetostriction to core deformation is

substantially greater than the contribution of electromagnetic forces. The odd harmonics information has no bearing on the magnetostriction [8]. The 100Hz component has the biggest amplitude among the even harmonics (for a 50Hz stimulation). Table I shows the 100Hz data from the measurement results for a completely sinusoidal magnetic induction with 1.2T amplitude and 50Hz. Table II shows the 100Hz findings for a sinusoidal magnetic induction with an amplitude of 1.2T and a frequency of 50Hz, as well as a third harmonic with the same amplitude ratios and phase delays as the sinusoidal magnetic induction.

Table I. The 100 Hz Magnitude [M] and Phase Spectrum [Rad] Displacement Data of the Selected Points Measured By the Scanning Laser Vibrometer under a Purely Sinusoidal Magnetic Induction ($B=1.2t$ and $F=50\text{hz}$).

	point 1	point 2	point 3
Purely sine	$3.80\text{e-}07 \angle -0.23$	$2.070\text{e-}07 \angle -0.08$	$1.300\text{e-}07 \angle -0.32$

TABLE II

The 100hz Magnitude [M] And Phase Spectrum [Rad] Displacement Data Of The Selected Points Measured By The Scanning Laser Vibrometer Under A Sinusoidal Magnetic Induction ($B=1.2t$ And $F=50\text{hz}$) With A Third Harmonic Component With 6%, 8% And 10% Amplitude Ratios And 0° , 90° And 180° Phase Delays, With Respect To That Of The Fundamental.

6% third harmonic			
phase delay	point 1	point 2	point 3
0°	$3.49\text{e-}07 \angle 0.16$	$1.82\text{e-}07 \angle 0.34$	$1.28\text{e-}07 \angle -0.31$
90°	$3.36\text{e-}07 \angle -0.61$	$1.97\text{e-}07 \angle -0.37$	$1.31\text{e-}07 \angle -1.39$
180°	$3.31\text{e-}07 \angle 2.80$	$1.96\text{e-}07 \angle 0.55$	$1.20\text{e-}07 \angle -1.61$
8% third harmonic			
phase delay	point 1	point 2	point 3
0°	$3.55\text{e-}07 \angle 0.19$	$1.77\text{e-}07 \angle 0.05$	$1.27\text{e-}07 \angle -0.37$
90°	$3.39\text{e-}07 \angle 0.16$	$1.79\text{e-}07 \angle 0.06$	$1.32\text{e-}07 \angle -0.31$
180°	$3.25\text{e-}07 \angle -0.89$	$1.91\text{e-}07 \angle -0.75$	$1.27\text{e-}07 \angle -1.62$
10% third harmonic			
phase delay	point 1	point 2	point 3
0°	$3.59\text{e-}07 \angle 0.16$	$1.92\text{e-}07 \angle 0.00$	$1.28\text{e-}07 \angle -0.09$
90°	$3.38\text{e-}07 \angle -0.12$	$1.74\text{e-}07 \angle -0.12$	$1.33\text{e-}07 \angle -1.24$
180°	$3.22\text{e-}07 \angle 2.27$	$1.76\text{e-}07 \angle 1.48$	$1.24\text{e-}07 \angle 2.08$

RESULTS DISCUSSION

A. Deformation of Points

The core deforms more at the corner of the leg than in the centre, according to the testing findings under simply sinusoidal magnetic induction. In points 1 and 3, the impact of the third harmonic on core deformation is greater than in points 2 and 3. This is illustrated in Fig. 3, which plots

the amplitude of the deformations of the points at 100Hz against the phase delay of the third harmonic.

The deformation of point 1 is shown by the blue lines with circle markers (the four top lines). The deformation of point 2 is shown by the red line with an asterisk (the four middle lines), which are all smaller

than those of point 1. The deformation of point 3 is shown by the green line with upward-pointing triangles (the four bottom lines), which are all smaller than those of point 2. The solid line represents the deformation under simply sinusoidal magnetisation for each position. The deformations under 6%, 8%, and 10% third harmonics are shown by dashed, dotted, and dashed-dotted lines, respectively.

b. 3D Animation of the Core Leg Deformation

A 3D animation of the free leg of the core is created to clearly demonstrate the deformation. In Fig.4, two views of the animation of the core free leg surface are

given for a solely sinusoidal magnetisation of the core, with the highest (top picture) and minimum (bottom picture) deformations.

In reality, the core free leg deforms unevenly over the surface, with higher deformation in the corners. A 3D animation may also be used to demonstrate the influence of the third harmonic. Figure 5 illustrates three images of free limb deformation animations under a 6 percent third harmonic with the aforementioned phase delays from top to bottom, corresponding to 0 phase delays, 90 phase delays, and 180 phase delays, respectively. Two key observations may be made based on Figures 5 and 4.

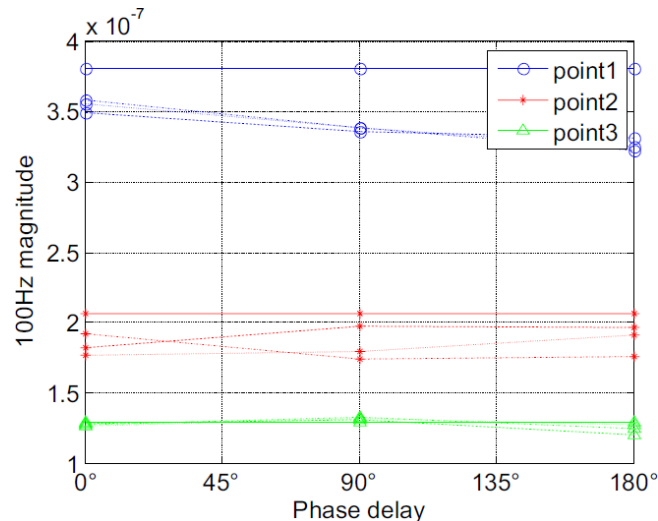


Fig. 3. The 100Hz magnitude [m] of the selected points measured by the scanning laser vibrometer under a purely sinusoidal magnetic induction ($B=1.2T$ and $f=50Hz$) and a sinusoidal magnetic induction with a third harmonic component with 6%, 8% and 10% amplitude ratios and 0° , 90° and 180° phase delays with respect to that of the fundamental.

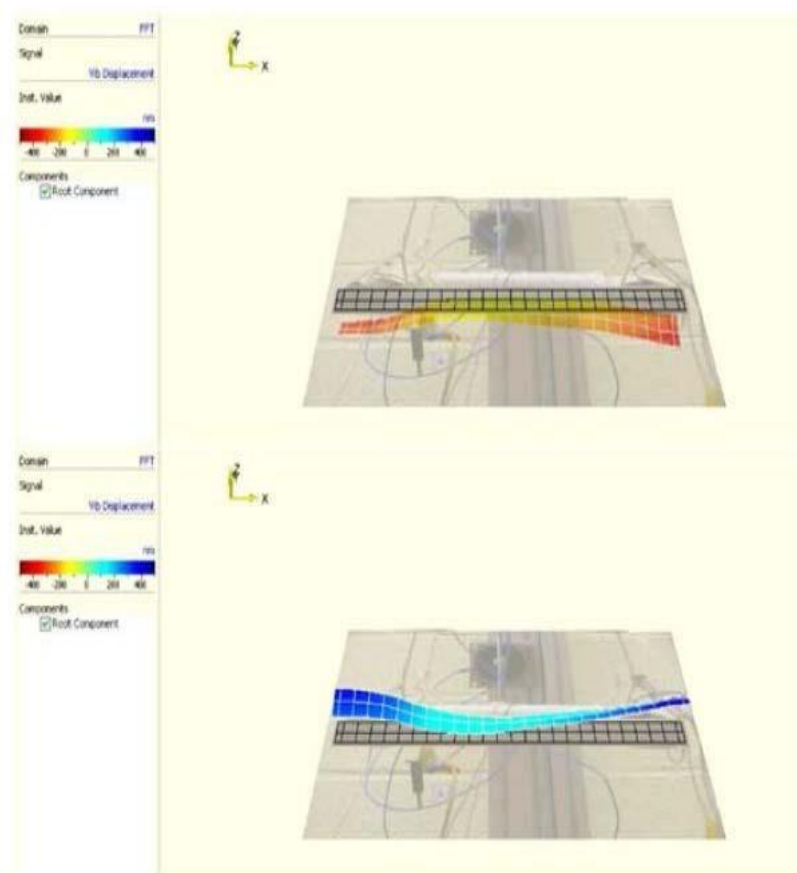


Fig. 4. A 3D vibration measurement of the free leg of the single-phase test transformer core under a purely sinusoidal magnetic induction with 1.2T amplitude and 50Hz representing the maximum (inward) and the minimum (outward) deformations from the top to the bottom, respectively.

The free leg surface deforms wavier under a third harmonic magnetisation than under a merely sinusoidal magnetisation in all three observations. Figure 4 shows how the surface deforms into a quadratic shape. In addition to the primary quadratic deformation, the surface deformation in Fig. 5 displays minor oscillations in a sinusoidal pattern. Furthermore, the bigger the phase delay of the third harmonic, the higher the fluctuations, as seen in the same figure.

The leg corners show variations when there is no phase delay. They develop more along the leg when the phase delay is set to 90. When the phase delay is 180 degrees, the entire leg deforms sinusoidally. We may infer that when considering the impact of higher harmonics in the grid on transformer core deformation, both the amplitude and phase delay of the higher harmonic relative to the fundamental are important.

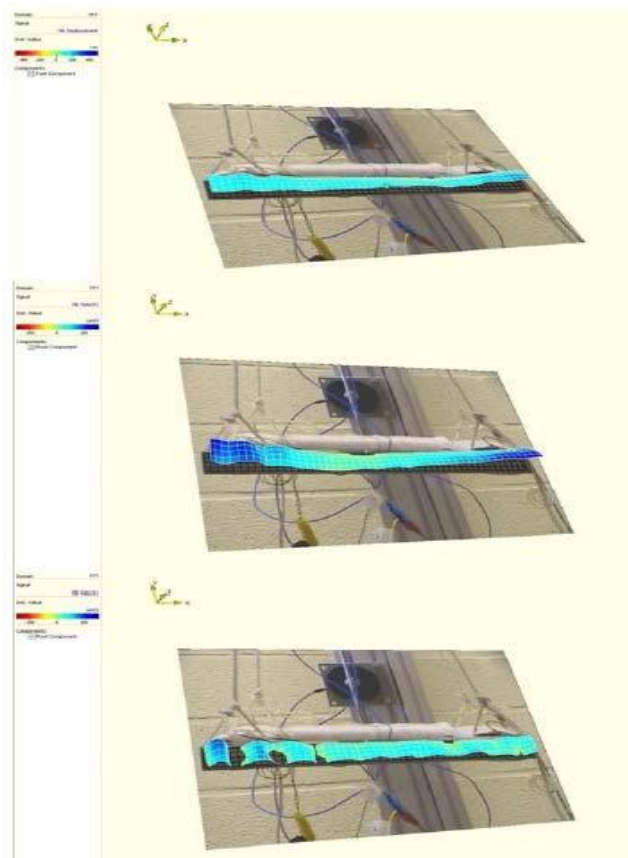


Fig. 5. A 3D vibration measurement of the free leg of the single-phase test transformer core under a sinusoidal magnetic induction with a fundamental harmonic of 1.2T amplitude and 50Hz and a third harmonic with 6% amplitude and 0°, 90° and 180° phase delays from the top to the bottom, respectively.

CONCLUSION

A laser scanning vibrometer is used to measure the vibrations and deformation of a test transformer core in this article. Magnetic forces and magnetostriction in the core, which occur concurrently, generate such deformation. Because grid voltage is never totally sinusoidal, measurements are made using a sinusoidal magnetisation with a third harmonic and compared to measurements made with a purely sinusoidal magnetisation. Along

with the point measurements, an animation of the core deformation is displayed. The results reveal that the core deforms more near the corner than in the centre in all circumstances. The leg deformation shape is more complicated in sinusoidal magnetisation with a third harmonic than in merely sinusoidal magnetisation. We may infer that when considering the impact of higher harmonics in the grid on transformer core deformation, both the

amplitude and phase delay of the higher harmonic should be considered.

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