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IN-PLANE FLUX DISTRIBUTION IN 45^{O} T-JOINT OF 3PHASE TRANSFORMER CORE WITH STAGGERED YOKE AND LIMB 10MM

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ABSTRACT
This paper describes the result of measurement of in-plane flux distribution on 100kVA 3phase distribution transformer assembled with 45o T-joint and mitred lap corner joint with stagger yoke and limb with overlap length of 10mm. The measurement involves the fundamental and third harmonic of the easy and hard direction of flux density at each location measurement. The flux distributions have been measured using no load test by arrays of search coil in M5 (CGO) grades material of transformer core laminations. The localised flux density at the outer 45o T-joint is 0.218T and rises to be 0.228T at the inner edges of 45o T-joint when the transformer core energized 1.5 T 50Hz. Harmonic occurs mostly in the T-joint where local regions are saturated and the flux deviates from the rolling direction. A small amount of flux deviation from the rolling direction occurs at the overlap, but no rotational flux is present in the joint.

KEY WORDS
Transformer core, in-plane flux distribution, search coil.

1. Introduction

Transformer iron loss can be reduced either by improving the quality of the steel or by using better building and design techniques. The efficiency of a transformer core is also largely dependent upon the design of the joints at the junctions of the yoke and limbs. In these regions the flux may deviate from the rolling direction of the steel or become distorted so that local areas of the high loss are produced. [1] The use of grain-oriented silicon iron has been the main beneficial factor in increasing transformer efficiency. [2]

The behaviour of this investigation is to understand the in-plane flux distribution of the transformer core built from electrical steel (M5) with 3% silicon iron assembled with 45^{o} T-joint and mitred lap corner joint with stagger yoke and limb with overlap length of 10mm by using arrays of search coil.

2. Experiment Apparatus And Measuring Techniques

The main apparatus consist of a model cores three-phase 100kVA transformer assembled with three limbs core with T-joint cutting angle 45^{o} assembled from CRGO (M5 grades) 3% Si-Fe material. The core has 550 mm x 580 mm with the limbs and yokes 100 mm wide as shown in Figure 1. The experimental cores assembled with T-joint 45^{o}, mitred overlap corner joints with staggered yoke and limb and overlap length is 10mm as shown in Figure 2 and assembled from 0.3 mm thick laminations of M5 grain-oriented silicon iron (CRGO). Associated instruments are used to measurement fundamental and third harmonic content of the localised flux density distribution.

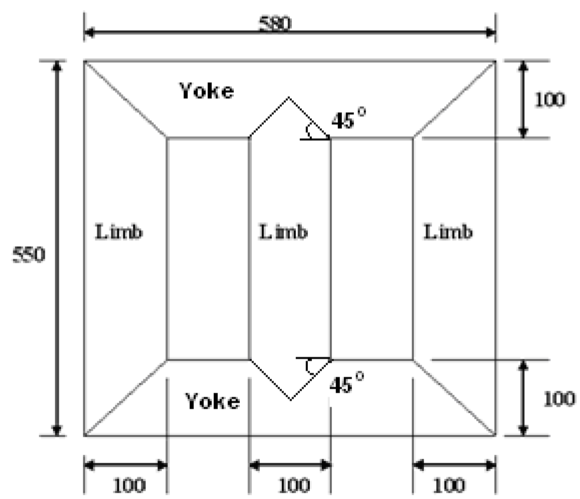

Fig. 1: Dimension (mm) of 100kVA transformer model

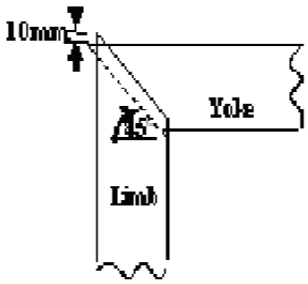

Fig. 2: Corner-joint transformer core type with staggered yoke and limb 10mm

The localized flux density distribution in individual laminations is measured using search coils. The samples are drilled with an aid of drilling machine. It is constructed from 0.15 mm diameter wire treaded through 0.8 mm diameter holes 10 mm a part as shown in Figure 3. Each measuring position suitable coils are wound to measure the easy and hard direction flux density. The search coil induced voltages are analysed to find the magnitude and plane coil induced voltage of flux density by using power analyzer [PM6000] as shown in Figure 4.

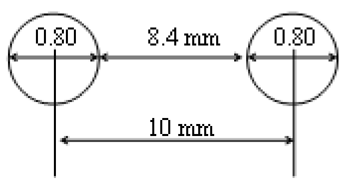

Fig. 3: Dimensions [mm] of the holes drilled in the specimen

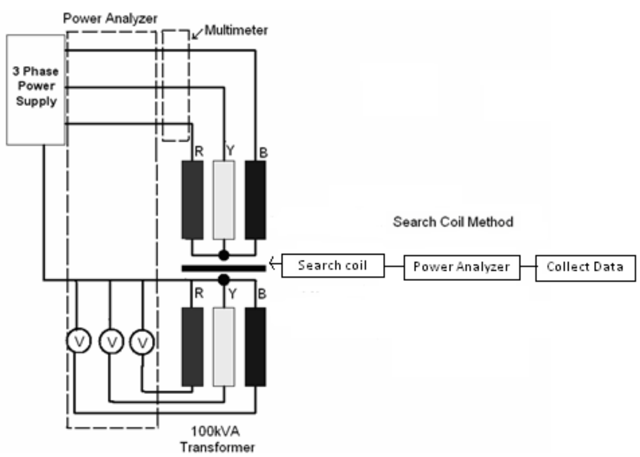

Fig. 4: The diagram of the methods that used to measure the localised flux density.

The magnitude and direction with reference to the x axis of the in-plane instantaneous flux density can be written in the form [3]:

$$|b| = \frac{1}{4\,fNAn}[\bar{e}_x^{\,2} + \bar{e}_y^{\,2}]^{1/2} \qquad (1)$$

And

$$\alpha = \tan^{-1}\left(\frac{e_y}{e_x}\right) \qquad (2)$$

Where

f = frequency supply

N = Number of transformer winding

A = Cross section area of transformer core lamination that measured

n = number of layer of transformer core lamination

e_x = maximum value of the component of induced emf in the easy direction

e_y = maximum value of the component of induced emf in the hard direction

Sample calculation as follow:

From transformer frame are obtain number of turn is 254 turns, area of lamination is 0.000003m^2 with number of layer is 15 layers and frequency supply is 50 Hz. When the supply adjusted to transformer at 1.5T so at the search coil will find the induced emf by oscilloscope measurements at easy direction is 190mV and hard direction is 180mV. By using the equation (1) will find the flux density at this point is 103mT.

The primary induced emfs in the windings of the three phase transformers core were monitored by three identical voltmeters and voltages displayed during the measurement were only allowed to vary well within $\pm$ 0.4% of the induced voltage corresponding to the required flux density.

Flux distribution in the Cold Rolled Grain Oriented (CRGO) is measured by using an array of search coils to get the satisfactory result. In this investigation an array of single turn search coil is employed to measure in-plane (longitudinal and transverse) of flux density in the lamination within the transformer core as indicated in figure 5.Because the flux tends to deviate out of the longitudinal direction in some region, small 10mm search coils are used to measure localized longitudinal and transverse flux component. The locations are chosen to cover the areas where the flux is more likely to vary direction so as to find distribution of the flux behavior as shown in Figure 5.

The testing process is done by using the No-Load Test Frame. The No-Load Test Frame consisting of three windings for each three phase core are designed in order not only to avoid introducing stress to the laminations but also to keep the magnetism exactly constant in all limbs of the cores. Each winding only extends along 85% on each limb in order to enable the stagger length of the three phase core to be varied. An extra softwood base 200mm high is used to raise the overall height of the core, in order to minimize the effect of the stray flux on the localized measurements.

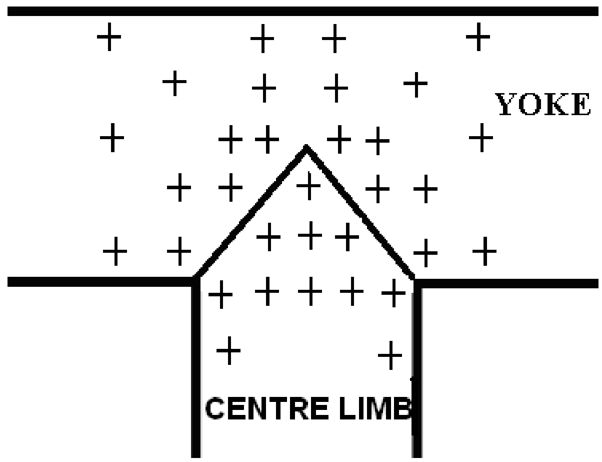

Fig. 5: Location of orthogonal search coils in the three phase core.

Installation search coil takes quite a long time in completing this step which every hole needs to be inserted with search coil. Search coil is the enamel copper coated 0.1mm diameter wire. Each set of test point (4 holes) consist of easy and hard direction where the holes of easy and hard direction will be inserted search coil and the leads are twisted together. All the holes at testing point need to be repeated the same method of inserting and twisting the leads.

After the search coils are wound and the leads twisted together, the holes are filled with polyurethane varnish to give added insulation protection. The search coil leads, which are twisted to prevent any spurious pick up, are stuck to the lamination by a polyurethane varnish. The leads from all the search coils are taken to a junction box placed in the core to prevent any interference from the core or magnetising windings.

3. Results and Discussion

The instantaneous magnitude and direction of flux at this instant is shown in Figure 6 on a larger scale. At this instant the total flux in the centre limb reaches its maximum and outer limb carry half their maximum flux. A small amount of flux deviation from the rolling direction occurs at the overlap.

The rotational flux produced in the T-joint region of the three-phase three limbs transformer core are due to a combined effect of alternating and rotating fields. This rotational flux illustrates the locus of the variation of the variation of the localized flux distribution throughout the magnetizing cycle. The rotational flux of the fundamental component (50Hz) of flux density in the 10mm staggered core at a core flux density of 1.5T is shown in Figure 7. A large rotational flux is present in the yoke area which near with centre limb. Rotational flux in this region is more circular. Some large rotational flux is also observed in or near the T-joint region.

Figure 8 shows the rotational flux of the third harmonic component of flux density in the T-joint of the core assembled with 45^0 at core flux density of 1.5T. The extent of rotating flux at this frequency is more widespread. As with the 50Hz component, a large amount of rotating flux is present in the T-joint region between the right yoke and centre limb in all four cores. A small rotating flux occurs also observed in the middle of centre limb region in the core. There is more rotational flux present in this region.

The major axes of the locus do not always follow those of the fundamental component but tend to be parallel to butt joints over much of the core where the fundamental components also deviate from the longitudinal direction of the strip in the yoke.

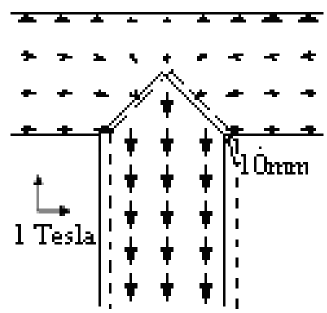

Fig. 6: Distribution of localized flux density at 45^o T-joint

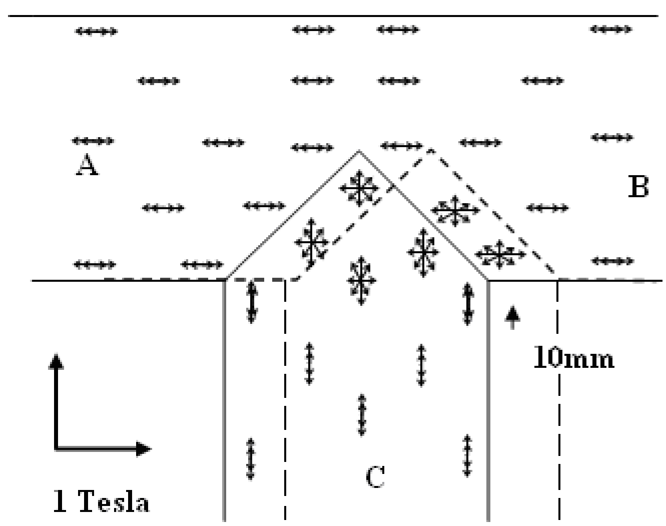

Fig. 7: Locus of the fundamental component of localised flux density in 45^0 T-joint staggered core with overlap length 10 mm at 1.5T, 50Hz

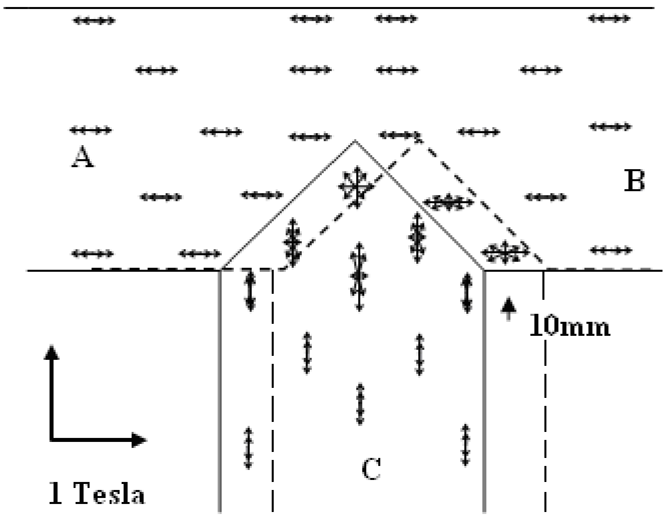

Fig. 8: Locus of the third harmonic component of localised flux density in 45^0 T-joint staggered Core with overlap length 10 mm at 1.5T, 50Hz.

A large amount of rotating flux is present in the T-joint region between the right yoke and centre limb in the core. Rotating flux in this region is elliptical with the 45^0 T-joint of core showing the highest value. A small rotating flux occurs also observed in the middle of centre limb region in the core.

Figure 9 shows the measuring point of location and localized flux densities at 45^o T-joint that are measured by using the search coil on transformer core. This result is produced by calculating localized flux density after the search coil measures the vector of the voltage in the easy and hard direction at the lamination.

The flux density in the yoke then drops rapidly as the flux distributes itself equally between the laminations. The flux density reaches a peak at the inner of 45^o T-joint; this is caused by the saturated material. The minimum flux density occurs at the outer of 45^o T-joint of transformer core lamination. The localised flux density will increase from the outer to the inner edge of the 45^o T-joint. The localised flux density at the outer 45^o T-joint is 0.218T and rises to be 0.228T at the inner edges of yoke at 45^o T-joint when the transformer core energized 1.5 T 50Hz.

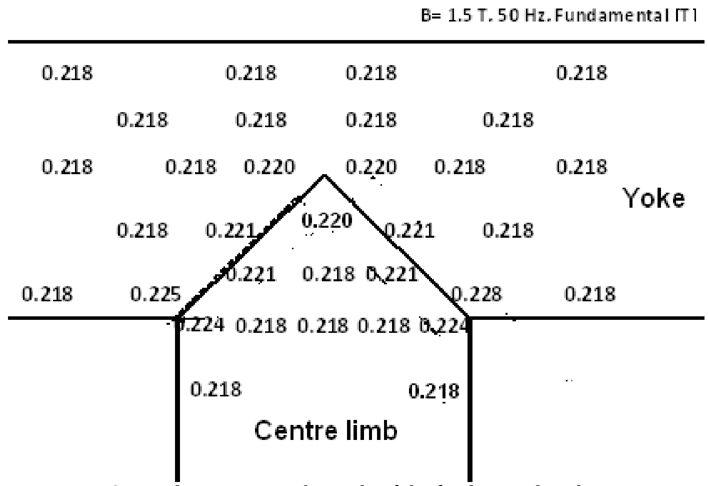

Fig. 9: Local variations in the Tesla of the fundamental peak in-plane flux density of the lamination in 45^0 T-joint of three phase staggered core with overlap length 10 mm at 1.5T, 50Hz.

The local variation in magnitude of the third harmonic component of peak in-plane flux density in the 45^o T-joint at a core flux density of 1.5T is shown in Figure 10. Most of the high third harmonic flux occurs in the T-joint region. The high third harmonic of peak in-plane flux occurs at the inner edge of right yoke passes over to the Butt-joint of centre limb is 14.765%. Harmonic occurs mostly in the T-joint where local regions are saturated and the flux deviates from the rolling direction. However, it has been confirmed experimentally that harmonics circulated in individual laminations in the limbs and yokes.

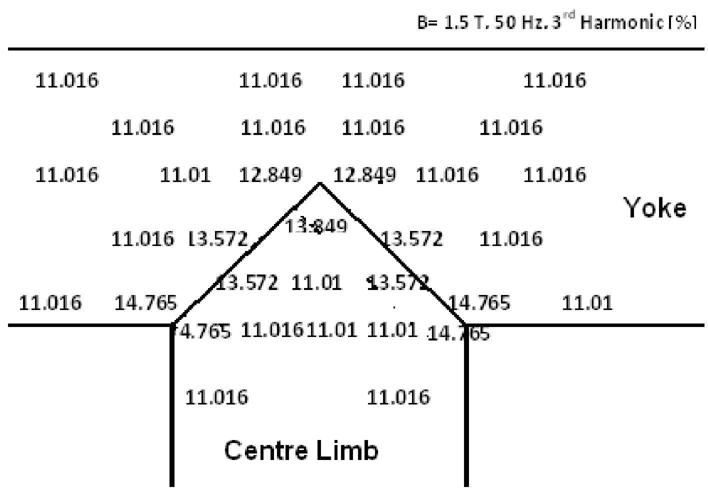

Fig. 10 Local variations in the % of the third harmonic peak flux density to the fundamental component in-plane of the lamination in 45^0 T-joint of three phase staggered core with overlap length 10 mm at 1.5T, 50Hz.

4. Conclusion

The flux distribution in cores assembled with M5 material was found varies along overlap area of the stagger at the T-joint. The localised in-plane flux density will increase from the outer to the inner of the 45° T-joint. The localised flux density at the outer edges 45° T-joint is 0.218T and rises to be 0.228T at the inner edges of 45° T-joint when the transformer core energized 1.5 T 50Hz. A large rotational flux is present in the yoke area which near with centre limb. Rotational flux in this region is more circular.

The high third harmonic of peak in-plane flux occurs at the inner edge of right yoke passes over to the Butt-joint of centre limb is 10.75%.Harmonic occurs mostly in the T-joint where local regions are saturated and the flux deviates from the rolling direction.

A small amount of flux deviation from the rolling direction occurs at the overlap, but no rotational flux is present in the joint.

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