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Evaluation of the Localised Loss Transformer Core Lamination

D.M.M. Ahmad
School of Electrical System Engineering, University Malaysia Perlis, Malaysia

Abstract: The magnetic flux has to change its direction at butt-joint meanwhile at butt-joint occur the hot spot. The hot spot can be measure using thermistor in term gradient temperature. These papers describe the result of measurement and evaluate the localized loss of 100 kVA 3phase distribution transformer assembled with the mix 60- 45° in different layers of T-joint core. Methodology that is used in this investigation is measurement of localized loss in the transformer core using no load test by arrays of thermistor on the surface of Cold-Rolled Grain Oriented (CRGO) material of transformer core lamination. The measurement involves the variation of temperature rise at each location measurement. From the result of this investigation that is the localised power loss at the outer edge of the mix 60-45° in different layers of T-joint core of three phase core is 1.22 W kg^{-1} and rises to be 1.72 W kg^{-1} at the inner edge of yoke when the transformer core energized 1.5 T 50 Hz. The localised power loss at the overlap area of the mix 60-45° in different layers of T-joint core is 1.72 W kg^{-1} and decreases to be 1.44 W kg^{-1} at the outer edge of middle limb when the transformer core energized 1.5 T 50 Hz. The several harmful effects can occur because the flux flows out of the rolling direction.

Key words: Core loss, no load loss, thermistor, temperature rise technique

INTRODUCTION

Losses in electrical steels used for transformer consume are around 5% of all electrical energy generated. A typical 1000 kVA distribution transformer might be over 99% efficiency at full load and its core loss only 1 kW. This energy waste may sound of little consequence but integrated over its lifetime it could cost more than the initial capital cost of transformer. It should be remembered that these losses occur in the core whether or not it is supplying power to a consumer and also such a transformer may be one of 8 to 10 through which energy is transmitted from the generating plant to the final user (Daut, 1992).

The behaviour of electrical steels in a magnetic field may be understood by referring to the magnetisation curve of the flux density B against field strength H for a typical magnetic material. If a material is put through a complete cycle of magnetisation, demagnetisation and remagnetisation in the opposite direction and then back to the original magnetised state, an amount of energy equal to the area enclosed by the hysteresis loop is put into the material. This energy is dissipated in the form of heat. It is proportional to both the area enclosed by the loop and the frequency (Loisos, 1998).

The major efficiency of transformer can be reached if the transformer is designed to operate near or below the knee of the magnetic performance curve for the steel core materials. This practice to avoid the core operating to the saturation region of magnetic performance curve which would cause the no load loss and magnetizing currents to increase sharply (Haidar *et al*., 2006).

In order for any of the electrical steel to be used in power applications, it should have a high electrical and high permeability at high flux density. Grain orientation processing was developed in the 1930s in the USA after finding that suitably applied cold rolling and heat treatment regimes led to the selective growth of grains having their easy directions of magnetisation in the strip rolling direction (Beckley, 2002). Cold-rolled silicon steel is supplied by the marker to guaranteed maximum total loss, at specific value of maximum flux density, usually 1.5 Tesla (Stigant and Franklin, 1980).

The design of the joint used at the junctions between yokes and limbs are particularly important to the transformer engineer since the efficient operation of the magnetic core of transformer depends on the design. Two essential functions are performed by a joint, firstly it enables the flux to transfer from one lamination to the next and secondly a joint also enables the flux to change direction in space 90° in the right angled corner and by 0° to 90° in a T joint., in the process of negotiating a corner, the flux may tend to deviate away from the longitudinal direction of the lamination. Due to the presence of anisotropy in the material, an increase in power loss is produced as flux deviates away from the rolling direction in the plane of the lamination. Increased eddy current loss is also possible due to the presence of normal flux in the overlap area (Daut, 1992).

The T-joint region is the common magnetic path at which the three generated total fluxes are superimposed. In this region unfavourable flux characteristics are appeared and the magnetic flux has to change its direction, therefore, local magnetic saturation is evident. The T-joint region is the most complex and loss influential area of 3-phase cores. Many researches less investigated the effect of the T-joint design on the power loss and flux distribution of T-joint of three-phase transformer cores. The localised power loss was measured at the corresponding locations by thermocouple technique (Moses and Thomas, 1974).

The extra losses are due to factors such as stress and temperature gradients, flux deviating from the rolling (easy) direction of magnetization and flux harmonic in localised regions of the core (Basak and Moses, 1978).

A survey carried out by Thomas and Albir, shows that the only possible temperature detectors suited for the requirement of the localised power loss measurement in laminated cores and needed in this investigation are thermocouples and thermistors (Daut, 1992).

The [001] (110) texture of grain-oriented steel is developed during a high temperature re-crystallisation process in the presence of grain growth inhibitors which suppress the development of other orientations. An important role is played by a coating applied to the surface of the strip at high temperature. It provides necessary interlaminar electrical insulation in laminated and wound cores and also imparts a beneficial tensile stress in the steel to enhance its magnetic properties and reduce the detrimental effect of mechanical stress produced during core assembly (Moses and Leicht, 2007).

The objective of this investigation is to evaluate the localised loss of the transformer core built from electrical steel (M5) with 3% silicon iron assembled with the mix 60-45° in different layers of T-joint core by temperature technique.

Case study: The core of the three phase 100 kVA distribution transformer, three limbs built from 3% Silicon Iron (CRGO), assembly the mix of 60-45° in different layers of T-joint core and mitred lap corner joint as shown in Fig. 1. The core has 550×580 mm with the limbs and yokes 100 mm wide as shown in Fig. 1 and 2 and assembled from 0.3 mm thick laminations of CRGO. The transformer core is a model in PhD project from 2006 until know at the Electrical Energy and Industry Electronic System (EEIES) research cluster University Malaysia Perlis (UniMAP).

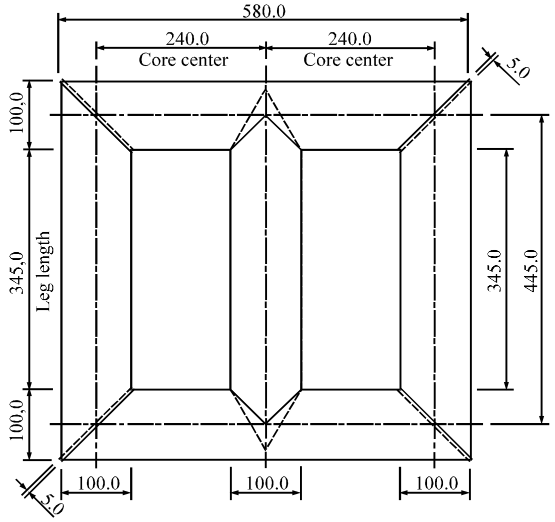

Fig. 1: Dimension (mm) of 100kVA transformer model

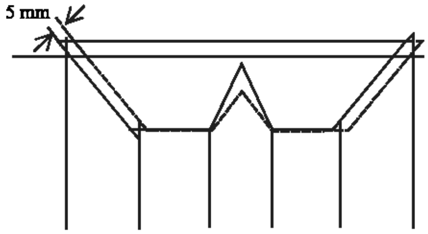

Fig. 2: Transformer core type the combination of 60-45° T-joint core

EXPERIMENTAL APPARATUS AND MEASUREMENT TECHNIQUE

The three phase transformer core with overall dimensions is shown in Fig. 1 and 2.

Several precautions are taken when locating the thermistor within the lamination. The inaccuracies in the initial rate of rise of temperature are due to the heat contribution from the adjacent laminations, which might be at a difference temperature. In order to prevent transfer of heat to other laminations a piece of 0.10 mm thick self adhesive paper tape was stuck on the back of the lamination under investigation to insulate it from the adjacent one. The thermistors were firmly fixed to the lamination by the 0.10 mm thick self adhesive tape to stop any heat transfer from the lamination facing the thermistors. Use of the paper tape enables the sensors to be removed after use without damage. Localised loss on the Cold Rolled Grain Oriented (CRGO) is measured by using an array of thermistor to get the satisfactory result. The locations chosen must cover the areas where the loss is more likely to vary direction so as to find distribution of the flux behavior as shown in Fig. 3.

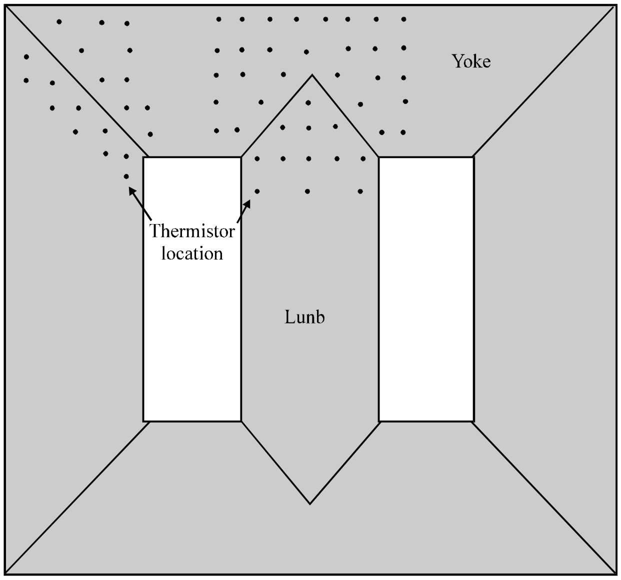

Fig. 3: Location of thermistor on the layer of lamination in the three phase core

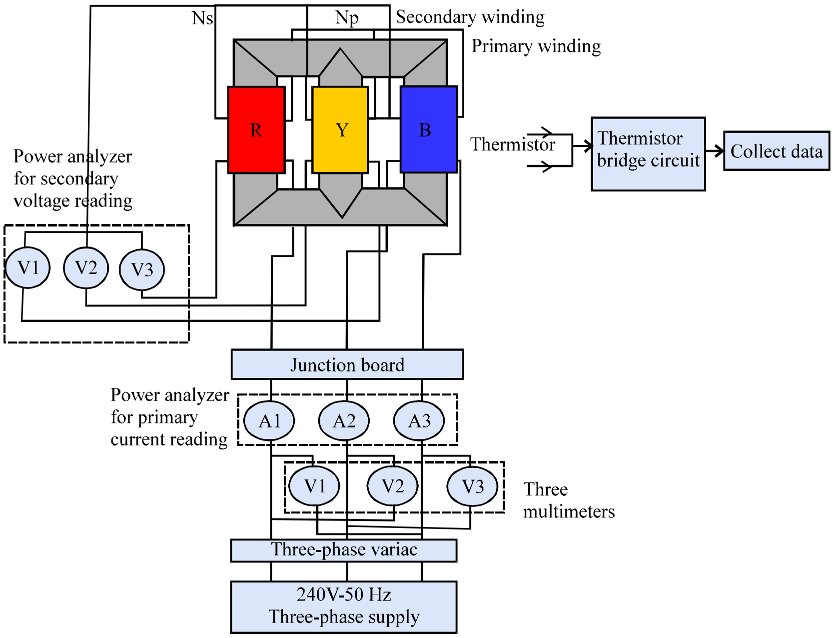

Fig. 4: The diagram of the methods that used to measure the localised power loss

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 as indicated in Fig. 4. The core could be energized to 1.5 T (50Hz).

Loss will be obtained by calculating the multiple of gradient temperature on the lamination to relationship constant of gradient temperature and power loss reference. The power loss reference is obtained by using Epstein test measurement with comparison temperature rise in the middle of the limb of core lamination and nominal loss at adjusted 1.5 T, 50 Hz.

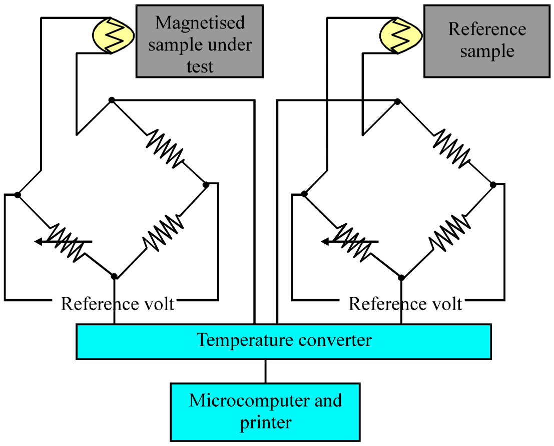

Fig. 5: Block diagram of the circuit for measuring localised power loss

The relationship between loss and temperature rise will be found from the equation as follows:

$$P_{loss} = C\ dT/dt \qquad (1)$$

where, C is the relationship constant that is C = 14 [W-min kg^{-1}-°C] dT/dt is temperature rise from measurement.

It is important to note that thermistor measures the temperature difference between two points, not absolute temperature. In traditional applications, one of the junctions that are the cold junction is maintained at a known (reference) temperature, while the other end is attached to a probe.

In this investigation the localized loss in the three-phase transformer cores are measured employing the temperature method as indicated in Fig. 5.

RESULTS

The localised power loss variations across the T-joint of the three phase core were measured using the thermistor method. The distribution of localised power loss at various positions across and along the lamination in the core was measured employing thermistors variations following the T-joint pattern.

Figure 6 shows the measuring point of location and localised power loss that are measured by using temperature method at the mix 60-45° in different layers of T-joint cores of three phase core. This result is produced by calculating the multiple of gradient temperature on the lamination to relationship constant of gradient temperature and power loss reference.

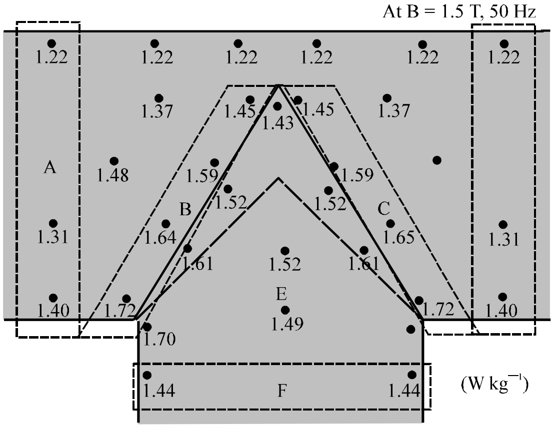

Fig. 6: Distribution of the localised power loss in the mix 60-45° in different layers of T-joint of three phase core at 1.5 T, 50 Hz

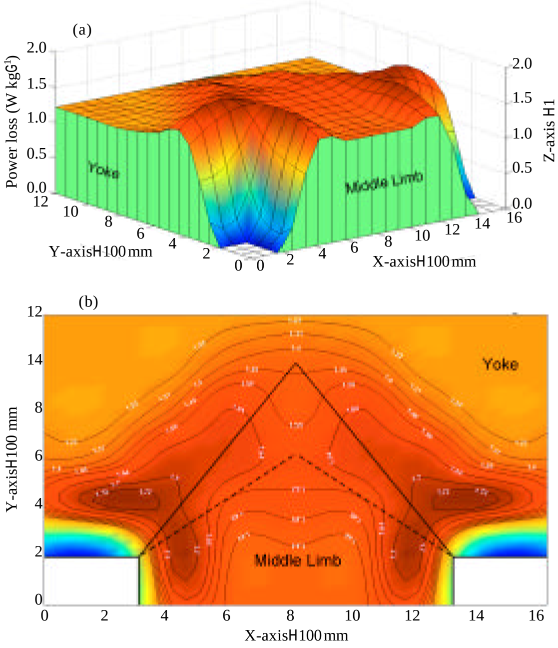

Fig. 7: Localised power loss distributions in the mix 60-45° in different layers of T-joint core at core flux density of 1.5 T, 50 Hz

Figure 7 shows the mesh graph of the localised power loss measured by using the temperature method at the mix 60-45° in different layers of T-joint core of three phase core of transformer core lamination. This mesh graph is drawn by using the Matlab software based on the result in the Fig. 6. The power loss at the mix 60-45° in different layers of T-joint core of three phase core shows that the power loss reaches a peak at the inner edge of butt joint of yoke of the mix 60-45° in different layers of T-joint core of three phase core and the minimum power loss occurs at the outer edge of yoke of the mix 60-45° in different layers of T-joint core of three phase core of transformer core lamination. The localised power loss will increase from the outer edge to the inner edge of yoke of the mix 60-45° in different layers of T-joint core of three phase core. The localised power loss at the outer edge of the mix 60-45° in different layers of T-joint core of three phase core is 1.22 W kg^{-1} and rises to be 1.72 W kg^{-1} at the inner edge of yoke of the mix 60-45° in different layers of T-joint core of three phase core when the transformer core energized 1.5 T 50 Hz.

The localised loss still high at the overlap area of the middle limb and will decreases when far away from the middle limb. The localised power loss at the overlap area of the mix 60-45° in different layers of T-joint core is 1.72 W kg^{-1} and decreases to be 1.44 W kg^{-1} at the outer edge of middle limb of the mix 60-45° in different layers of T-joint core when the transformer core energized 1.5 T 50 Hz.

DISCUSSION

The distribution of the localised loss in the cores presented in the result, Fig. 6 shows that the loss gradually decreasing from the inner to outer edges of the T-joint lamination. The presence of high loss in this area is a result of high fundamental in-plane and normal flux density. This phenomenon also occurs in research by Basak and Moses (1978) and Daut (1992).

The highest loss region exists in the core material situated above the butt-joint in the alternate layers of laminations. This is a direct result of the combined effect of high fundamental and harmonic components of flux density and high normal flux density. Uneven edges found in 3% silicon iron strips created extra air gap at the T-joint region along the butt-joint as shown in Fig. 8. This extra air gap with high reluctance has an influence on flux and loss distribution in this region. The highest peaks of power loss occur at the upper edges in the core. In-plane and normal flux were also maximum in these regions due to the high reluctance paths of alternating laminations provided by the combination of the butt-joint, which allows more flux to transfer from alternating laminations. The increase in peak flux density towards both edges of the middle limb was observed in previous work by Daut (1992) on POWERCORE material.

The T-joint has a greater overlap area between two adjacent laminations than that of the corner region. Localised power loss increases in the overlap areas between two adjacent laminations. These results of the high losses are associated with high in-plane, normal and rotating flux.

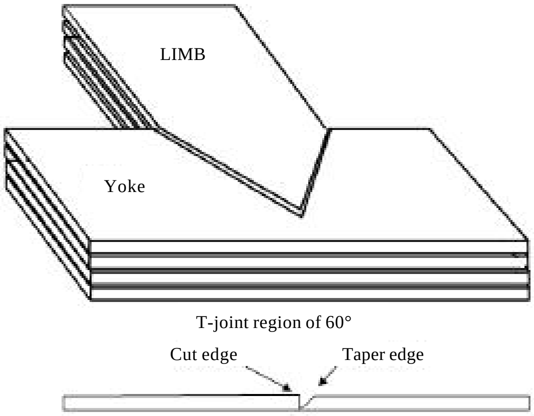

Fig. 8: The air gap between the cut edge and the tapered edge at the T-joint region

By far the highest loss occurs in the yoke lamination along the butt-joint in alternate layers in the T-joint region. As stated earlier, the extra air gap due to the uneven edges found in the 3% silicon iron strips increase the in-plane and normal flux and consequently increased the localised power loss still further. The highest localised power loss occurs in this region indicating that if the extra air gap is improved by improving the manufacturing process, the average localised power loss of the T-joint region consequently the overall power loss of the core, can be reduced still further.

The result to that found by Basak and Moses (1978), on the three phase transformer core assembled with 45-90° T-joint core from 3% silicon iron material that the average localised losses at T-joint is 1.6 W kg^{-1} when flux density of 1.5 T. It shows that the result of the three phase transformer core assembled with the mix 60-45° in different layers of T-joint core is lower 9% than the three phase transformer core assembled 45-90° T-joint core.

CONCLUSION

The localised loss distribution on cores assembled with 3% Silicon iron materials varies along overlap length of the mix 60-45° in different layers of T-joint of core laminations. The localised power loss will increase from the outer edge to the inner edge of the mix 60-45° in different layers of T-joint core. The localised power loss at the outer edge of the mix 60-45° in different layers of T-joint core of three phase core is 1.22 W kg^{-1} and rises to be 1.72 W kg^{-1} at the inner edge of yoke of the mix 60-45° in different layers of T-joint core of three phase core when the transformer core energized 1.5 T 50 Hz. The

T-joint of core lamination occur several harmful effects caused by the flux flows out of the rolling direction and there are the harmonic content at that point.

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