Asian Journal of Scientific Research 6 (1): 115-121, 2013
ISSN 1992-1454 / DOI: 10.3923/ajsr.2013.115.121


# Effect of Rubber Material Clamp on Core Loss of 3-phase 100 kVA Transformer Core

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## ABSTRACT

This study describes the result of an investigation on the effect of rubber material clamp of core lamination with stagger yoke on three 100 kVA three-phase distribution transformer. The investigation involves the variation of power loss, building factor and the total harmonic distortion of flux. The method that used in the measurement is a no load test. Loss at the core of the clamps of wood is lower than the core without clamps and using rubber materials clamp. The Total Harmonic Distortion (THD) of flux is larger in the core using wood clamp material and smaller in the core assembled without clamp, over the whole flux density range. Using wood material clamp of core lamination in transformer core is more efficient than using the other two types of transformer core lamination. In which the use of rubber in addition as clamp material will increase the losses in transformer core due to the surface area of core clamp is inhibit and not easily released to air in a short period.

**Key words:** Transformer core, power loss, clamp material, rubber, building factor

## INTRODUCTION

It is important to measure the overall power loss of the material when assembled in transformers and to evaluate and understand the variation of Building Factor (B.F.) which is the ratio of core loss to nominal loss (Haidar *et al.*, 2006; Qader and Basak, 1982; Daut, 1992). From the calculation result of building factor will be obtained later on the appropriate design.

In making the core of the transformer is required once a clamp with a view to holding a core when it was founded and use clamp have a lot of research done by researchers. As the use of compression stress will increase the loss at the core (Sasaki *et al.*, 1987) but as a result of the clamping pressure is not expected to arrive at the core of transformer losses increase to 20% (Daut, 1992). For the best configuration of the core can be achieved by estimates obtained from the local loss of flux changes among lamination (Yao *et al.*, 2007). Hence, shows that the using of materials clamp on the core is more important than the configuration of the core connection. (Basak *et al.*, 1990). The various factors which contribute to the total no load loss and magnetising power of transformers it is difficult to quantify directly the effect of stress.

According to Norman P. Goss, that the grain orientation process material will have easy directions of magnetisation in the strip rolling direction (Beckley, 2002) with the purposes to facilitate the flow flux in the in-plane and normal direction.

The objective of this investigation is to know the rubber material clamp effect on power loss of the transformer core of identical geometry built and the grain oriented of electrical steel (M5) with 3% silicon iron assembled without clamp, with wood material clamp and combination of wood and rubber material clamp.

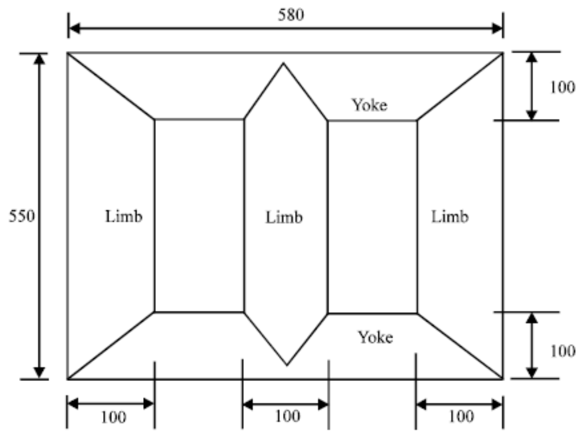


Fig. 1: Dimension (mm) of 100 kVA transformer core model

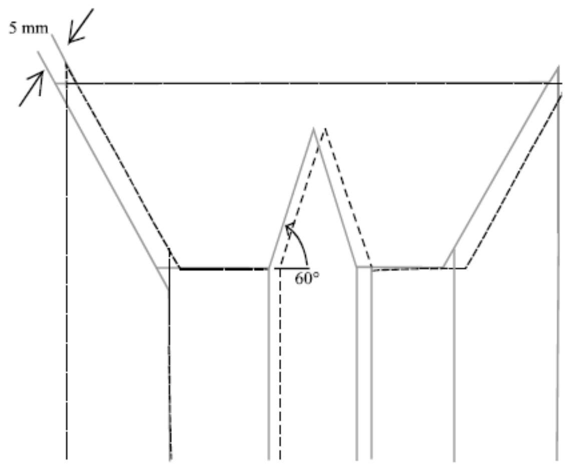


Fig. 2: Transformer core type of 60° T-joint core

**Experimental apparatus and measuring techniques:** The three-phase of three limbs stacked core are assembled with T-joint 60° mitred overlap corner joints are shown in Fig. 1. The outer core dimensions are 580×550 mm with the limb of 100 mm wide. The three cores are assembled using 0.3 mm thick of laminations of M5 grain-oriented silicon iron (CGO) with a nominal loss of 1.12 W $kg^{-1}$ at 1.5 T and have stagger yoke of core with overlap length of 5 mm from other adjacent lamination when setting the transformer core lamination as shown in Fig. 2.

Each transformer core comprises of 15 layers. One transformer has without clamp. Other transformers have clamp material like first will be clamped use wood and the second will be clamped use combination of wood and rubber. Sample clamp model as shown in Fig. 3. The pressure will be taken at 12, 16 and 20 Nm.

Each core could be energized 1-1.8 T with less than 1.5% third harmonic distortion and the power loss is measured with repeatability better than±1% using a three phase power analyzer.

**Experimental result:** Figure 4 shows the variation of overall power loss with flux density in the three phase cores for without clamp, with wood material clamp and combination of wood and rubber

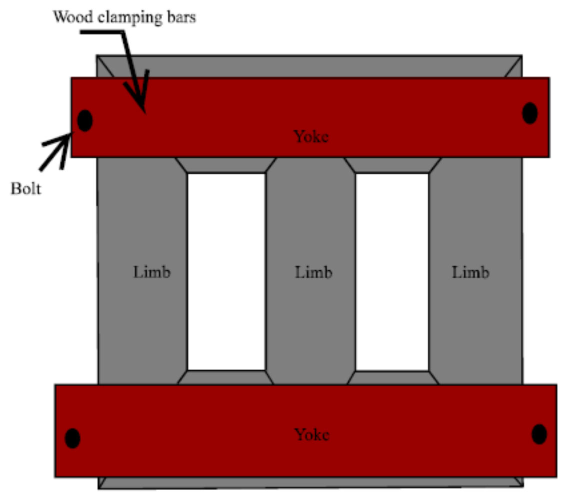


Fig. 3: Transformer core assemble with clamping stress

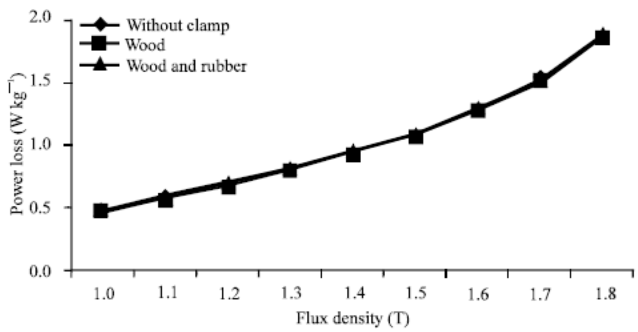


Fig. 4: Power loss from measurement for without, wood and combination wood and rubber clamp material of core lamination of transformer core

material clamp of core lamination of transformer core. The power loss of the transformer core assembled with wood material clamp increases up 1.29 and 0.83% when the transformer core without clamp and with combination of wood and rubber material clamp at flux density of 1.5 T, 50 Hz, respectively.

The BF of each core reaches a peak at around 1.4 T as shown in Fig. 5. The BF of the core assembled with wood clamping material is lower than without clamp and with combination wood and rubber clamp material over the whole flux density range. The use of wood material clamp is suitable material for construct which is the calculation result of building factor shows 1 that is the actual result is similar with nominal loss of transformer core.

Figure 6 shows that the loss of core assembled 20 Nm clamping stress of core using wood clamp material is lowest than the core assembled with 12 and 16 Nm clamping stress of core using wood clamp material, over the whole flux density range. In transformer design application of the 20 Nm clamp stresses will be used. The result shown is in accordance with opinion of Daut (1992).

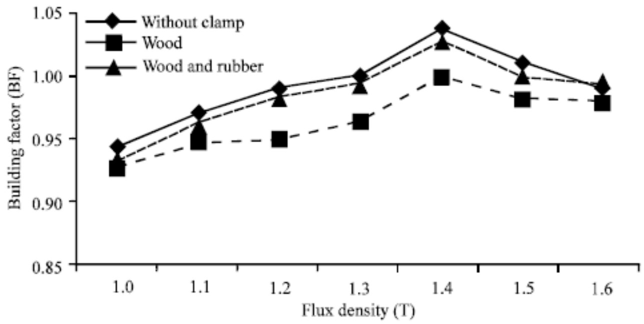


Fig. 5: Building factor for without, wood and combination wood and rubber clamp material of core lamination of transformer core

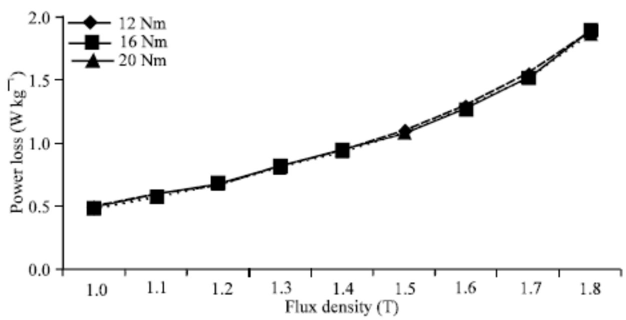


Fig. 6: Power loss from measurement for transformer core using wood clamp material

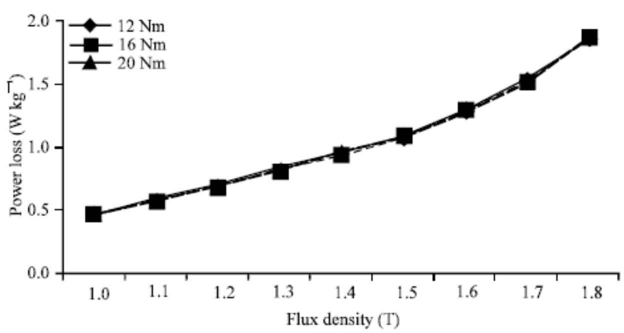


Fig. 7: Power loss from measurement for transformer core using combination of wood and rubber clamp material

Figure 7 shows that the loss of core assembled 20 Nm clamping stress of core using combination wood and rubber clamp material is lowest than the core assembled with 12 and 16 Nm clamping stress of core using combination wood and rubber clamp material, over the whole flux density range. Application of 20 Nm clamping stress could still be used than other clamping stress that investigate.

Figure 8 shows that the Total Harmonic Distortion (THD) of flux is larger in the core using wood clamp material and smaller in the core assembled without clamp, over the whole flux density range. Which is application of rubber material clamp also can reduce the total harmonic distortion but the data record for the without clamp of core shows the lowest data of total harmonic distortion because in the without clamp of core lamination position is not stable.

## DISCUSSION

The transformer core without material clamp will cause the air gap among layers of lamination. Hence, the flux will be existing from laminate through air gap in normal direction as shown in Fig. 9. It will cause the leakage flux. The flux which is stay in the laminate is the useful flux. The loss that produces by transformer core is highest than the core using clamp as shown in Fig. 4. So, it will reduce the efficiency of transformer core. This view is also explained by the Yao *et al.* (2007) and Basak *et al.* (1990).

With using the material clamp as shown in Fig. 10 and 11 will reduce the air gap among laminate and flux full flows in plane direction and also the noise and joint air gaps at corners and T-Joint according to Basak *et al.* (1990). With increases clamping stress so the power loss of transformer core will decreases as shown in Fig. 6 and 7.

Adding rubber material as the clamp material in Fig. 11 will increase heat on the surface of core so the loss is higher than using wood clamp material only as shown in Fig. 4. Which is the rubber makes heat on the surface of core inhibited and not easily released to air in a short period because

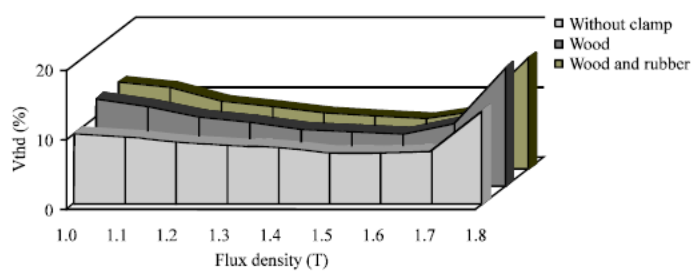


Fig. 8: Total harmonic distortion of flux for without, wood and combination wood and rubber clamp material of core lamination of transformer core

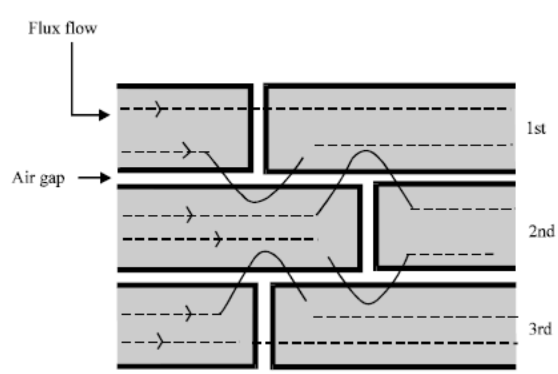


Fig. 9: Core lamination model without clamp

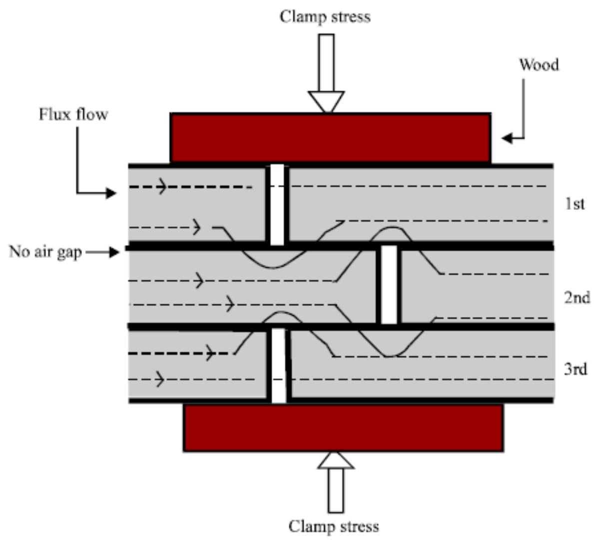


Fig. 10: Core lamination model with wood clamp material

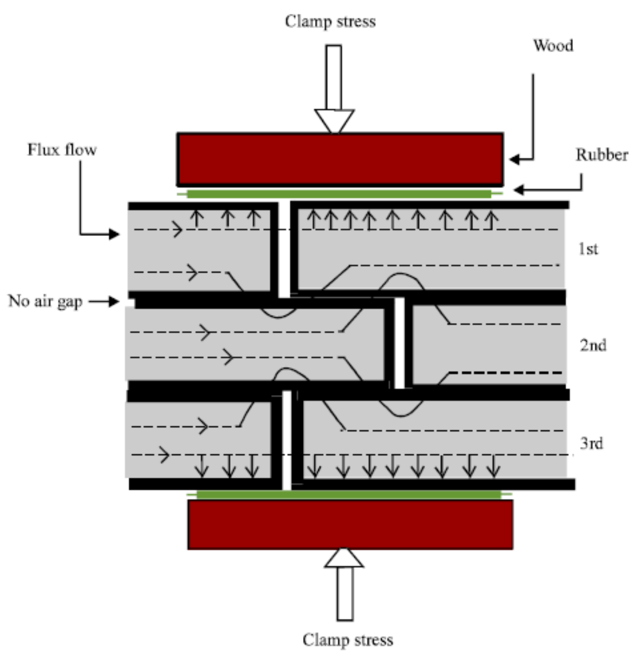


Fig. 11: Core lamination model with combination wood and rubber clamp material

rubber is isolator function. The rubber cannot stop harmonic vibration as shown in Fig. 8 because rubber has the elasticity whiles the wood only static.

It is suitable to developed transformer core using wood clamp material based on Fig. 5 because to reduce losses on the core is best to use the wood clamp material only.

## CONCLUSION

From the result of this investigation it is obvious that if the core is assembled with the wood clamp material of core lamination we can find smaller power loss, smaller Building factor but higher total harmonic distortion of flux. In other words, the core assembled with the wood clamp material of core lamination is still more efficient than the core assembled without clamp and the combination of wood and rubber clamp material of core lamination.

Using the rubber makes heat on the surface of core inhibited and not easily released to air in a short period and also cannot stop harmonic vibration that occurs on transformer core.

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# Asian Journal of Scientific Research

ISSN 1992-1454

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Asian Journal of Scientific Research 6 (1): 122-128, 2013
ISSN 1992-1454 / DOI: 10.3923/ajsr.2013.122.128


# Analyze Eddy Current Loss in the Three Phase 100 kVA Transformer Core with the Mix 60°-0° T-joint Core

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## ABSTRACT

The study of eddy current loss has done much research and this research is to study the influence of eddy current which cause higher energy loss at higher frequencies of magnetization. This paper is about analyses of eddy current loss in 100 kVA 3 phase distribution transformer assembled with the mix 60°-0° T-joint and mitred lap corner joint with stagger yoke of 5 mm. The loss has been measured using no load test with variable frequency. The eddy current loss rises to be 39.1% when the transformer core is energized at flux density of 1.5 T and frequency of 55 Hz. increase of the frequency will cause the increase of power loss in the transformer core. It caused not all the flux flowing into the middle limb or other limb at difference instant in time of transformer core because there is still flux left in the area of butt-joint and the core loss that produced at the frequency more than 50 Hz will known as classical eddy current loss.

**Key words:** Frequency, flux density, magnetization, ferromagnetic core

## INTRODUCTION

Hysteresis and eddy current losses include the no-load loss (Olivares-Galvan *et al*., 2010). The influences of eddy currents cause higher energy loss at higher frequencies of magnetisation which is visible in the increased width of the B-H loop. The eddy currents contribution to the power loss can be calculated as follow:

$$P_e = k\,B_{peak}^{2}\,f^{2}\ \ [\mathrm{W\,kg^{-1}}] \tag{1}$$

where, k is constant which is depend on the material, $B_{peak}$ is peak flux density [T], f is frequency, [Hz].

As it can be seen from Eq. 1 the eddy current component of power loss is proportional to the frequency supply. Therefore, the magnetic core of transformer has the power loss and reaches high values at higher frequencies (Leite *et al*., 2012). Investigation even with the use of a transformer core model of ferromagnetic material shows the core loss increased with increasing frequency (Chandrasena *et al*., 2006).

Hysteresis loss cannot be as easily estimated as the eddy current loss but at very low magnetising frequency the eddy currents become negligible and only the hysteresis component is present. This allows using a method of separating the power loss into eddy current and hysteresis component which is thought to be linearly, is one on frequency as shown in Fig. 1 (Zurek, 2005).

However, as it is shown in Fig. 1, the calculated eddy current loss added to the hysteresis loss obtained by low frequency measurements does not result in the total

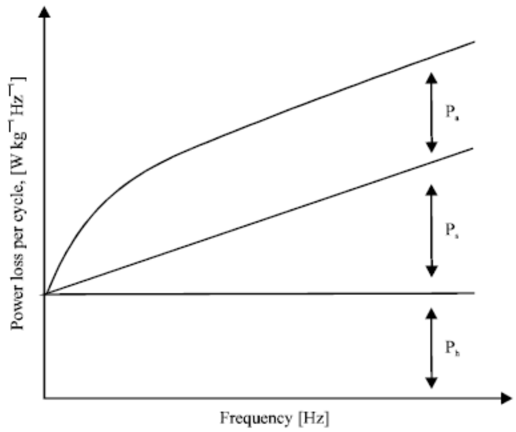


Fig. 1: The concept of separating the power loss into hysteresis and eddy currents components, $P_h$: Hysteresis loss, $P_e$: Eddy current loss, $P_a$: Anomalous loss (excess loss), (Zurek, 2005)

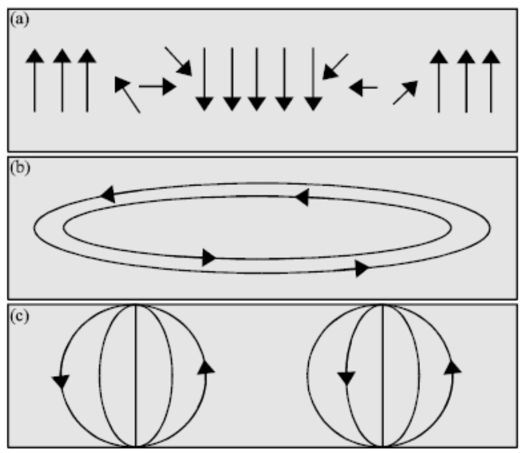


Fig. 2(a-c): Summary of core loss mechanism, (a) Hysteresis losses, (b) Classical eddy current losses and (c) Excess losses (Mthombeni, 2006)

measured power loss. The difference has been named as anomalous loss or excess loss. Therefore, the equation for total power loss can be written as (Zurek, 2005):

$$P_{tot} = P_h+P_e+P_a \ [\text{W kg}^{-1}] \tag{2}$$

where, $P_{tot}$ is total power loss, $P_h$ is hysteresis loss, $P_e$ is eddy current loss, $P_a$ is anomalous loss.

Eddy current loss in the transformer can also be influenced by the input signal (Mayuri *et al.*, 2010; Liu *et al.*, 2008; Yao *et al.*, 2007). In which the eddy current loss to the input through the PWM inverter is 1.196 times larger than the eddy current losses with sinusoidal supply (Mayuri *et al.*, 2010). While in the classical eddy current loss in the frequency of 50, 100 Hz and induction 1.3 and 1.5 T obtained eddy current loss reduction component ranges 40% in the low-frequency magnetization (Yao *et al.*, 2007).

According to Mthombeni (2006) as shown in Fig. 2 summarizes the three core loss mechanism. Domain walls are shown moving towards lamination edge, at speed v, the applied field intensity is coming out of the page and the middle domain is growing. For classical eddy current models overestimate losses at higher frequency.

Eddy currents are minimized in transformer cores by using thin laminations of electrical steel which reduces associated classical eddy current losses which in turn are strongly dependent on the steel thickness. In a perfectly assembled core, the eddy current paths are restricted to individual laminations (Mazurek *et al.*, 2010). Effect of the plate thickness on eddy current loss also can investigated by EC sensor coil method (Le Bhan, 2003).

Grain oriented steel sheet used in transformer cores is covered on both sides with a thin inorganic coating, applied onto the glass film layer that forms during annealing. A number of standard test procedures are available to assure the quality of this surface insulation (Schulz *et al.*, 2010).

The behaviour of this investigation was to analyze the eddy current loss of the transformer core built from electrical steel (M5) with 3% silicon iron assembled with the mix 60°-0° T-joint and mitred lap corner joint with stagger yoke of 5 mm by using no load test with sinusoidal input signal.

## MATERIALS AND METHODS

The main apparatus consists of a model cores three-phase 100 kVA transformer assembled with three limbs core with T-joint cutting angle the mix 60°-0° assembled from CRGO (M5 grades) 3% Si-Fe material. The core has 550×580 mm with the limbs and yokes 100 mm wide as shown in Fig. 3. The experimental cores assembled with the mix 60°-0° T-joint, mitred overlap corner joints with staggered yoke and overlap length is 5 mm as shown in Fig. 4 and assembled from 0.3 mm thick laminations of M5 grain-oriented silicon iron (CRGO). Associated instruments are used to measure fundamental and third content of the power loss (Maizana, 2011).

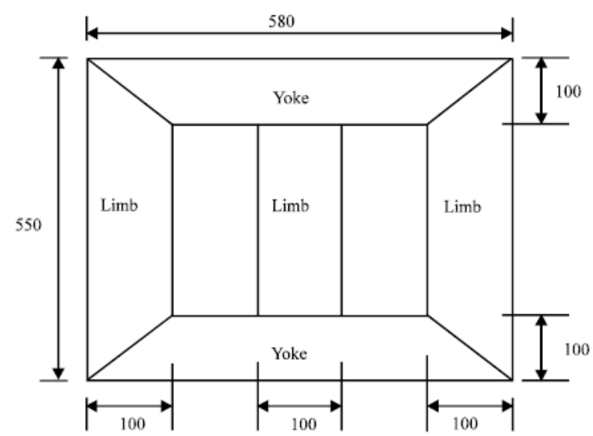


Fig. 3: Dimension (mm) of 100 kVA transformer model

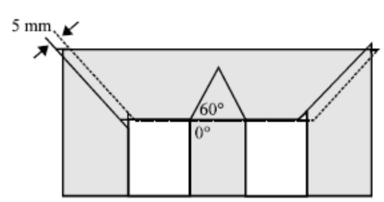


Fig. 4: Transformer core type with the mix 60°-0° T-joint

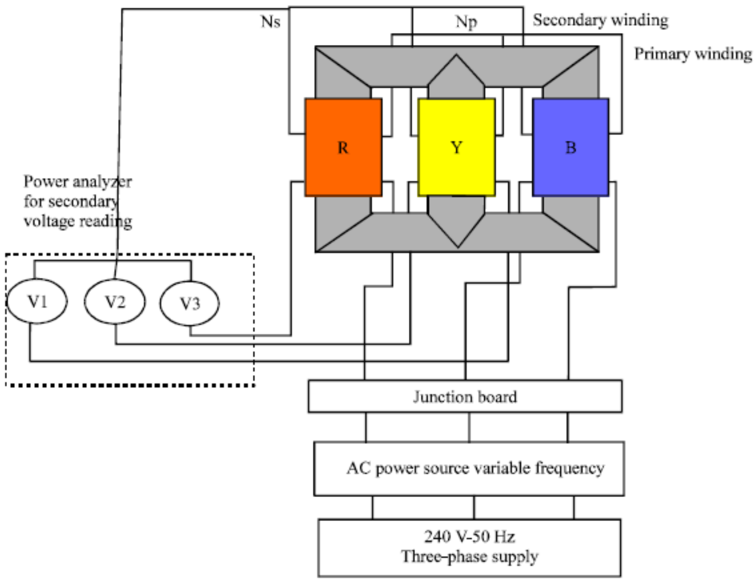


Fig. 5: Diagrams of the methods that used to measure the eddy current losses, Ns: Secondary winding turns, Np: Primary winding turns, R: Red colour cable, R: Yellow colour cable, B: Blue colour cable and V1, V2, V3: Voltmeter

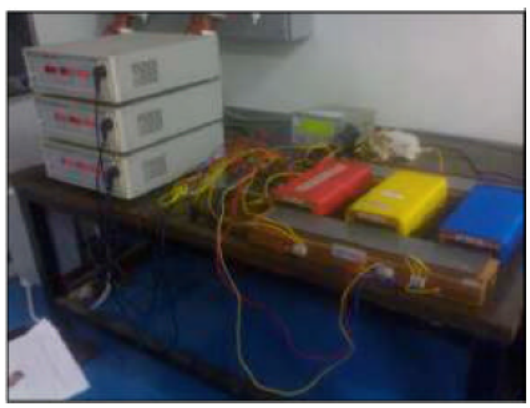

Fig. 6: The actual circuit

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 is 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 to enable the stagger length of the three phase core to be varied. An extra softwood base 200 mm high is used to raise the overall height of the core, to minimize the effect of the stray flux on the localized measurements. The core could be energized 1-1.8 T at 50 Hz with less than 1.5% third harmonic distortion and also with variable frequency at 1.5 T and the power loss is measured with repeatability better than ±1% using a three phase power analyzer as shown in Fig. 5 and the actual circuit is shown in Fig. 6.

## RESULTS AND DISCUSSION

From the measurement results obtained some data such as the loss of the core for each different frequency. Data presented in graph form such the following shows that picture. Signal input to this study similar to that used in the study by Mayuri *et al.* (2010).

Figure 7 shows the variation of overall power loss with flux density in the three phase cores. The core with adjusted at frequency of 50 Hz has lowest loss over the complete range of flux density. This situation also applies to the investigation conducted by the Yao *et al.* (2007). At this frequency, the loss that occurs in the transformer core is assumed as hysteresis loss only. The result of this investigation shows the core loss is 1.508 W $kg^{-1}$. Figure 8 is shown the variation of power loss with frequency in the three phase core. The graph shows that the losses will increases with increases of the frequency. The loss that produces in this investigation is classical eddy current. As shown in concept by Zurek (2005). The eddy current loss is rise to be 39.1% at frequency of 55 Hz, flux density of 1.5 T. The variation of eddy current loss that obtains from measurement as indicated in Table 1.

Table 1: Eddy current losses refer frequency

| Frequency (Hz) | Eddy current loss (W $kg^{-1}$) |
|---|---|
| 50 | 0.000 |
| 51 | 0.168 |
| 52 | 0.247 |
| 53 | 0.270 |
| 54 | 0.367 |
| 55 | 0.392 |

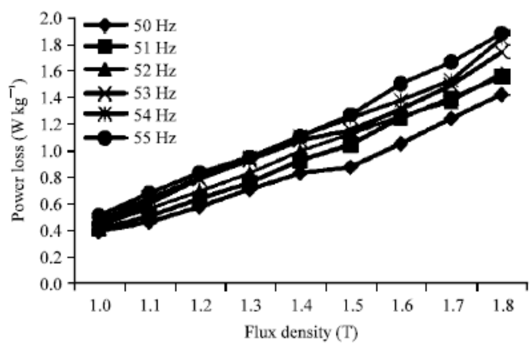


Fig. 7: The variation of overall power loss with flux density at different frequencies

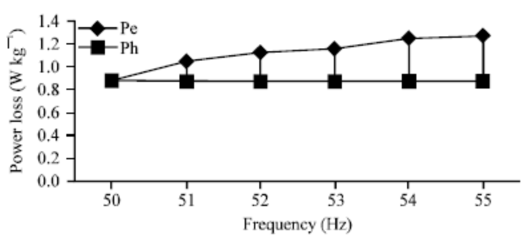


Fig. 8: The variation of hysteresis loss (Ph) and eddy current loss (Pe) with frequencies at 1.5 T flux density

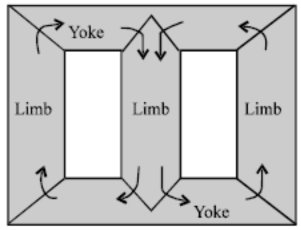


Fig. 9: The flux flow in transformer core

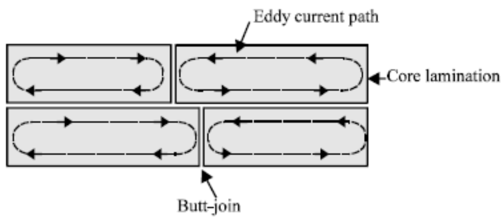


Fig. 10: The flux flow in core lamination

Where frequency supply increases more than 50 Hz, these will makes eddy current loss increase and at the same time as showed in Eq. 2, the flows of flux through the lamination plate also increase as showed in Fig. 8. During the investigation, there is a lot of thing regarded to the eddy current losses can be explain clearly. The results obtained show the variation of the value is dependent on the variable flux density and frequency respectively as showed in Eq. 1. For example, the flow of the flux at the joint and what happen to the movement of flux when the value of flux density and frequency increased. Since there are air gap among the joint, the movement of flux stuck on the joint and this will makes the flux flows to the other lamination. In this condition not all the flux flowing towards into the middle limb or other limb at difference instant in time of transformer core because there is still flux left in the area of butt-joint as showed in Fig. 9. The flux will be circulated in the area as showed in Fig. 10. The circulating flux then will present hot spot on the joint and it is known as eddy current. These phenomena occurred due to the laminate as described by Mthombeni (2006) and Mazurek *et al.* (2010).

## CONCLUSION

From the result of this investigation is found that the smallest power loss of transformer core at the core when adjusted in frequency of 50 Hz which are the rotational fluxes make large contributions to the total power loss in three phase transformer core.

With increase of the frequency will cause the increase of power loss in the transformer core. It caused not all the flux flowing towards into the middle limb or other limb at difference instant in time of transformer core because there is still flux left in the area of butt-joint and the core loss that produced at the frequency more than 50 Hz will know as classical eddy current loss.

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