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Evaluation of Transformer Magnetizing Core Loss

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Abstract: Loss in transformer core is the electrical power lost in terms of heat within the core of transformer, when core is subjected to AC magnetizing force. It is composed of several types of losses such as Hysterics loss, eddy current loss within individual laminations and inter-laminar losses that may arise if laminations are not sufficiently insulated from each other. To assess the level of no load loss relative to the occurrence of an inaccurate manufacturing of transformer core, a quantitative measure is often considered. The objective of this research is to study the magnetic behavior of transformer core and compare the performance of building factor is comparable to the calculated values. Open circuit tests were conducted on 1000 kVA transformer with 90°T-joint and 45° mitred corners joint to determine the efficiency of the transformer. The results showed that the building factor is useful index in assessing the impact on the core.

Key words: Transformer core, no load loss, magnetic behavior, building factor

INTRODUCTION

A transformer is designed to transfer electrical energy from one AC system voltage to another with a high efficiency. This performance characteristic is achieved through a combination of the special dimensions of the transformer and the materials that are used in its fabrication. The clamping arrangement also influences the dynamic behavior of a core. Accurate mechanical modelling of the core structure is important for a proper description of its dynamic behavior (Ravish *et al.*, 2004). No load losses are very small part of the power rating of transformer, usually less than 1% since these losses are essentially constant over the lifetime of the transformer (do not vary with load), they generally represent a sizable operating expense especially when energy cost are high, therefore accurate measurement are essential in order to evaluate individual transformer performance accurately. 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 avoids the core operating to the saturation region of magnetic performance curve which would cause the no load loss and magnetizing currents to increase sharply (Ahmed *et al.*, 2006).

The exciting current and no load loss or core loss is the energy required to establish (excite) the magnetic flux in the core. To obtain accurate values of no load losses, the wave shape of the applied voltage must be a close as possible to a sine wave. The several types of core loss are: Hystereses Loss is the power expended in a magnetic material as a result of the lack of correspondence between the changes in induction resulting from the increase or decrease of magnetizing force, which is a result of it being cyclic, i.e., alternating. Eddy current is the energy lost by the circulating current induced in the metal by the variation of magnetic fields in the metal. Therefore, more uniform the magnetic field in the metal, lower the eddy current losses. Inter-laminar loss is the power expended in a stacked or wound core as a result of weak insulation resistance between laminations resulting in the flow of eddy current within a core, across lamination sheets.

Steel sheet of very inferior quality compared to present days standards were used in the very early days of transformers manufacturer and magnetic ageing caused a great deal of trouble at that time. Resulting from the aging effect, the hysteresies component of the iron loss in a transformer magnetic circuit was found to have trebled in value during the very early of transformers it was subsequently found that very small quantities of silicon alloyed with low carbon content steel produced a material with low hysteresis losses and high permeability (Stigant and Franklin, 1980). Transformer cores are built from thin sheets of steel. These sheets are manufactured

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specifically for use in transformer. Core steel low carbon content <0.1%. Increased carbon content has a detrimental influence on the hysteresis loss as well as the ageing properties. Core steel is alloyed with silicon (Si). Silicon increases the specific electrical resistance, which again reduce the eddy current loss in the core. Increased silicon content makes the core steel brittle, therefore the content is kept below 3%. Today only grain-oriented steel is used by cold rolling the steel sheets. The magnetic domains in the steel sheet will tend to be oriented in the rolling direction. Cold-rolled silicon steel is supplied by the marker to guaranteed maximum total loss, at a specific value of maximum flux density, usually 1.5 teslas (Stigant and Franklin, 1980). Transformer supplier offer transformers with the user requested power rating and voltage ratio, which in addition fulfill certain dielectric, thermal and mechanical requirements. A transformer may be designed to achieve the lowest possible purchase price. The losses of such a transformer are relatively high and the operational costs will be accordingly high (IEC and ABB, 2004).

In this study a practical approach to evaluate transformer core loss using building factor index, have been carried on 1000 kVA distribution transformer that was manufactured by Malaysia Transformer Manufacturing Sdn .Bhd. The objective of this work it to study the magnetic behavior of core and compare the performance of building factor is comparable to the calculated values and to verify that the core has been designed and built correctly, that the quality of the core materials is satisfactory and the core is operating in the correct range of flux density (1.4-1.6)T as suggested by Abdulmonem (1994).

CASE STUDY

The core of three phase 1000 kVA distribution transformer, three-limb built from M5 materials (posmmit) 3% silicon 97% iron, T-joint 90°butt-lap and with 45°mitred corners. The core consists of two dimensions the lamination with a nominal thickness of 0.30 mm. The transformer core was designed and employed for 1000 kVA distribution transformer that was manufactured by Malaysia Transformer Manufacturing Sdn Bhd (Fig. 1).

EXPERIMENTAL APPARATUS AND MEASUREMENT TECHNIQUES

The three phase transformer with overall dimensions is shown in Fig. 1 the no-load losses and the exciting current are measured by using connections is shown in Fig. 2 rated voltage is applied to either the high voltage or low voltage side of transformer while the other side remains open circuit. A range of flux densities from 1.0 T to 1.8 T 50 Hz, were energized in the core which induces or causes a voltage to appear across the terminals of the other side. The various methods of measurement and calculation are given in this section. This study was conducted in the laboratory of transformer design, Northern Malaysia University College of Engineering, 2005.

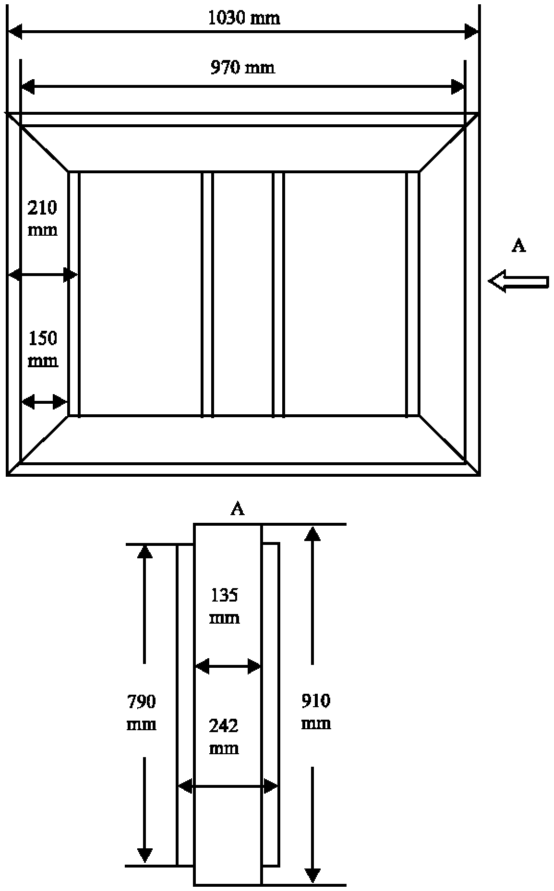
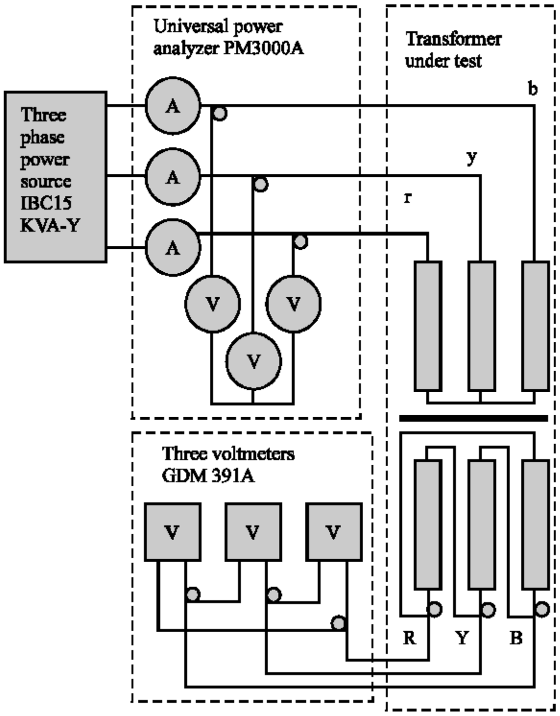


Fig. 1: T-joints 90° and other two cores were assembled with 45° mitred

Power loss: Electrical steels are marked primarily in terms of power loss performance. Within a power loss grade the permeability of the steel is next in importance. The thickness and price at which a given power loss range is attained is very influential in stimulating demand. Electrical steel are critically assessed not only on their electromagnetic properties, but on there mechanical properties also. Additionally aesthetic consideration apply to finished material. The power loss of transformer



Technical information of transformer distribution transformer 3Ph-D/Y, Power- 1000 KVA, type-S, No load loss-1500 W, Load loss- 11700 W, Impedance 5%, Total weight- 3671 kg, Oil quantity- 782 L, Lenght- 1927 mm, Width- 1177 mm, Height- 1913 mm, Core weight- 1246 kg

Fig. 2: Test circuit of no load loss

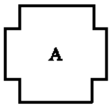


Fig. 3: Cross section area of the limb

Table 1: The measurement and calculated values of power loss

Flux density T	Line voltage V	Total power loss W	Power loss kg^{-1} W kg^{-1}
1	235.32	495.4	0.398
1.1	258.85	597.2	0.479
1.2	282.39	725.0	0.582
1.3	305.91	849.6	0.682
1.4	329.45	1017	0.816
1.5	352.99	1125	0.903
1.6	376.51	1514	1.215
1.7	400.05	1812	1.454
1.8	423.59	2380	1.910

core can be obtained by the results of measurement based on Eq. 1 which determine the value of the injected voltage into the primary winding. A range of flux densities from 1.0 T to 1.8 T 50 Hz, were energized in the core which induces or causes a voltage to appear across the terminals of the other side Fig. 2. In Table 1 are demonstrated the measurement and calculated values obtained by 1, 2 and 3.

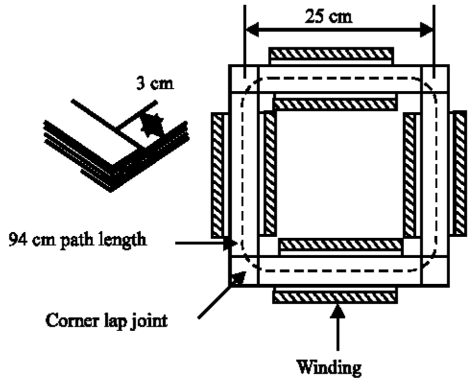


Fig. 4: Epstein test frame

$$V = 4.44 * B * N * F * A * SF \quad (1)$$

$$B = \frac{V}{4.44 * N * F * A * SF} \quad (2)$$

$$P_{CKg} = \frac{P_{CT}}{W_C} \quad (3)$$

where;

B: Magnetic flux
N: No. of turns (for the no load loss measurement recommended between (15-17) turns in the both primary and secondary sides of transformer)
F: Frequency of supply = 50 Hz
A: Cross section area of the limb
SF: Stacking factor = 96% (It reduced with fabrication if there are burrs)
P_{CKg}: Power loss per kg
P_{CT}: Total power loss of core
W_C: Core weight = 1246 kg

For the given case study and referring to Fig. 3 cross section area expressed as,

Length × width

$$A = [(0.132+(2\times0.052))\times(0.15+(2\times0.027))][4\times(0.052\times0.0)]$$

$$A = 0.0425\ M^2$$

Nominal loss: Nominal loss of the core strips (sample strips) for M5 materials (posmmit) two layers was obtained using a single stripe tester (Epstein Test Frame) that built to test the nominal power loss for any magnetic materials the lay out of the 25 cm Epstein Test frame is shown in Fig. 4 and the measurement result was found by

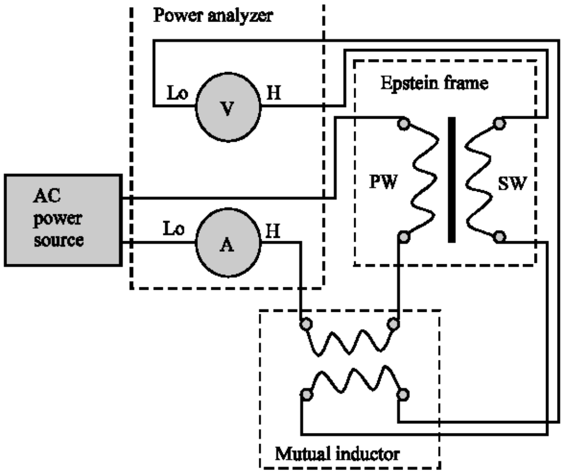


Fig. 5: Circuit for use of Epstein frame

Table 2: The measurement and calculated values of nominal loss

Flux density	AC voltage source	Primary currant	Total power loss	Power loss kg^{-1}
Tesla	V	A	W	W kg^{-1}
1.0	2.52	0.031	0.064056	0.471
1.1	2.77	0.033	0.071944	0.529
1.2	3.02	0.0417	0.087176	0.641
1.3	3.28	0.0527	0.090984	0.669
1.4	3.53	0.066	0.101048	0.743
1.5	3.78	0.084	0.122944	0.904
1.6	4.03	0.103	0.138040	1.015
1.7	4.28	0.124	0.147016	1.081
1.8	4.54	0.144	0.167008	1.228

using connections is shown in Fig. 5. The test frame comprises four sets of winding within which the four sample limbs were placed, each winding having primary (magnetizing) and secondary coils. The hole amounts to small model transformer. The Epstein frame involved exciting a magnetizing (700 turns spread over 175 turns per limb of the square) so that the sample attained the desired peak induction. Care has to be taken due to such meters often being RMS scaled to meet user demand in Electrical Engineering. The scale has, by appropriate arithmetic, to be re-scaled for correct use. Formula (4) is waveform independent and reflects the core notion setting (Johns and Warne, 2002). The Nominal loss of the sample strips can be obtained by (4 and 5). In Table 2 are demonstrated the measurement and calculated values.

$$V = 4 * B * N * F * A \tag{4}$$

$$P_{NKG} = \frac{P_{ST}}{W_S} \tag{5}$$

where;

P_{ST}: Total loss of sample strips

W_S: weight of the sample strips (eight samples strips) = 0.136 Kg

A: Cross-sectional area of sample strips

N: Number of Turns = 700

F: Frequency = 50 HZ

B- Peak induction

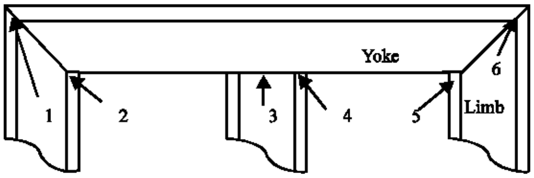


Fig. 6: Position of temperatures measurement

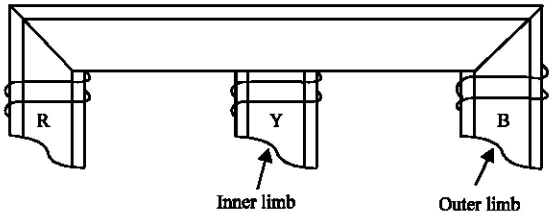


Fig. 7: Position of flux leakage measurement

Table 3: The calculated values of building factor

Flux density	Nominal loss per kg	Power loss per kg	Building factor clamping
Tesla	W/kg	W/kg	24 Nm
1.0	0.471	0.398	1.07
1.1	0.529	0.479	1.12
1.2	0.641	0.582	1.14
1.3	0.669	0.682	1.15
1.4	0.743	0.816	1.21
1.5	0.904	0.903	1.14
1.6	1.015	1.215	1.39
1.7	1.081	1.454	1.48
1.8	1.228	1.91	1.72

For the given two layers cross section area of samples expressed as,

$$\text{width} \times \text{thickness} \times \text{number of layer}$$

$$A = ((0.03 \times 0.0003) \times 2) = 0.000018\ M^2$$

Temperature rise: The temperature in joints of core at the points mentioned in Fig. 6 was measured using Portable Digital Temperature Meter with accuracy of 1%. The initial rise in temperature (dT/dt) at the joints of various positions in a magnetized core can be used to evaluate the local loss at the various pointes.

Flux leakage: The flux leakage of primary winding for all phases was measured using Portable Magnetic Field

Meter with accuracy of 3%. The flux in transformer core has three components: mutual flux, primary leakage flux and secondary leakage flux (Colonel and Mclyman, 1998). For the part of core on Fig. 7 the primary leakage flux caused by primary current.

Building factor: The building factor index reflects the behavior of the rotating magnetic flux and how a power flux is distributed in butt-lap of joints. This behavior will verify that the core has been designed and built correctly, that the quality of the core materials is satisfactory and the core is operating in the correct range of flux density. The building factor is expressed by (6) and the values are demonstrated in Table 3.

$$BF = \frac{P_{CKG}}{P_{NKG}} \qquad (6)$$

RESULTS AND DISCUSSION

The results of the measurements and calculated values for each case are shown graphically as in Fig. 8-18. The criteria for determining the performance of calculated building factor is based on the building factor in Fig. 19 which reflect the characteristic of silicon iron core.

The power loss of transformer core with clamping 12 Nm and 24 Nm are shown in Fig. 8 and 9, respectively. From Fig. 10, it can be seen that the power loss decreased up to 3% when clamping was 24 Nm, this is due to the reducing of air gap in joints. Referring to Fig. 11-13, respectively the third and fifth harmonic components distortion are increased until 1.5 T than slightly decreased at 1.5 T as well as the core impedance, this increasing than decreasing because of core saturation in which an increase in current results in a decrease in inductance.

It is noted form Fig. 8, 9 and 14 that growing of power loss will cause a drop in power factor and decrease the efficiency off transformer core.

The flux induced in transformer core is not symmetry in both primary and secondary winding. From Fig. 15 is

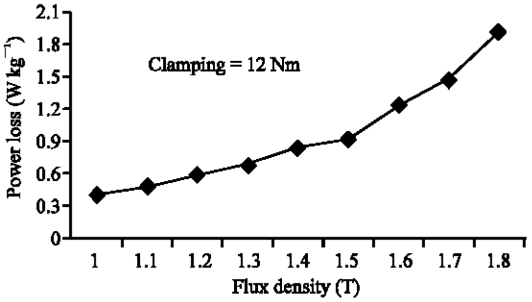


Fig. 8: No load power loss Nm = 12

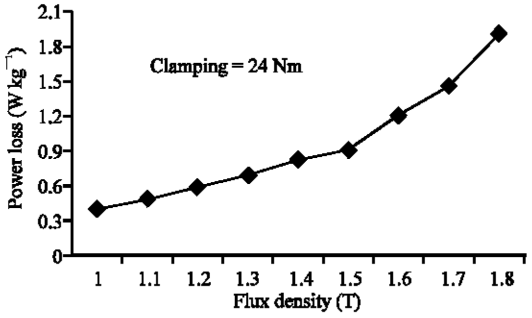


Fig. 9: No load power loss Nm = 24

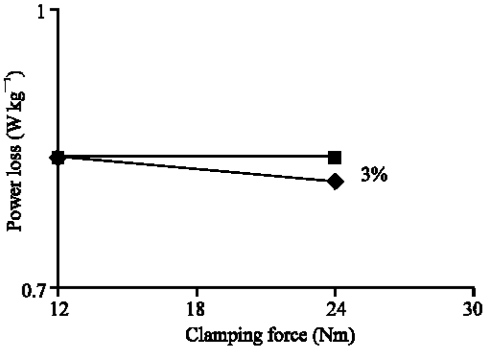


Fig. 10: Clamping force at 1.4 T

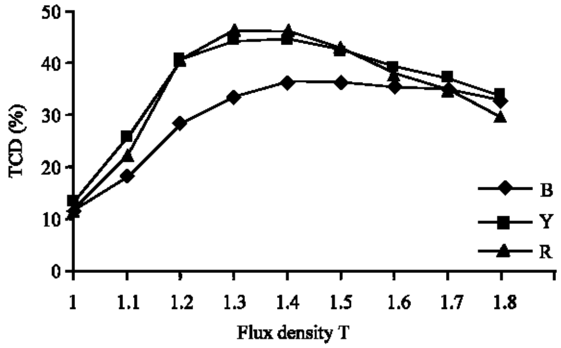


Fig. 11: Harmonic analysis of third component distortion

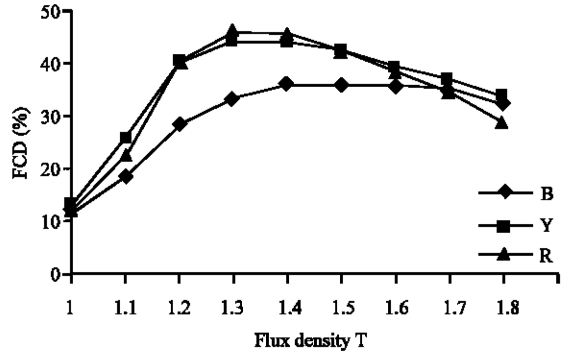


Fig. 12: Harmonic analysis of fifth component distortion

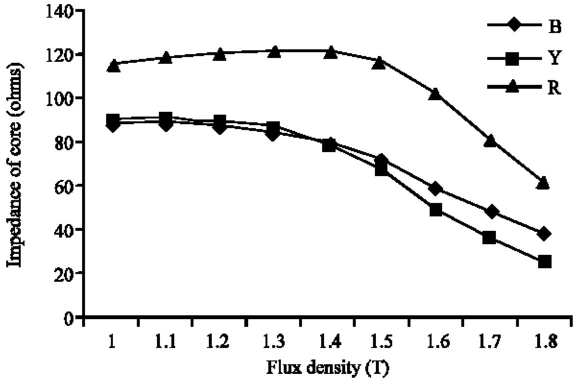


Fig. 13: Impedance load of core

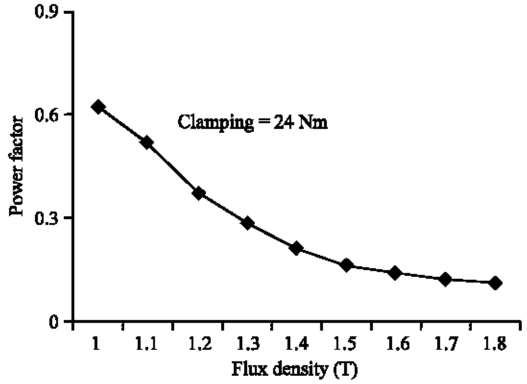


Fig. 14: Power factor Nm = 24

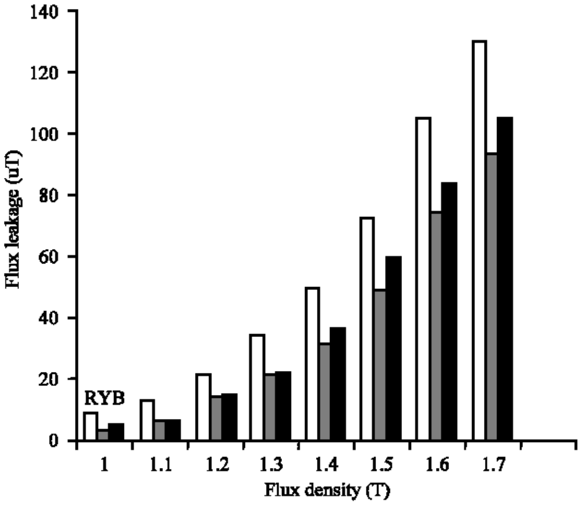


Fig. 15: Flux leakage in inner and outer limb

shown that the flux leakage higher in outer limbs R and B compare in to the inner limb Y at various ranges of flux densities. It means that the flux distribution in the mitred corners is uniformly and non-uniformly in the T-joint.

From Fig. 16 and 17 is shown that the localized temperature is higher at the T-joint compare to the corner joints. Increasing of flux density results in increasing of temperature related to the power loss. As a result of non-uniform of flux distribution in butt-lap of T-joint it can be seen that the higher power loss occurred in the positions 4 when the core is subjected to flux densities 1.4 and 1.6 T. More uniform the magnetic flux in the core, lower the eddy current loss (Daut, 1992).

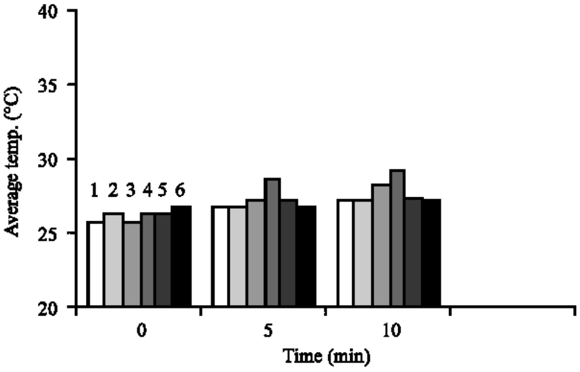


Fig. 16: Average temperature after switching flux = 1.4 T

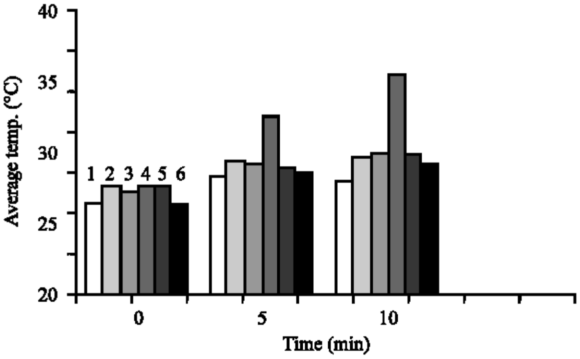


Fig. 17: Average Temperature after switching Flux = 1.6 T

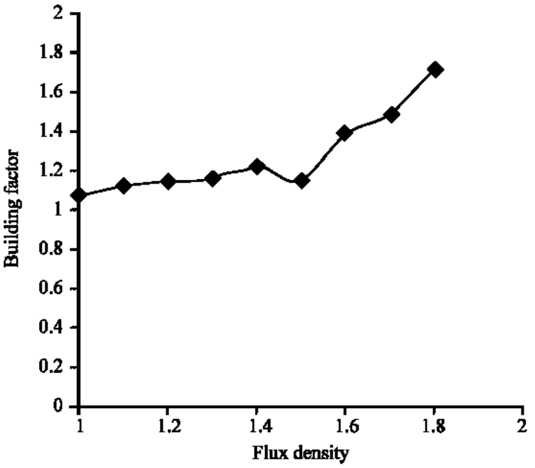


Fig. 18: Building factor

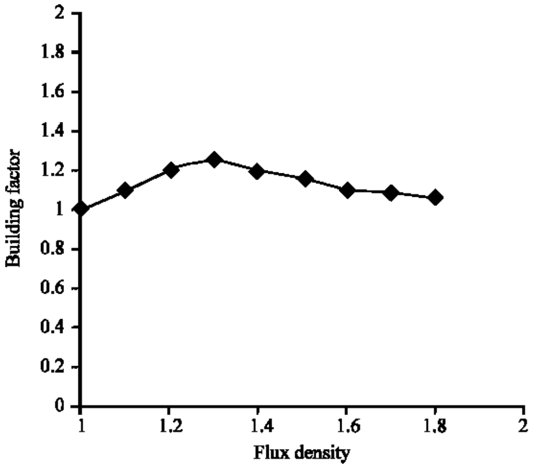


Fig. 19: Building factor for comparison

The building factor in two cases of core clamping (12 and 24 Nm) is shown similar increased the maximum occurs at 1.4 T than dropped until 1.5 T. After 1.5 T, the building factor increased sharply as seen in Fig. 18. The measurements were repeated several times to confirm this finding. The continuing upward trend at high flux density is not characteristic of silicon iron core. It is expected that better flux uniformity at high flux density should reduce the building factor as seen Fig. 19 (Moghadam and Moses, 1989). Other factors such as stress can be result for this increasing, normal flux or flux harmonic are having a large influence on the losses (Daut *et al.*, 2005). Assembly method is also important in controlling the building factor.

CONCLUSIONS

In assessing the level of no load loss relative to the occurrence of an inaccurate manufacturing of transformer core when the core is subjected to a range of flux densities, initial works have been carried on the transformer core T-joint 90° butt-lap and 45° mitred corners that was designed and employed for 1000 kVA distribution transformer by Malaysia Transformer Manufacturing Sdn .Bhd. and rejected because of the higher no load loss. Test results demonstrate that the transformer core is not affected by clamping. The flux in the core distributed non-uniformly in the T-joint. The building factor index is accurate in assessing the level of the no load loss relative to the occurrence of an inaccurate manufacturing of transformer core. Such building factor index can used to determine the weakness in the Assembly method.

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