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Magnetic Properties of Somaloy 700 (5P) Material Under Round Magnetic Flux Loci

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***Abstract:** Electrical machines has enabled human to do their chores with easier and more comfortable way. Most of the current electrical machines require the magnetic cores to operate at higher frequency to meet the demand of high–speed performance. The study of rotating core loss gives big significance to the rotating electrical machines since in real situation, the magnetic flux densities in the electrical machines are rotated during the operation. In this paper, magnetic properties of new material; SOMALOY 700 (5P) are studied by conducting 2-D core loss measurements at 50 Hz, 100 Hz, 500 Hz and 1000 Hz. Magnetic flux density is controlled to be in round shape in clockwise and anti-clockwise directions by using LabVIEW to resemble the actual core loss of rotating machines. B and corresponding H loci are plotted and these collected data are analysed by using Mathcad to obtain the core loss curves at different magnitude of magnetic field and frequencies. The findings show that the rotational core loss is increased with frequencies. At 1.8 T under 50 Hz of rotating magnetic fluxes, 8.9 Watt/ kg is recorded and keep increasing up to 2.4 T. The detail of core loss is important in providing information to the engineers for the motor design proposes.*

***Index Terms:** Core loss, magnetic properties, rotating electrical machines, round loci, SOMALOY 700.*

I. INTRODUCTION

A few years ago, Hoganas AB introduced SOMALOY 700 (5P) material to the market by aiming for the lowest losses during the operation. This material has a larger grain with ultra-thin insulation, a new coating concept after experiencing the high-temperature treatment at 630 - 650 ^{o}C under acceptable mechanical strength which is more than 55 MPa [1][2]. These highly pure iron particles with surface coating have controlled the electrical resistivity in order to reduce the bulk eddy current losses. Eddy current is one of the elements of the core loss besides hysteresis and anomalous losses. The reduction of eddy core loss has significantly reduced the core loss that makes SOMALOY 700 (5P) as the lowest loss material.

The information about the core losses will increase the efficiency and performance of the electrical machines. In parallel, the characteristics of this magnetic material are needed to be analysed to ease engineers for designing the future electric machines.

II. EXPERIMENTAL SET UP

Round loci of magnetic flux density are generated by controlling two sinusoidal waves of magnetic flux density, B_x and B_y to be in the same magnitude at 90^0 of phase angle. The round shape of B loci is presented from low to high frequencies on a plane of 2 axes to predict the core loss produced under rotating magnetic fluxes.

The B loci are generated in the XOY-plane by adjusting the magnitudes and angles between B_x and B_y waveforms. Rotating core losses are examined by measuring them in clockwise and anti-clockwise direction.

2-D measurement of SOMALOY 700 (5P) core losses starts by magnetise the cubic sample at 50 Hz and up to 1000 Hz. The loci of B and H are plotted and core loss curves in clockwise and anti-clockwise are illustrated before is being averaged.

B-H Loops of Rotating Core Loss

The measurement of SOMALOY 700 (5P) properties has been conducted at four different frequencies. Fig. 1 exhibits the round B loci under 2-D magnetic flux density at (a) 50 Hz, (b) 100 Hz, (c) 500 Hz and (d) 1000 Hz.

The magnetic fluxes are excited to be circularly controlled up to 2.42 T, 1.22 T, 0.37 T and 0.09 T at 50 Hz, 100 Hz, 500 Hz and 1000 Hz, respectively. The ability of being generated become lower with high frequency due to high vibration and high heat dissipation.

Both B and H loci lie in the same plane but the shape of H loci are distorted when these is an increment of B. It explains that the rotating domain moved and slowly portrays the anisotropy property when there is involvement of high magnetic field in different direction.

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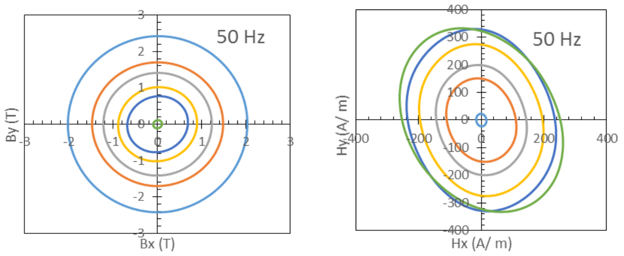

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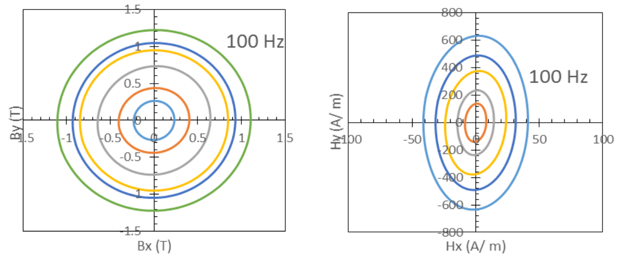

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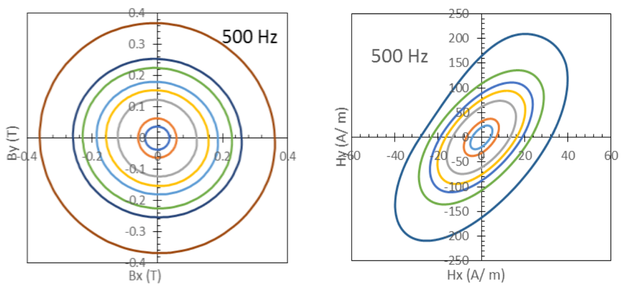

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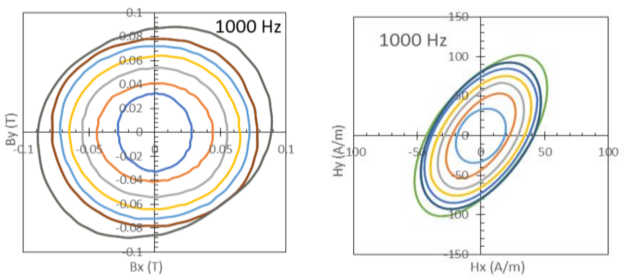


(d)

Fig. 1 Round B loci and corresponding H loci in the XOY-plane at (a) 50 Hz (b) 100 Hz (c) 500 Hz and (d) 1000 Hz

Based on Fig. 1 (d), the shape of circular B loci shows quite wobblier at 1000 Hz of magnetization due to coupling between cord poles which contributed to the noise production. However the production of core losses does not corresponds to this [3].

Core Loss of Rotating Magnetic Flux Density

The rotating core loss is contributed by two magnetic flux density from different axes, x and y. The measurements are started by repeating them for three times in order to ensure the collected data is accurate. Fig. 2 describes the data selection after three times of measurements. From the figure, it can be shown that the first reading is considered because of the resemblance to the averaged data.

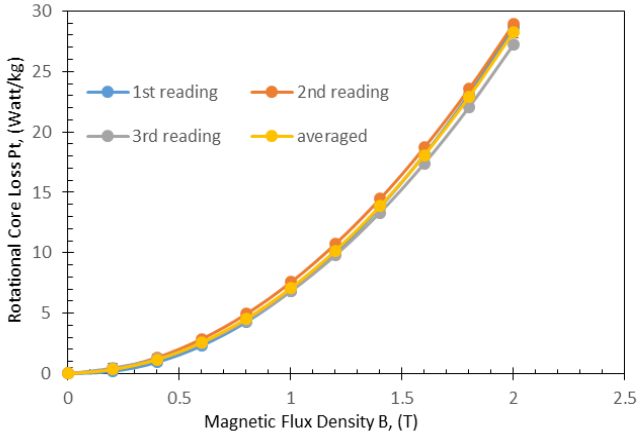
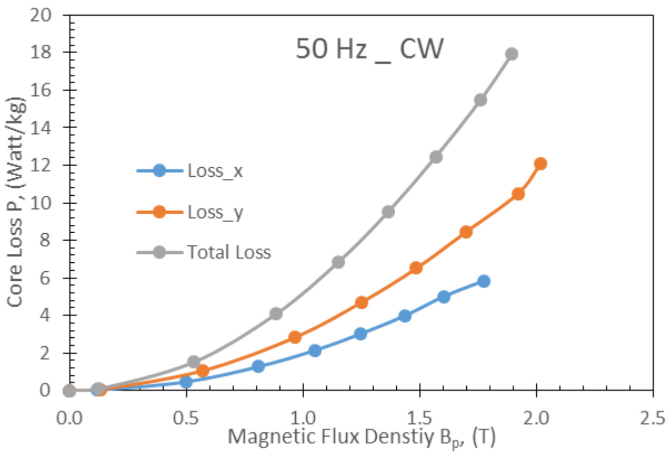


Fig. 3 Three times of rotational core loss measurements with 0.474 of standard deviation

Figs. 4 (a) and (b) explain the individual core loss in x- and y-axes in clockwise and anti-clockwise directions. The summation of these components will produce the actual rotating core loss of the material.



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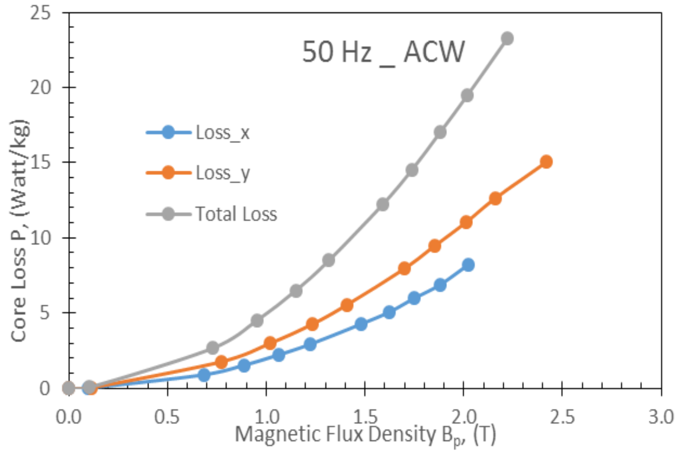

(b)

Fig. 4 The individual core losses and total core loss at 50 Hz in (a) clockwise and (b) anti-clockwise directions

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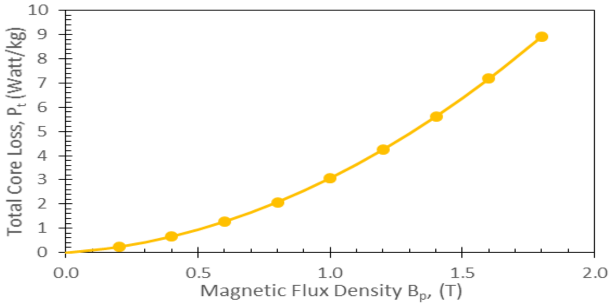
Figs. 5 (a), (b), (c) and (d) show measurements of 50 Hz, 100 Hz, 500 Hz and 1000 Hz magnetization for SOMALOY 700 (5P) material respectively. It is individual core loss summation of magnetic flux density excitation from x and y. These figures clearly explain the proportional relation between the total core loss and the squared of magnetic flux density. The domain wall will be moved during the magnetization of the sample due to the changes of the magnetic domain. Hence, the possibility of domain walls to transform into crystal structure material is high in the presence of high magnetic flux excitation. This condition will increase the core loss throughout the operation.

At 1.8 T of magnetic flux density, the total core loss is recorded at 50 Hz is about 8.92 Watt/kg whereas at 1.2 T, the rotating core loss is 23.01 Watt/kg when the measurement is conducted at 100 Hz. However, the rotating core losses at 500 Hz and 1000 Hz are 25.51 Watt/kg and 2.14 Watt/kg when *B* is at 0.36 T and 0.085 T, respectively.



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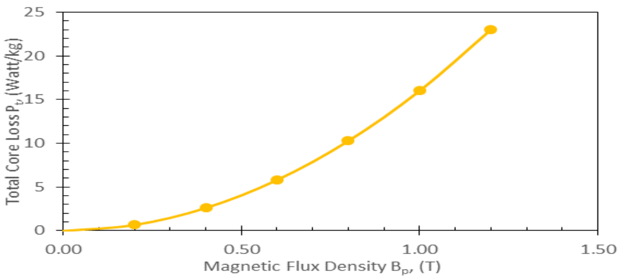

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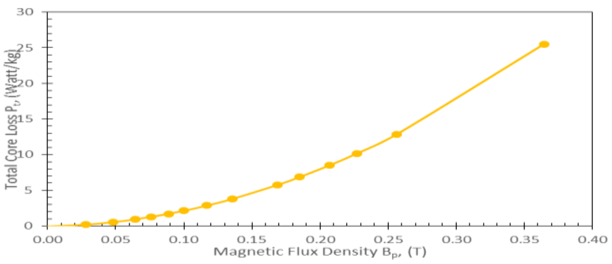

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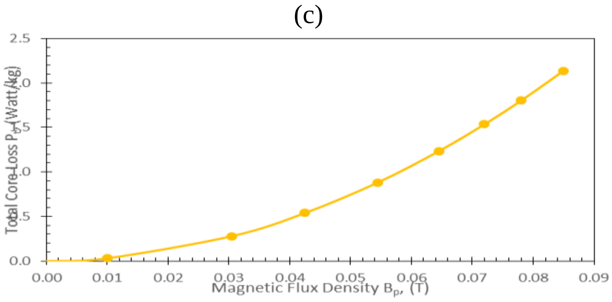


(d)

Fig. 5 Loss curve of SOMALOY 700 (5P) material at (a) 50 Hz (b) 100 Hz, (c) 500 Hz and (d) 1000 Hz after B fluxes being formed into round shapes

By referring all plotted curves in Fig. 6, it shows that the core loss steadily increased with the magnetic flux density and frequency. This is caused by the magnetic material vibrations at high magnetic flux density and frequency lead to the additional heat dissipation throughout core loss measurement. Another effects that have been introduced when the magnetization is conducted at high frequency are thermal effects on hysteresis, winding coils and cores skin effects, the inductance leakage effect and the stray capacitance [4][5].

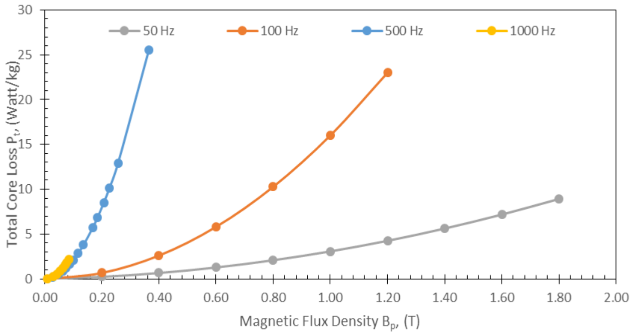
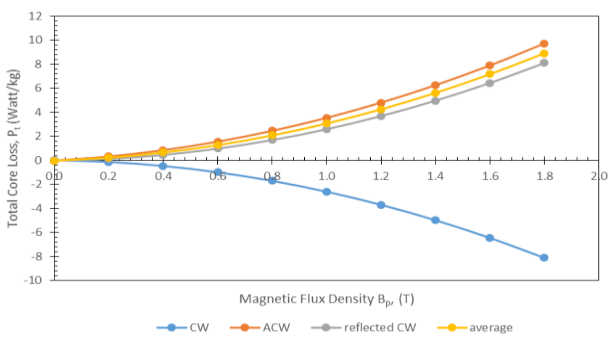


Fig. 6 The rotating core losses at low to high frequencies

Clockwise and Anti-clockwise 2-D Measurements

2-D measurements of SOMALOY 700 (5P) are conducted in clockwise and anti-clockwise directions at different of operating frequencies. Figs. 7 (a), (b), (c) and (d) are the set of plotted graphs that explain the total core loss of each frequency in clockwise, anti-clockwise directions and the reflected of clockwise core loss at 50 Hz, 100 Hz, 500 Hz and 1000 Hz, respectively. There are four different colours of curve line that describe modes of rotation during the magnetisation process. The blue line represents the clockwise rotation and the brown line represent the magnetic flux rotation in anti-clockwise direction, the grey line is the reflected curves of clockwise rotation and the yellow line represents the average of rotating core loss.

It can be seen that, there is a mirror-image which describes the total core loss for both directions; clockwise and anti-clockwise has same magnitude that has been reflected on the x-axis due to opposite pole of magnetic flux density during the magnetisation process. This proved that the core loss production for both directions is the same and can be determined by averaging the core losses of both directions.



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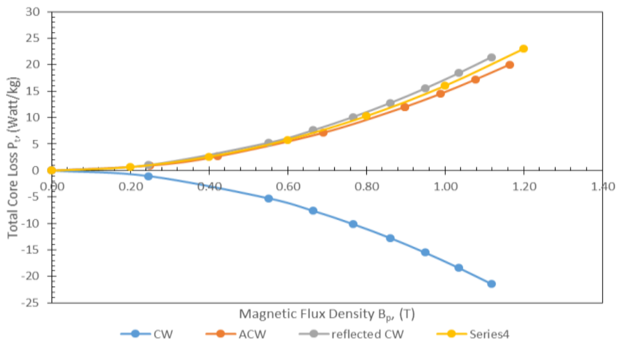

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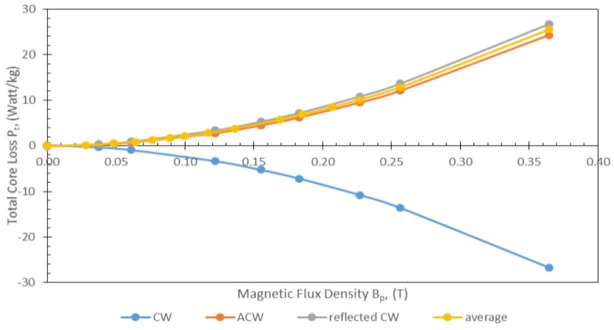

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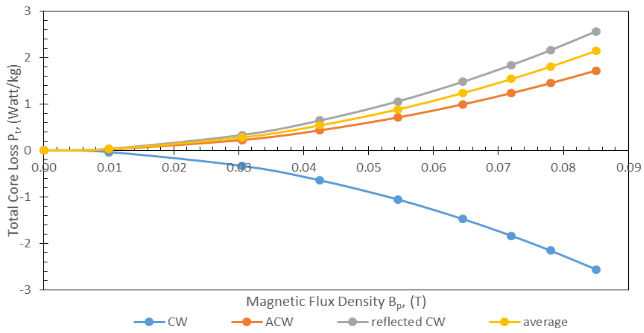


(d)

Fig. 7 The loss curve of SOMALOY 700 (5P) material in clockwise and anti-clockwise 2-D measurements at (a) 50 Hz (b) 100 Hz (c) 500 Hz and (d) 1000 Hz

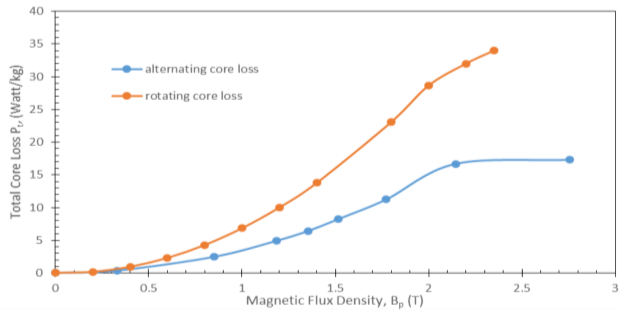
Core Loss under Alternating and Rotating Magnetic Flux Densities

The magnetic flux densities are controlled to be in circular shape along XOY-plane during the 2-D measurement. This is resemblance of rotating electrical machine which is operated in the presence of rotating magnetic flux density. Due to that, the core loss under rotating magnetic flux density is important to be studied in order to predict the total core loss of the magnetic material which will be used in designing the real electrical machines in the future.

In this section, the production of rotating core loss is compared to the alternating core loss which is described in previous chapter. Both types of core losses are plotted in the same graph to estimate the ratio between them.

Figs. 8 (a), (b), (c) and (d) illustrate the core losses of SOMALOY 700 (5P) under alternating and rotating magnetic flux density at 50 Hz, 100 Hz, 500 Hz and 1000 Hz, respectively. The alternating core loss is measured in the presence of sinusoidal B and the rotating core loss is measured by considering circular B vector with different magnitude of magnetic flux densities.

The figures below explain that the ratio of rotating core loss to alternating core loss at 50 Hz, 100 Hz, 500 Hz and 1000 Hz are approximately 2. These show the strong agreement with a conclusion by other researchers that the rotational core loss of SMC is larger than alternating core loss due to the extra heat dissipation upon the magnetisation process [6]. In 2006, Guo *et al.* stated that the rotational core loss is nearly twice compared to the alternating core loss with the same peak value at the mid-range of magnetic flux density as showed in Fig. 8 (a) [7].



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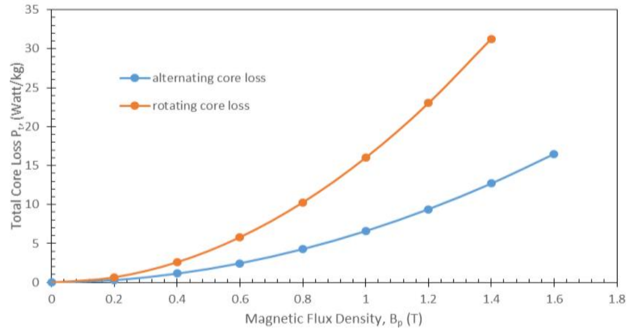

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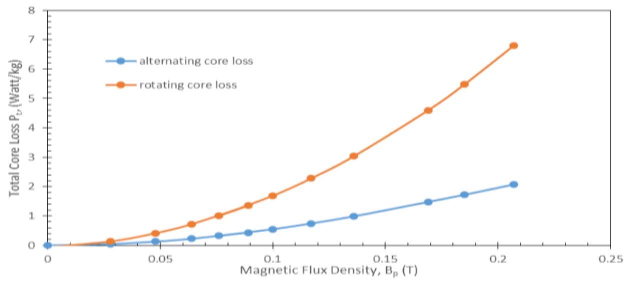

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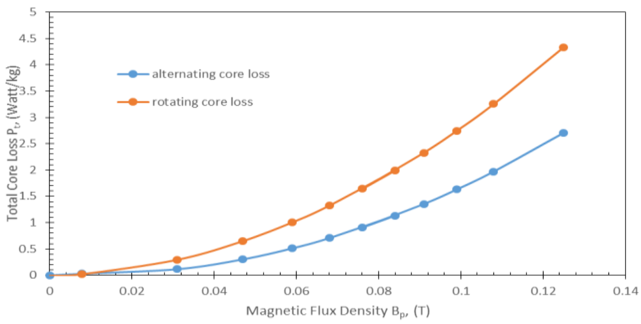

(d)

Fig. 8 The alternating core loss and rotational core loss of SOMALOY 700 (5P) at (a) 50 Hz, (b) 100 Hz, (c) 500 Hz and (d) 1000 Hz

Figs. 8 clearly show that SOMALOY 700 (5P) material produced lower alternating core losses as compared to the rotational core losses of same magnetic material which give same agreement with previous researcher in 2006 [7].

III. RESULTS AND DISCUSSIONS

Based on the core loss measurement at 50 Hz in Fig. 8 (a), the core losses slowly decreased when approaching 2.4 T for both types of core losses due to the saturation condition of SOMALOY 700 (5P) material. In addition, the core losses under alternating and rotating magnetic flux densities are 16.7 Watt/kg and 32 watt/kg, respectively at 2.2 T.

However, the recorded alternating core loss at 100 Hz is 31.27 Watt/kg and 12.69 Watt/kg is produced by rotating fluxes during the operation at 1.4 T. The maximum magnetic field generated by 3-D tester at 100 Hz is only 1.4 T for rotating fluxes and 1.6 T for alternating flux due to high vibration.

The rotational core losses are recorded as 2.6 Watt/kg and 4.33 Watt/kg for 500 Hz and 1000 Hz when the measurements are conducted at 0.125 T. On the other hand, the alternating core losses are 0.9 Watt/kg and 2.71 Watt/kg for 500 Hz and 1000 Hz at the same generated magnetic field. The ability to generate magnetic field is decreased due to the condition of 3-D tester. High vibration and high heat dissipation at higher frequency limits the magnetic field to hit the saturated condition.

IV. CONCLUSION

The measurements that involved the circular magnetic fluxes have been conducted by using the 3-D tester. The results of experiment at certain range of frequency such as B loci, corresponding H loci and loss curve are described in details. The measurement of SOMALOY 700 (5P) magnetic properties are conducted by considering both directions clockwise and anti-clockwise rotating magnetic fluxes as proposed by Sievert [8][9][10][11].

From the graphs and explanations, it can be concluded that the rotational core loss is higher than alternating core loss for SOMALOY 700 material. Additionally, the rotational core loss is twice compared to core loss under alternating magnetic field as exhibited by plotted graphs at 50 Hz measurement.

However, the tester has a restriction in measuring the core loss at high frequencies which limits the magnetic material to be magnetised at high magnetic flux density. For the recommendation, the ability in predicting the magnetic properties of SOMALOY 700 (5P) can be increased by considering the symmetrical ‘C type’ cores of 3-D tester. This type of laminated core provides the frustum of cone pole that is able to balance the magnetic flux path in three axes smoothly for the higher field homogeneity inside the sample. Thus, the sensing voltages of B and H can be induced easily and efficiently.

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