

## Investigation of 24 Slots Stator Core of 0.5 HP Induction Motor and Its Performance Evaluation

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### ABSTRACT

In this paper, we have investigated a new prototype of 24 slots stator core for 0.5hp induction motor with reduced slots to predict wherever the maximum localized flux distribution and localized power loss to be occurred. In order to evaluate the performance of this new prototype, we measured localized flux distribution in various places using search coils and also measured localized power losses using thermistor in various places of the stator core. The comparison results within 1.0T, 1.5T and 1.8T revealed that the localized flux distribution increases 39.06% from outer region to the inner region of the stator core and simultaneously power loss also increases 40% where the maximum flux distribution found compared to the outer regions of the stator core.

**Keywords:** Tesla (T), 24 slots stator core, non-grain materials, induction motor

### I. INTRODUCTION

In this investigation, the search coil methods were used to measure flux density distribution in the stator core which is magnetised at 1.0 Tesla (low excitation), 1.5 Tesla (medium excitation) and 1.8 Tesla (over excitation). The results produced from this method are measured in terms of the magnitude of induced voltage of the stator core of induction motor. The localised flux density of stator core has been investigated under fundamental and third harmonic level. The localised flux density measurement using search coil method have been done where the magnetic cores of three phase induction machines has shown that the regions behind the teeth of stator exhibit the highest distortion of flux density [1]. The investigation of the stator cores of three-phase induction motors has shown that the regions behind the teeth of the stator cores exhibit the highest distortion of flux density distribution. Localized power losses are also seen to be highest in the teeth of the stator core, where alternating flux is forced, due to the geometry of the teeth. The observation made on the localized flux and localized loss behaviors within the three phase stator core show that a much larger flux distortion occurs within the stator teeth. The localized loss for these regions is also seen to be the highest within these regions

[1]. Localized flux density and power losses were measured in various location of the core, using small search coils and thermistors, under the core induced from 1.0T to 1.8 T, at 50 Hz.

Induction Motors (IMs) are widely used in various sectors including industrial, residential, commercial building, transport system, communication, public and household sectors. It is documented that the IMs consume about 75% of the electrical energy that consumed by all electric motors in a country, which is in fact the equivalent to about 43% of the total electrical energy consumption of a country [2]. We also noticed that one percent (1%) increase in motor electrical energy efficiency can save 20 billion kW-hrs per year or 1.4 billion dollars in electricity and 3.5 million barrels of oil in the United States. It has been then the current demand of the society to develop high efficiency low cost IMs using lower power loss stator core of induction motor. By using low cost high efficiency IMs, we can save the national revenue as well as the environment from global warming.

The stator and rotor magnetic cores are made of thin silicon steel lamination (non-grain oriented steel) to reduce hysteresis and eddy current [3]. Non grain oriented steel have magnetic properties that are as isotropic as possible. This material produced multidirectional magnetisation where useful for the rotating machines [4]. Rotating machines are considered a source of harmonics because the windings are embedded in slots which can never meet exactly sinusoidally distributed so that the mmf is distorted. Low-order harmonics have a larger impact on the three-phase induction motor than that of high-order harmonics [5-6]. The iron loss can be increased in between 15-20% under PWM excitation. Surprisingly, the increase in iron loss in a typical induction motor stator core lamination was 3% lower than that in Epstein strips of the same electrical indicating an effect of the magnetic circuit geometry and the voltage waveform [8-9].

The paper is organized as follows. The Section 2 shows the basic development process of the stator core of induction motor. The Section 3 describes the performance evaluation

of the stator core. In Section 4, we discuss the results, and some concluding remarks are drawn in the Section 5.

## II. MATERIALS & METHODS

A series of steps are necessary to develop a prototype stator core of induction motor. We followed the steps as shown in Fig.1 in developing the 24 slots stator core of our developed prototype.

### 2.1 Development process of stator core

We followed the steps as shown in Fig.1 in developing the stator core of our developed prototype.

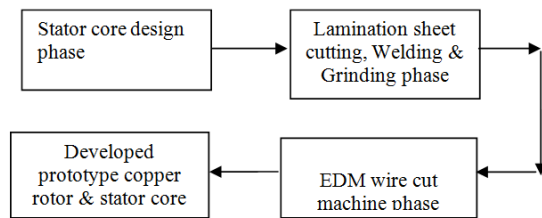


Fig. 1: Basic flow diagram of development process of stator core of IMs

#### Stator core design phase

This phase is the starting phase for the development process of our prototype stator core. We calculate the stator slot area for the prototype. We used AutoCAD design dxf file to perform the design work.

#### Lamination sheet cutting, Welding and Grinding phase

In this phase, the lamination steel sheets (grade H10 non-grain) are cut based on the specifications as obtained from design phase, which was 150mm×150mm with the thickness of 0.35mm. Then 220 pieces of single laminations sheet are divided into two lamination stacks, because the EDM wire cut machine cannot cut more than 45mm length of lamination stack. The 100 pieces of lamination steel sheets are stacked and welded together. In order to make the stacks smooth, the grinding process is done so that the stacks can be fit with EDM wire cut machine without further interruption.

#### EDM wire cut machine phase

The Electro discharge machine (EDM), model AQ 327L, is used to cut the lamination stacks based on the design specification as obtained from design phase. Here, we need to upload AUTOCAD dxf file in EDM machine and operate under high temperature of 11000°C to 13000°C on the conductor wire as to melt the material during the cutting process. The EDM uses 0.25 mm diameter non paraffin hard wire which is made of brass materials to cut the lamination stack.

### 2.2 Developed prototype of stator core of induction motor

The developed prototype of copper rotor and stator frame are shown in Fig. 2.

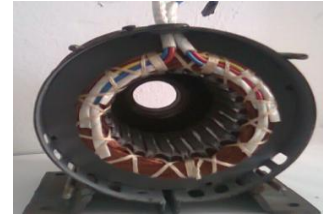


Fig. 2: Developed prototype of stator core of induction motor

## III. PERFORMANCE EVALUATION

In this section, we evaluated the performance of our developed prototype 24 slots of stator core for 0.5hp induction motor and compared within the various tesla level. We calculated localized flux distribution and localized power loss at various places of the stator core from 1.0T to 1.8T, at 50 Hz.

### 3.1 Localised Flux Density of Fundamental Harmonics

Localised flux density of fundamental harmonics was shown in Fig. 4, 5 and 6 respectively, it shows the flux density distribution of the stator core magnetised at 1.0T, 1.5T and 1.8T respectively. Three factors should be considered during measurement of the localised flux density distribution throughout the stator core, e.g. (i) the effect of different positions of the lamination in the stack on the measured flux density distribution, (ii) the repeatability of the flux density measurements and (iii) the effect of the introduction of search coils on the flux density distribution in the lamination.

When the stator core were magnetised at flux density of 1.0T (low excitation), the localised flux density found increases from outer region to inner region of the stator core because the maximum induction occurred near to the slot area of the core. That is why high flux density is present in the vicinity of the slot area.

The localised flux distribution was found greater in the induction area of the core approximately 207% compared to outer core back area. The flux distribution was found at the middle of the core approximately 126.9% compared to outer core back area because in the middle area no windings i.e. it is less inductive area as shown in Fig. 4.

Fig. 3 shows the localised fundamental component of flux density at core excitation from 1.0T to 1.8 T where it shows the magnitude of the fundamental component of flux density in the tooth area gradually increases compared to outer core back area.

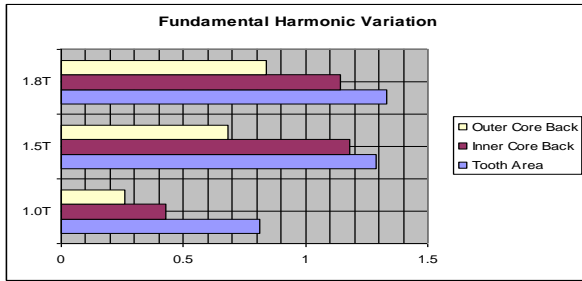


Fig. 3: Magnitude of fundamental component of flux density along the three different area of the stator core

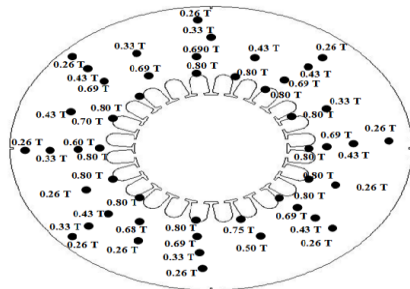


Fig. 4: Fundamental Peak Flux Density Distribution in the Stator Core Magnetised at 1.0T

When the stator core was magnetised at flux density of 1.5T (normal excitation), the localised flux density found increases from outer region to inner region of the stator core. That is why flux distribution is less uniform at the outer region and more concentrated in the inner region. The localised flux distribution was found at the inner region of the core approximately 89.7% compared to outer core back area because in stator teeth area occurred maximum induction due to its windings effect. The localised flux distribution was found at the middle of the core approximately 47.05% because this points a bit far away from the slot area.

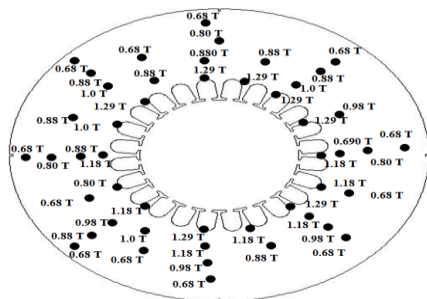


Fig. 5: Fundamental Peak Flux Density Distribution in the Stator Core Magnetised at 1.5T

While the stator core magnetised at 1.8T (high excitation), the localised flux density found still increases towards induction area tooth centre of the core and that is why it is found that localised flux density greater in the slot area instead of outer region approximately 58.21% because this area having higher induction compared to outer region of

the stator core. Localised flux distribution was found at the middle of the core approximately 35.71% because of less inductive area which is shown in Fig. 6.

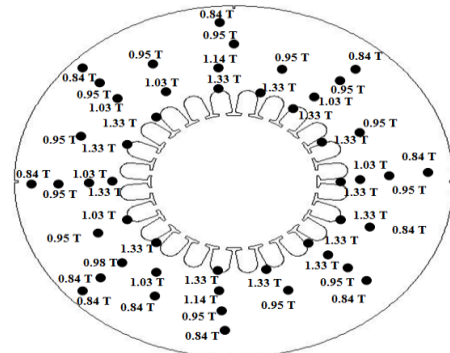


Fig. 6: Fundamental Peak Flux Density Distribution in the Stator Core Magnetised at 1.8T

### 3.2 Localised Flux Density of the Third Harmonics

The third harmonic components of peak flux density of the stator core shown in Fig. 8, 9 & 10 which is magnetised at 1.0T (low excitation), 1.5T (medium excitation) and 1.8T (over/high excitation) respectively.

The stator core magnetised at flux density of 1.0T as shown in Fig. 8, where the third harmonic components found increases from the outer regions to the inner regions of the stator core because in the inner region having maximum induction due to three phase windings of the core. That is why the localised flux distribution found very high in this area approximately 111.76% compared to outer core back area of the core. The localised flux distribution was found at the middle of the core approximately 47.05% compared to outer core back area because it is a bit far away from the slot area of the core.

It is therefore very important to understand the localized flux distribution within the stator core where and how much in percentage (%) occurred. It will help to design and predict of high efficiency induction motor about core losses.

Fig. 7 shows the localised third harmonic component of flux density distribution at core excitation from 1.0T to 1.8 T where it shows the magnitude of the third harmonic component of flux density in the tooth area gradually increases at 1.0T & 1.5T but at 1.8T it is going to decreased i.e. it shows during magnetization of flux density at 1.8T (high excitation) the flux distribution is maximum in the outer core back area of the stator core because of high saturation level.

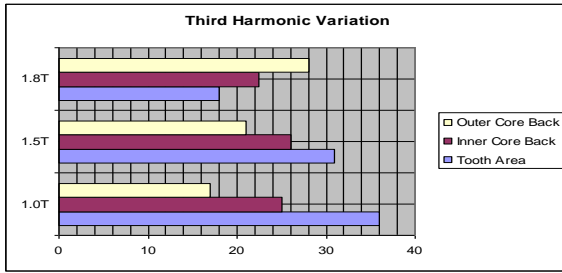


Fig. 7: Magnitude of third harmonic component of flux density distribution along the three different areas of the stator core

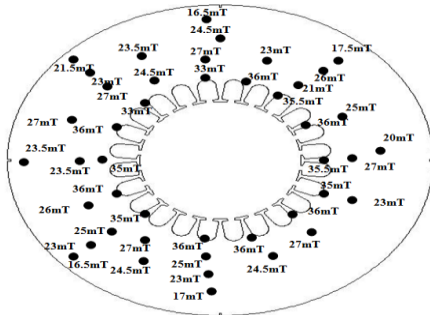


Fig. 8: Third Harmonic Component of Peak Flux Density at the Stator Core Magnetised at 1.0T

When the stator core magnetised at flux density of 1.5T (normal excitation), then the third harmonic components still found increases towards to the slot area of the stator core. The localised flux distribution was found extremely greater at the stator teeth area i.e. vicinity to the windings area of the core approximately 47.62% compared to outer core back area. Localised flux distribution was found at the middle of the core approximately 19.04% and obviously it will be less because of less induction effect of the core as shown in Fig. 9.

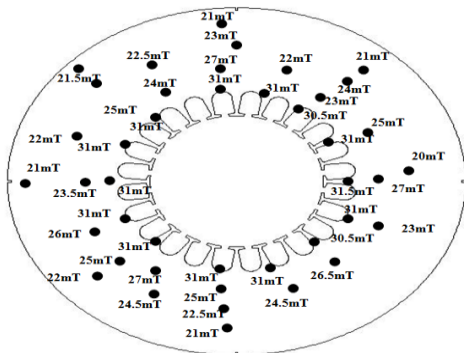


Fig. 9: Third Harmonic Component of Peak Flux Density at the Stator Core Magnetised at 1.5 T

When the stator core magnetised at flux density of 1.8T (over/high excitation) which is shown in Fig. 10, where the third harmonic components found suddenly decreases from outer regions to the inner regions of the stator core of the induction motor because of its high excitation. At this level flux density becomes saturated due to its over excitation

and as a result, it is tends to decreased. That is why localised flux distribution was found extremely greater at the outer region of the core approximately 55.55% compared to inner region of the core and at the middle of the core found approximately 22.22% compared to the slot area of the core.

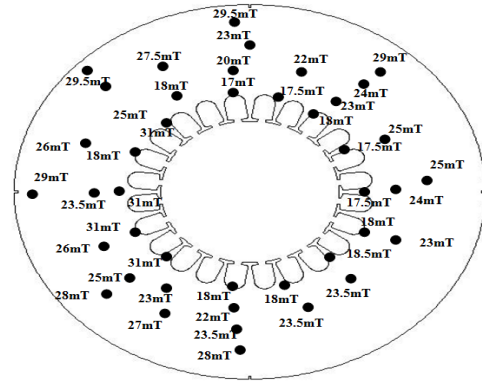


Fig. 10: Third Harmonic Component of Peak Flux Density at the Stator Core Magnetised at 1.8 T

### 3.3 Average Peak Flux Density Distribution In plane at Stator Core

The location of peak flux density distribution in plane in the stator core of the induction motor has shown in Fig. 11.

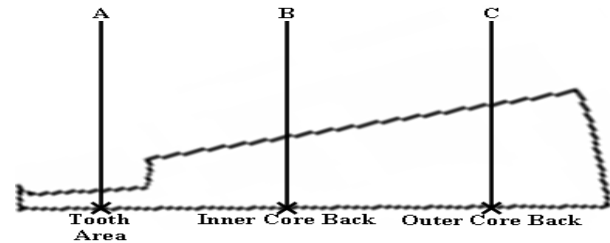


Fig. 11: Location of Peak Flux Density Distribution in Plane in the Stator Core

The overall localised flux density variation in the magnitude of the fundamental harmonic components of peak flux density magnetised at 1.0T as shown in Fig. 4, the third harmonic components of peak flux density magnetised at 1.0T in plane in the stator core shown in Fig. 8. It shows the tooth centre, inner core and outer core back area at low excitation (1.0T) data at fundamental and third harmonic level.

Table 1 shows the variation in average magnitude of fundamental and third harmonic peak flux density distribution in the stator core in different areas at flux density of 1.0T, 50 Hz. A high average of peak flux density was observed just inside the stator tooth area adjacent to the windings. In the stator core, the values of the fundamental & third harmonics found a gradual increase towards the inner region of the stator core. The highest peak values of

flux density at tooth areas found 0.78T and 35.58mT for the fundamental and third harmonic level as shown in Fig. 4 and 8 respectively.

Flux Distribution	Fundamental Harmonics (T)	Third (3 <sup>rd</sup> ) Harmonics (mT)
Search Coil Location		
A- Tooth Centre	0.78	35.58
B- Inner Core Back	0.54	25.22
C- Outer Core Back	0.26	19.83

Table 1: Average Peak Flux Density Distribution of Fundamental and Third (3<sup>rd</sup>) Harmonic components in the Stator Core Magnetised at 1.0T, 50Hz

The variation in average magnitude of fundamental and third harmonic peak flux density distribution in the stator core at different areas at magnetised flux density of 1.5T as shown in Table 2. A high peak flux density was observed just inside the stator tooth area enclosed to the windings. In the stator core, only the values of fundamental peak flux density in this area show a gradual increase towards the inner region of the stator core. The highest peak value of flux density at tooth area is 1.15T for the fundamental harmonics. The magnitude of third harmonic peak flux densities found increases towards the stator tooth due to its medium excitation. The highest peak values at tooth centre are 31mT for the third harmonic level.

Flux Distribution	Fundamental Harmonics (T)	Third (3 <sup>rd</sup> ) Harmonics (mT)
Search Coil Location		
A- Tooth Centre	1.15	31
B- Inner Core Back	0.94	28.38
C- Outer Core Back	0.72	21.33

Table 2: Average Peak Flux Density Distribution of Fundamental and Third (3<sup>rd</sup>) Harmonic components at the Stator Core Magnetised at 1.5T, 50Hz

The variation in average magnitude of fundamental and third harmonic peak flux density distribution in the stator core at different areas at a flux density of 1.8T as shown in Table 3. A high peak flux density was observed just inside the stator tooth area enclosed to the windings. In the stator core, only the values of fundamental peak flux density in this area show a gradual increase towards the inner region of the stator. The highest peak value of flux density at tooth area is 1.28T for the fundamental harmonic. The magnitude of third harmonic peak flux densities decreases towards the stator tooth. The highest peak values at outer core back are 28.92mT for the third harmonic.

Flux Distribution	Fundamental Harmonic (T)	Third (3 <sup>rd</sup> ) Harmonic (mT)
Search Coil Location		
A- Tooth Centre	1.28	18
B- Inner Core Back	1.02	23.72
C- Outer Core Back	0.84	28.92

Table 3: Average Peak Flux Density Distribution of Fundamental and Third (3<sup>rd</sup>) Harmonic components at the Stator Magnetised at 1.8T, 50Hz

### 3.4 Localized Power Loss Distribution in Stator Core

The localised power loss distribution in the newly developed stator core shown in Fig. 12, 13 and 14 which is magnetised at 1.0T (low excitation), 1.5T (medium excitation) and 1.8T (over/high excitation) respectively.

The stator core magnetised at flux density of 1.0T as shown in Fig. 12, where the localised power loss found increases from outer core back area to proximity of the tooth centre of the stator core because in this area high flux density distribution are available compared to outer core area, that is why localised power loss found higher (refer to Fig. 4). The highest power loss occurred at the tooth centre around 80% compared to the outer region and at the middle power loss found around 40% compared to the outer region of the stator core.

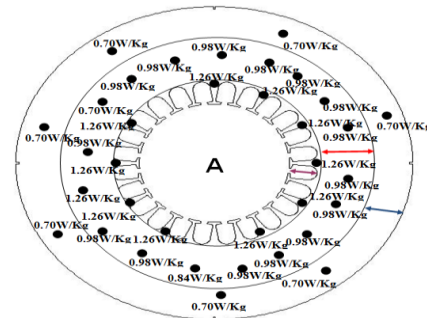


Fig. 12: Localised Power Loss in the Stator Core (A) Magnetised at 1.0T

It is very obvious because the localised flux density is higher due to its windings affect and highly inductive area, therefore, when the stator core magnetised at flux density of 1.5T as shown in Fig. 13, the localised power loss found increases from outer core back area to proximity of the tooth centre of the stator core (refer to Fig. 5). The highest power loss occurred at the tooth centre around 83.33% compared to the outer region and at the middle power loss found around 33.35% compared to the outer region of the stator core.

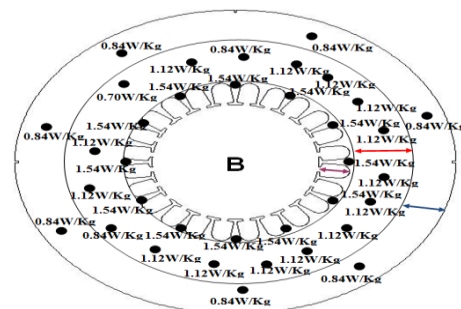


Fig. 13: Localised Power Loss in the Stator Core (B) Magnetised at 1.5T

When the stator core magnetised at flux density of 1.8T as shown in Fig. 14, where the localised power loss found still increases from outer core back area to proximity of the tooth centre of the stator core because in this area high peak localised flux density distribution are available including its high excitation and also for windings affect. Power loss varies from outer region to inner region to tooth centre of the stator core depending on that where the maximum flux distribution occurring. The highest power loss occurred at the tooth centre around 50% compared to the outer region and at the middle power loss found around 10% compared to the outer region of the stator core. Localised power loss varies from 1.40W/kg to 2.10W/Kg during high excitation in the stator core.

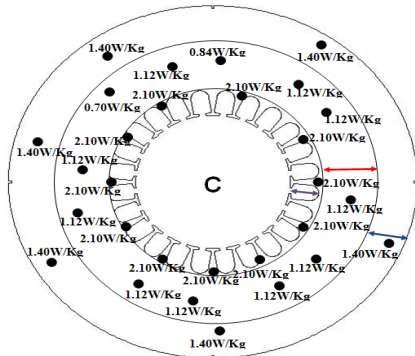


Fig. 14: Localised Power Loss in the Stator Core (C) Magnetised at 1.8T

### 3.5 Average Localised Power Loss Distribution In plane at Stator Core

The value of average power loss of stator core has shown in Table 4. The minimum average power loss were found when the stator core has magnetised at 1.0T refer to Fig. 12, while the maximum average power loss found magnetisation at 1.8T refer to Fig. 14.

In Table 4 also shown that the value of power loss gradually increasing from the outer core back area into the teeth area of the stator core of induction motor. The high average value of localised power loss observed very close to stator teeth area which is enclosed with the three phase windings of motor. In the stator core, all the average values of localised power loss in this area had shown a gradual increase towards the inner region of the stator because of its low excitation to high excitation. The highest average power loss found as 1.26W/kg, 1.54W/kg and 2.10W/kg in very close to tooth centre of the core, the lowest average power loss found in outer core back area as 0.70W/kg, 0.84W/kg and 1.40W/kg and the medium average power loss found in inner core back area as 0.97W/kg, 0.101W/kg and 1.06W/kg respectively.

Average Power Loss (W/kg) at Core-Flux Density (T) Measurement Area	1.0T	1.5T	1.8T
A- Teeth Area	1.26W/kg	1.54W/kg	2.10W/kg
B- Inner Core Back Area	0.97W/kg	1.01W/kg	1.06W/kg
C- Outer Core Back Area	0.70W/kg	0.84W/kg	1.40W/kg

Table 4: Average Localised Power Loss in Stator Core at Flux Density of 1.0T, 1.5T and 1.8T

## IV. RESULTS AND DISCUSSIONS

Under fundamental harmonic level, the localised flux distribution (1.0T) was found greater in the induction area of the core approximately 207% compared to outer core back area and found at the middle of the core approximately 126.9% compared to outer core back area (refer to Fig. 4), the localised flux distribution (1.5T) was found at the inner region of the core approximately 89.7% compared to outer core back area and found at the middle of the core approximately 47.05% (refer to Fig. 5), the localised flux density (1.8T) greater in the slot area instead of outer region approximately 58.21% and found at the middle of the core approximately 35.71% (refer to Fig. 6).

Furthermore, under third harmonic level (1.0T, 1.5T & 1.8T) also flux distribution found increases from outer region to inner region of the stator core. From the practical observation, localised losses are also seen to be highest in the tooth regions of the stator core, where alternating flux is forced, due to the geometry of the teeth. The observations made on the localised flux and loss behaviour within the tooth tip regions of a stator core shown that a much larger flux distortion occurs within the tooth tips. The localised loss for these regions is also seen to be the highest within these regions. Localised flux and iron losses were measured in various locations of the stator core, using small search coils and thermistors, under the core overall excitations of 1.0T, 1.5 T and 1.8T at 50 Hz.

## V. CONCLUSION

We developed a new prototype of stator core which is 24 slots that can be used for 0.5hp induction motor. In order to evaluate the performance of this new prototype stator core, we measured localized flux distribution and power loss in various locations to estimate the motor losses. Based on the above discussion, the following conclusions found as follows:

- The localised flux density found increases from the outer region to the inner region of the developed stator core and the distribution of localised flux density is found to be much higher density at the stator teeth i.e. induction area of the stator core.
- The localised flux density of stator teeth found increased 39.06% while the stator core magnetised from 1T to 1.8T, at 50Hz.
- The localised power loss found also increases from the outer region to the inner region in the developed stator core and the distribution of localised power loss is

found to be much higher density at the stator teeth i.e. induction area of the stator core.

- The localised power loss of stator teeth found increased 40% while the stator core magnetised from 1T to 1.8T, at 50Hz.

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