DESIGN AND DEVELOPMENT OF SINGLE PHASE AC INDUCTION MOTOR USING COPPER ROTOR BARS

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by

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LIST OF SYMBOLS, ABBREVIATIONS OR NOMENCLATURE

A	Ampere
Al	Aluminium
Cu	Copper
B	Magnetic Flux Density
f	Frequency
M	Magnetization
m	Magnetic moment
mmf	Magneto Motive Force
N	Nitrogen
N	Number of Turns
N-M	Newton Meter
R	Resistance
RD	Rolling Direction
R_m	Reluctance
RPM	Revolution per Minute
T	Tesla
V	Velocity of the Bar Relative to the Magnetic Field
W	Watt
Wb	Weber
H	Magnetic Field Intensity
DC	Direct Current
AC	Alternating Current
HP	Horse Power

N	North
S	South
P	Power
Pin	Input Power
2D	Two Dimension
IEEE	Institute Electric and Electronic Engineering
IEC	International Electrotechnical Commission
LIM	Linear Induction Motor
PWM	Pulse Width Modulation
IPM	Interior Permanent Magnet
EMF	Electromagnetic Force
FEM	Finite Element Method
LF	Load Factor
ASD	Adjustable Speed Drive
NEMA	National Electrical Manufacturers Association
TNB	Tenaga Nasional Berhad
AES	Annual Energy Saving
TCS	Total Cost Saving

REKABENTUK DAN PEMBANGUNAN MOTOR ARUHAN ULANG ALIK SATU FASA MENGGUNAKAN BATANG ROTOR TEMBAGA

ABSTRAK

Dalam tesis ini, Motor aruhan arus ulang alik satu fasa telah di kaji dan dianalisa dengan bahan batang rotor yang berbeza pada aspek parameter, kecekapan, faktor kuasa dan kehilangan kuasa yang berlaku pada motor aruhan. Satu batang rotor kuprum dihasilkan dan dibandingkan dengan batang rotor aluminium yang sedia ada sepanjang project ini. Fasa pertama projek adalah perbandingan dilakukan dengan menggunakan simulasi perisian Opera 2D diantara batang rotor aluminium dan batang rotor kuprum untuk motor aruhan kuasa kuda 1.5 yang mempunyai konfigurasi belitan pemegun yang sama. Perbandingan Opera 2D yang dilakukan merangkumi aspek kehilangan kuasa, ketumpatan arus pusar, tork terhadap kelajuan, tork terhadap gelincir, kehilangan kuasa terhadap kelajuan dan kehilangan kuasa terhadap gelincir. Fasa kedua projek adalah perbandingan yang dilakukan di makmal iaitu perbandingan diantara batang rotor kuprum yang dihasilkan dengan batang rotor aluminium yang sedia ada. Dalam bahagian ini, batang rotor kuprum dan batang rotor aluminium dikaji dengan melakukan ujian tanpa beban, ujian rotor tertahan dan ujian rintangan arus terus untuk mengkaji perbezaan kecekapan, kehilangan dan pembaikan faktor kuasa diantara kedua-dua rotor berkenaan. Kesimpulan penyelidikan, baik perisian mahupun ujian makmal menunjukkan bahawa batang rotor kuprum mampu menaikkan kecekapan motor dan faktor kuasa sebanyak 1.07 % dan mengurangkan kehilangan kuasa sebanyak 11 Watt berbanding dengan pengunaan batang rotor aluminium. Satu perhitungan ekonomi telah disediakan untuk menunjukkan bilangan tenaga dan wang yang boleh dijimat dengan mengantikan batang rotor aluminium dengan batang rotor kuprum. Untuk aspek penjimatan tenaga tahunan (AES) dan penjimatan jumlah kos (TCS), rotor kuprum mampu menjimatkan 124.51kWh untuk setahun dan kadar utiliti sebanyak RM41.76 untuk satu motor setahun. Akhir sekali, satu anggaran kasar dibuat untuk penjimatan 100, 000 biji motor aruhan yang telah digantikan dengan batang rotor kuprum dan menunjukkan sebanyak RM4.2 juta boleh dijimatkan.

DESIGN AND DEVELOPMENT OF SINGLE PHASE AC INDUCTION MOTOR USING COPPER ROTOR BARS

ABSTRACT

In this thesis, the single phase AC induction motor have been investigated and analyzed in terms of the induction motor parameter, efficiency, power factor and loss segregation of different rotor bar material. A copper rotor bar is fabricated and compared with the existing aluminium rotor bar through out this project. First aspect of comparison is done with software simulation using Opera 2D between aluminium rotor bar and copper rotor bar for the same 1.5HP stator slot design and winding configuration. The Opera 2D is compared in range of power loss, magnetic flux density, torque vs. speed, torque vs. slip, power loss vs. speed and power loss vs. slip. The second aspect is the hardware comparison between the fabricated copper rotor bars with the existing aluminium rotor bar. In this part, the copper rotor bar and aluminium rotor bar are tested using no load, blocked rotor, and DC resistance test to achive the difference of efficiency, losses and power factor improvement. From the overall experiment of software and hardware, results shows that copper rotor bar does increase the efficiency and power factor to 1.07 % and reduce losses to 11 watts compare to aluminium rotor bar. An economical aspect is presented to show the amount of energy and money that can be saved from replacing the aluminium rotor bar with a copper rotor bar. As for the annual energy saving (AES) and total cost saving (TCS), the copper rotor manage to save 124.51kWh per year and utility billing by RM41.76 per year per motor. Finally a rough estimation of 100,000 pieces induction motor that have been replaced with the copper rotor bars is assumed and shows that it will save approximately RM4.2 million.

CHAPTER 1

AIMS OF INVESTIGATION

It is well known that incorporation of copper for the conductor bars and end rings of the induction motor in place of aluminum would result in attractive improvements in motor energy efficiency. Die cast motor rotors are universally produced in aluminum today because of fabrication by pressure die casting is a well established and economical method. Only small numbers of very large motors utilize copper in the rotors by mechanical fabrication. Such fabrication involves intensive hand labor and therefore is expensive. Die casting, when it can be performed, is widely recognized as a low cost manufacturing process. For these reasons, die-casting has become the fabrication method of choice and aluminum the conductor of choice in all but the largest frame motors. Tool steel molds as used for the aluminum die casting process have proved to be entirely inadequate when casting higher melting point metals including copper. Lack of a durable and cost effective mold material has been the technical barrier preventing manufacture of the copper cast rotor.(J.G. Cowie and D.T 1998)

This thesis focuses on the effect in single phase AC induction motor by replacing copper material instead of the existing aluminium material in the rotor slot of an induction motor. The efficiency and performance of the induction motor using these two materials is investigated. The investigations consider two aspects which are the experimental as well as software to compare and validate the results in term of efficiency of the induction motor.

The design and simulation of single phase AC induction motor by using Opera 2D software version 12.0 for aluminium and copper rotor bars are done as well. The design consists for the rotor bar parameter and the shape for the induction motor. The design parameters are similar with the existing induction motor but vary in terms at the material usage. From this simulation, the magnetic flux density, torque, speed, slip and the loss bar were verified. The performance of the copper rotor bar is investigated in terms of efficiency, power factor, losses reduction potential and economical aspect analysis in terms of money and energy saving is presented as well. The losses such as stator copper loss, rotor loss, core loss, friction and windage loss, stray loss can be obtained by conducting experiments such as no load test, DC resistance test and blocked rotor test. The efficiency of the 1.5HP single phase AC induction motor based on the losses parameters is obtained in both rotors and the results are compared to see if the copper rotor bar of an induction motor can produce the better performance than the existing aluminum rotor bar induction motor.

CHAPTER 2

INTRODUCTION OF ROTATING MACHINE

2.1 Introduction

An induction motor is simply an electric transformer whose magnetic circuit is separated by an air gap into two relatively movable portions, one carrying the primary and the other the secondary winding. Alternating current supplied to the primary winding from an electric power system induces an opposing current in the secondary winding, when the latter is short-circuited or closed through external impedance. Relative motion between the primary and secondary structure is produced by the electromagnetic forces corresponding to the power thus transferred across the air gap by induction. The essential features which distinguish the induction machine from other type of electric motors is that the secondary currents are created solely by induction, as in a transformer instead of being supplied by a dc exciter or other external power sources, as in synchronous and dc machines. (Nyein Nyein Soe, T. T. H. Y, & Soe Sandar Aung, 2008).

2.2 Single Phase Induction Motor Background

Single phase motors are the most familiar of all electrical motors because they are used in home appliances and portable machine tools. In general, they are employed when 3-phase power is not available. There are many kinds of single-phase motors on the market, each designed to meet a specific application. They are composed of a squirrel-cage rotor and a stator. The stator carries main winding, which creates a set of N, S poles. It also carries a smaller auxiliary winding that only operates during the brief period when the motor starts up. The auxiliary winding has the same number of poles as the main winding has.

Starting with the laminated iron stator, paper insulators, called slots liners are first inserted in a slots. The main winding is then laid in the slots. Next, the auxiliary winding is embedded so that its poles straddle those of the main winding. Each pole of the main winding consists of a group of four concentric coils, connected on series. Adjacent poles are connected so as to produce alternate N, S polarities. The empty slots in the center of each pole and the partially filled slots on either side of it are used to lodge the auxiliary winding. The latter has only two concentric coils per pole. The large main winding and the smaller auxiliary winding are displaced at right angles to each other. (W.Theodore, 2006)

2.3 Manufacturing aspect for rotor construction

New lines of high-efficiency induction motors are now being produced by all major manufacturers and they are forming an ever-increasing share of the induction motor market. Several techniques are used to improve the efficiency of these motors compared to the traditional standard-efficiency designs. Among these techniques are: (Peter B.Charlton 1959)

- More copper is used in the stator windings to reduce copper losses.
- The rotor and stator core length is increased to reduce the magnetic flux density on the air gap of the machine. This reduces the magnetic saturation of the machine, decreasing core losses.
- More steel is used in the stator of the machine, allowing a grater amount of heat transfer out of the motor and reducing its operating temperature. The rotor's fan is then redesigned to reduce windage losses.
- The steel used in the stator is special high-grade electrical steel with low hysteresis losses.
- The steel is made of an especially thin gauge (i.e., the laminations are very close together), and the steel has a very high internal resistivity. Both effects tend to reduce the eddy current losses in the motor.
- The rotor is carefully machined to produce a uniform air gap, reducing the stray load losses in the motor.

In addition to the general techniques described above, each manufacturer has his own unique approaches to improving motor efficiency.

The most common three-phase (polyphase) induction motors fall within the following major types:

NEMA(National Electrical Manufacturers Association).

- NEMA design B : Normal torques, normal slip, normal locked amperes
- NEMA design A : High torques, low slip, high locked amperes

- NEMA design C : High torques, normal slip, normal locked amperes
- NEMA design D : High locked-rotor torques, high slip
- Wound-rotor : Characteristics depend on external resistance
- Multispeed : Characteristics depend on design – variable torque, constant torque, constant horsepower

There are many specially designed electric motors with unique characteristics to meet specific needs. (Peter B.Charlton 1959)

2.4 Rotor Models

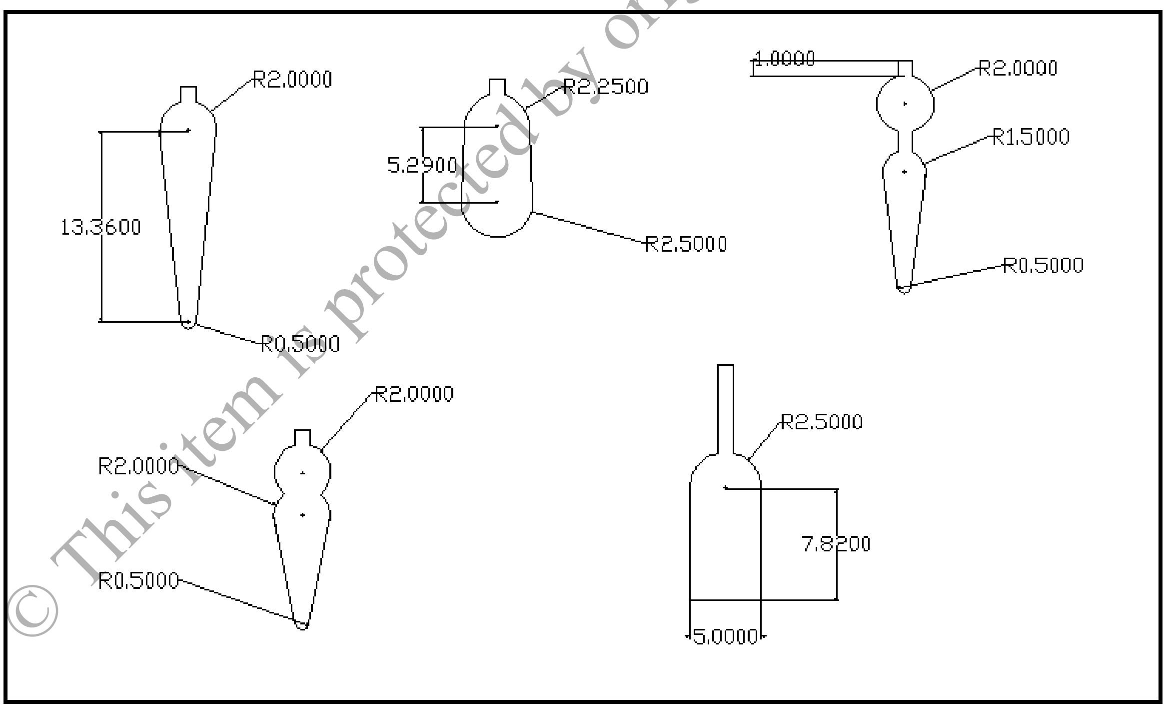

Figure 2.1: Rotor Slot Model

The rotor slots geometry can be considered as an independent design parameter. Nowadays, with the computing tools based on the numerical analysis, it is possible to redesigning of the rotor slots to improve the electromagnetic performance of squirrel cage induction motor without significant cost. (V.A Galindo, 2010). The Figure 2.1 shows the variety of rotor shape that can be used by the manufacturer to improve the efficiency of the motor.

2.5 Investigation of Induction Motor Losses based on Mathematical Modeling

Mathematical modeling is a basic for the dynamic simulation of induction motor. The dynamic simulation is one of the key steps in the validation of the design process of the motor drive systems and it is needed for eliminating inadvertent design mistakes and the resulting error in the prototype construction and testing. The dynamic simulation mostly demonstrates steady state performance of induction motor.

Synchronous speed calculation

$$n_s = \frac{120\,f}{p} \tag{2.1}$$

f = Frequency

p = Number of pole in induction motor stator

n_s = Synchronous speed

Voltage Induced in the rotor calculation

Voltage induced, $e_{ind} = (V \times B) xI$ (2.2)

$V =$ Velocity of the bar relative to the magnetic field

$B =$ Magnetic flux density vector

$I =$ Length of conductor in the magnetic field

Slip in the Induction Motor calculation

Slip speed, $n_{slip} = n_s - n_r$ (2.3)

$$\text{Slip, } S = \frac{n_{slip}}{n_s} = \frac{n_s - n_r}{n_s} \times 100\% \quad (2.4)$$

$$= \frac{\omega_s - \omega_r}{\omega_s} \times 100\,\% \quad (2.5)$$

$\omega_s = Rad/\sec$

$n_r = (1 - S) n_s$

$\omega_r = (1 - S) \omega_s$

n_{slip} = Slip speed of the machine
(Difference in between stator & rotor speed)

n_s = Synchronous speed

n_r =Mechanical shaft/rotor speed

S = slip

Frequency on the rotor

$$sf = f_r \tag{2.6}$$

f = fundamental frequency

Condition 1: $n = 0$, $f_r = f$, $S = 1$

Condition 2: $n = n_s$, $f_r = 0$, $S = 0$

Condition 3: any speed in between , f_r proportional to $(n_s - n)$, slip speed

Slip, $S = \dfrac{n_s - n}{n_s}$ $\qquad\qquad f_r = sf$

$$f_r = \left(\frac{n_s - n}{n_s}\right) f = n_s - n\left(\frac{p}{120 f}\right) f$$

$$= \frac{p}{120}(n_s - n)$$

$$f_r = \left(\frac{n_s - n_r}{n_s}\right) f \quad (\text{Since } n_s = \frac{120\, f_r}{p})$$

$$= n_s - n_r\left(\frac{p}{120 f}\right) f = \frac{p}{120}(n_s - n_r) = \frac{p}{120} \times (\text{Slip speed})$$