Australian Journal of Basic and Applied Sciences, 5(5): 1275-1280, 2011
ISSN 1991-8178

Fabrication and Investigation of Copper Rotor Bar on 0.5HP Induction Motor-A Performance and Economical Study

I. Daut, N. Gomesh, Y. Yanawati, S. Nor Shafiqin, M. Irwanto, Y.M. Irwan, K. Anayet

Power Electronics and Electrical Machine Design Research Cluster School of Electrical Systems Engineering Universiti Malaysia Perlis (UniMAP)

Abstract: The paper deals with the fabrication of copper rotor bars for 0.5HP induction motor and then comparing it with the existing aluminium rotor bars. From this experiment the rotors are compared in terms of efficiency increment as well as losses reduction capabilities and an economical aspect is analyzed and explained. From this investigation it shows that copper rotor bars losses are reduced to ± 5 watts and 1% efficiency increment compared to aluminium rotor bars. The copper rotor has an annual energy savings (AES) of 40.32kWh/year per motor and total saving cost (TSC) per copper rotor motor is RM13.54. 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 RM1.3 million.

Key words: Induction motor, Copper Rotor Bars, Efficiency, Losses, Energy Saving

INTRODUCTION

Induction motors have been used worldwide as a workhouse of the industries. Electric motors are used extensively in every sector of the economy. They perform a wide range of duties throughout the industrial, commercial, residential and agricultural sectors. Motor systems are the largest industrial loads, on average accounting for more than 70 percent of all electricity consumption. Energy consumption of electric motor systems is an important economic and environmental issue. Industrial sectors are the biggest consumer in the electric power generated in Malaysia for about 51.9% of the total electricity consumption (Hassan, M.Y., 2000).

In a study conducted by R.saidur (Saidur, R., 2009) the maximum emphasis was given to find out the end-use electricity used in the industrial production process for the year 2006. Based on the analyzed data, it has been found that electrical motors used the highest amount of energy which is 47% of the total power generated by the industries. As electric motors use a major fraction of industrial energy, several measures could be taken to reduce their energy use such as the usage of energy-efficient motors that can reduce the financial cost of the industrial sector (Saidur, R., 2009) or the usage of copper rotor bars to replace the conventional rotors. The causes and effect is discussed by Bonnet and Soukup (Bonnett, A.H. and G.C. Soukup, 1988) including the rotor failures in squirrel cage induction motors. They gave a practical solution to maintenance in order to avoid rotor failures; meanwhile Craggs (Craggs, J.L., 1976) and Harland (Hartung, E.C., 1994) make a case for consideration of aluminum, including the case for large induction motors. The result is that aluminum rotor bars are not suitable in high slip machines, nor in machines that must accelerate extremely high inertia loads, due to the higher temperature generation in the bars in each of these cases. The design temperature limits for aluminum alloys are generally lower than for copper alloys, comparing tempered and annealed materials. Tempered copper alloys normally yield at a range almost double that of tempered 95 WM 064-6 EC by the IEEE Electric Machinery Committee of the IEEE Power Engineering Society. The paper recommended and approved aluminum, however, tempered aluminum yields at double the range of annealed copper.

Lomax (Lomax, I.D., 1991) reviewed the fatigue life of induction motor cages. Lomax notes that creep failures occur in Copper bars (as well as aluminum) under elevated temperatures during excessive out-of-balance vibration. He also describes failure modes due to high inertia load acceleration over extended acceleration periods, especially for T-type rotor bars. Lomax describes the propagation of cracks starting at the top of the web due to the generation of excessive heat in the bar during starting, followed by cooling and the resultant tensioning. The cracks propagate toward the bulb on each successive start. At the web root, separation may occur, resulting in catastrophic failure as the web is ejected into the air gap due to centrifugal force.

Corresponding Author: I. Daut, Power Electronics and Electrical Machine Design Research Cluster School of Electrical Systems Engineering Universiti Malaysia Perlis (UniMAP).
E-mail: ismail.daut@unimap.edu.my, gomz_84@yahoo.com,

Negative sequence unbalance can exacerbate the problem of vibration failure (Brandolino, J. and R.D. Findlay, 1994). Even a small voltage unbalance of 5% can result in very large Current unbalance (up to 50%), resulting in the development of excessive heating in the rotor bars, as well as vibrations at almost double the synchronous frequency.

Copper Rotor Bar Fabrication Procedures:

Firstly, AUTOCAD software is used to plot the design of the rotor of the 0.5HP AC induction motor. The first step is to measure the exact diameter of the original rotor for 0.5HP motor so that the new design will fit into the stator frame. The only difference is that the rotor slot material is change with copper material rather than the conventional aluminium. The rotor slot type is shown in Figure 1.

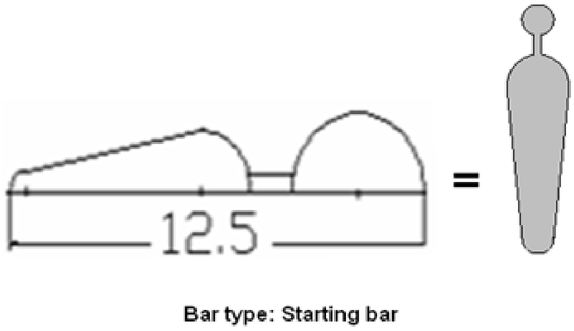

Fig. 1: Dimension of Half Rotor Slot.

Total 192 pieces of laminations sheets is stacked and wielded together on side and in the middle to form the rotor body based on Figure 2(a). A plunger is use to compress the copper powder into the rotor slot with force of 3-4 tons using the pressing station. The pressing station which consists of hydraulic press could apply a maximum force of 10 tons. Melting is the process of hardening the copper to form the rotor slot. The furnace is use to bake the copper for hours straight. At the beginning of the baking process the temperature is set at 200°C for 2 hours. Next step is baking the copper at the temperature of 900°C for 5 hours. Finally the baking process is to be cooled down for another 2 hours. The process is very dangerous as it deals with very high temperature and cost and it may cause health problem due to copper heating. As the rotor bars are copper, 2 copper end rings are sliced and joined with the copper rotor before the pouring of melted copper. Before the argon gas can be supplied to the furnace, the pressure gauge and flow meter is installed to the tank of the argon gas. Water filled with soap is sprayed along the tube and joints to make sure that the argon gas will not leaked during the purging process. The final process is by using the EDM wire cuter machine shown in Figure 2.

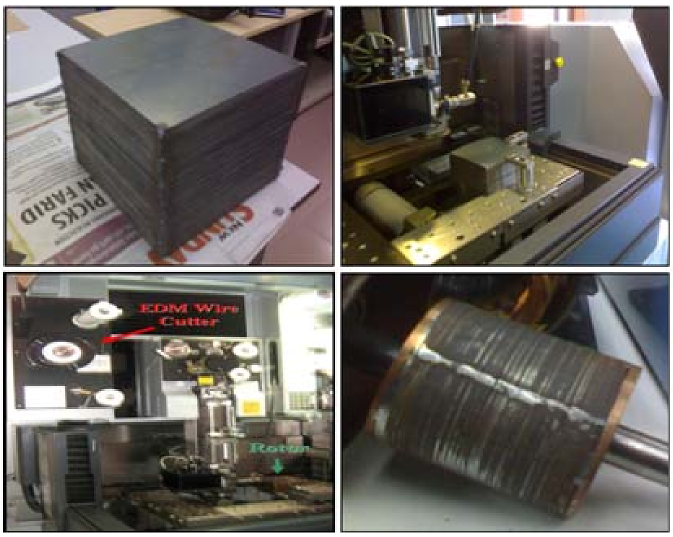

Fig. 2: Copper Rotor Fabrication Procedures.

This machine needs to be set-up by inserting the AutoCAD drawing into the EDM control panel. After initializing the rotor drawings the route of the wire is assign by the operator in which the wire will cut based on the assigned route. Then as these procedures are finish, the rotor is then milled to have a smooth surfaced as shown in Figure 3. The rotor is then inserted into the existing motor shaft. Based on Figure 4 this rotor is then assembled into the stator and laboratory experimental test is performed such as the no load, DC Resistance and block rotor test to obtain the motors efficiency and losses at 0.5HP rated current (1.07A).

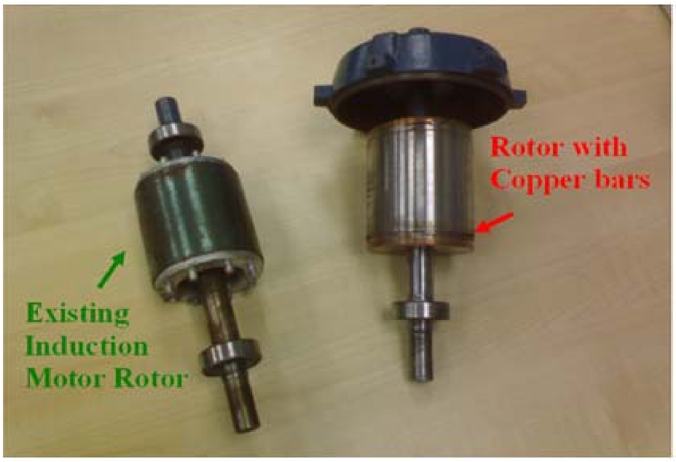

Fig. 3: Copper Rotor of Induction Motor after Milling Process.

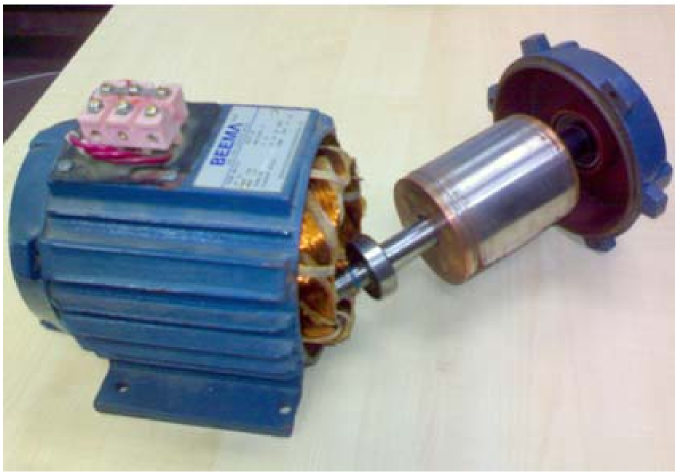

Fig. 4: Copper Rotor assemble into the Induction Motor Stator.

Copper Rotor Bar Efficiency Measurements:

The constructed copper rotor is tested to compare the performance between the copper rotor bars and the existing rotor using the same stator slot and winding configuration. The experimental setup that is performed for the induction motor is the no load, block rotor and DC Resistance test. Through this experiment, the losses are segregated and efficiency is obtained. Table I shows the losses and efficiency of the induction motor with the copper rotor assembled.

The motor efficiency based on equation 1after using the copper rotor is:

$$\eta = (1 - \frac{P_{losses}}{P_{in}}) \times 100\% \qquad (1)$$

$$(1 - \frac{98.41}{569.15}) \times 100\% = 82.7\%$$

Table 1: Loss Segregation of 0.5HP induction motor with copper rotor bars

Loss Segregation	Value(w)
Stator Copper Loss	6.77
Rotor Loss	4.8
Core Loss	64.61
Friction and Windage Loos	8
Stray Loss	14.23
Total Loss	98.41

Comparison of Copper Rotor Bars with Existing 0.5HP Rotor Performances:

Table II shows the comparison of energy consumption and losses between the existing rotors with the fabricated copper rotor. The Opera2D analysis shows that copper has better performance and efficiency and based on Table II, it shows that copper indeed lower the losses compare to the conventional rotor used in the 0.5hp induction motor.

Table 2: Loss Comparison of Existing Rotor to Copper Rotor

Loss Measurement	Existing Rotor(w)	Copper Rotor(w)	Energy Saved (Existing Rotor-Copper Rotor)(w)
Stator Copper Loss	11.84	6.77	5.07
Rotor Loss	5.82	4.8	1.02
Core Loss	63.63	64.61	-0.98
Friction and Windage Loos	8	8	0
Stray Loss	14.23	14.23	0
Total Loss(w)	103.52	98.41	5.11
Efficiency(%)	81.8	82.7	Increased Approximately =1%

From the table, a bar graph is plotted and shown in Figure 5 and it shows that although there is a slight increased in the core loss but the total efficiency of the motor does increase and the losses are reduced up to 5.11Watts per motor. This shows that copper rotor bars can reduce the copper loss hence increase the efficiency of the induction motor.

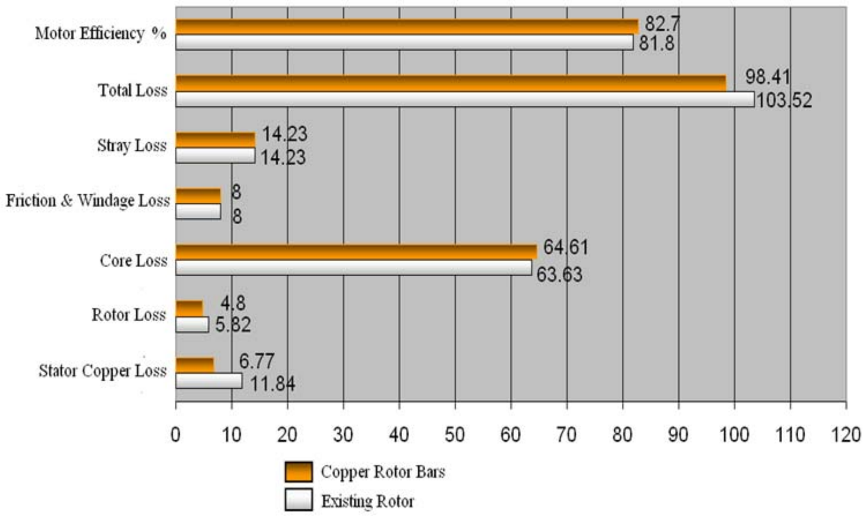

Fig. 5: Copper Rotor and Existing Rotor Performance.

Economical Aspect From Copper Rotor bars:

The amount of money can save depends on motor size, annual hours of use, efficiency improvement, and the serving utility's charges for electrical demand and energy consumed. Three pieces of information are required to evaluate the economic feasibility is (Saidur, R., 2009):

- First, obtain a copy of your utility's rate schedule.
- Then determine load factor or percentage of full rated output.
- Finally, determine the number of motor operating hours at rated load

With this information can determine your annual energy and cost savings. Based on Table II the induction motor efficiency using the copper rotor has increased approximately to 1%. This shows that copper rotor does increase the efficiency of the motor and reduces the stator copper loss and rotor copper loss of the copper rotor motor even though it has a slight increase in the core loss. From this analysis and based on equation 2, the annual energy savings (AES) (Saidur, R., 2009) by replacing copper rotor with an existing rotor can be estimated assuming the load factor to 100%.

$$AES = hp \times L \times 0.746 \times hr \times \left[\frac{100}{E_{std}} - \frac{100}{E_{cr}} \right] \tag{2}$$

Hp=0.5
L= Load factor=100%
Hr =Yearly Operating hours
=24×336 working days = 8064hours
E_{std}=Efficiency of existing rotor=81.8%
E_{cr}=Efficiency of copper rotor=82.7%

Annual Energy Saving (AES):

The average industrial tariff in for factories in Malaysia are 32.5 sen/kWh based on and the minimum monthly charge is RM7.20 for overall monthly consumption more than 200kWh per month. So the Annual energy savings (AES) is

$$AES = 0.5 \times 1 \times 0.746 \times \left[\frac{100}{81.8} - \frac{100}{82.7} \right] = 5Watts$$

This is the amount of energy conserved by the copper rotor induction motor during each hour of use. Annual energy savings are obtained by multiplying by the number of operating hours at the indicated load (Saidur, R., 2009).

$$kWh_{Savings} = 8064h \times 5W = 40.32kWh/Year$$

Total Saving Cost (TSC):

So the amount of energy conserved by the copper rotor induction motor during each hour of use $Wh_{Savings}$ is 40.32kWh/year.The Total saving cost (TSC) (Saidur, R., 2009) can be described by equation 3.

$$TSC = (AES \times 12 \times MontlyDemandCharge) + (kWh_{Savings} \times Energycharge) \tag{3}$$

In Malaysia, with the Monthly Demand Charge = RM7.20, Monthly Energy Charge=RM 0.325/kWh $AES = 5Watt$ and $kWh_{Savings} = 40.32kWh/Year$ so the total saving cost per copper rotor motor is.

Conclusions:

As presented, copper rotor bars is fabricated and tested. Based on experiments it shows that the copper rotor bars reduces losses and the annual energy is saved for about 40.32kW/Year per motor. The total saving cost by replacing the existing rotor with the copper rotor bars in the induction motor reduces utility billing by RM13.54 per year per motor. Let assume that for instance there are 100,000 working motor that have been replaced with the copper rotor bars, an outstanding amount of money which is RM1.3million is being saved in a year. This amount is very huge for small horse powers motors.

ACKNOWLEDGMENT

The authors wish to thank School of Electrical Systems Engineering, Universiti Malaysia Perlis (UniMAP) for providing technical and UniMAP's short term grant scheme for financial support.

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