Shape Design of a Rotor Bar for Improving Starting Torque And Running Efficiency in Squirrel Cage Induction Motor

Ha Jeong Lee[1], Sang Hyeon Im[1] and Gwan Soo Park[1]

[1]School of Electrical and Computer Engineering, Pusan National University, Busan 46241, South Korea gspark@pusan.ac.kr

This paper presents a design of rotor bar to improve the starting torque. The starting torque was improved by increasing the rotor resistance at start-up, and the rotor reactance was considered to maintain the characteristics during operation. And this paper describes the influence of current density of rotor bar on starting torque and rotor copper loss. The rotor bar was designed to improve the starting torque without reducing the operating efficiency.

***Index Terms*— Squirrel cage induction motor, starting torque, efficiency, rotor bar shape, rotor resistance, rotor reactance,**

I. Introduction

Squirrel cage induction motors are widely used in many industrial fields because of their simple structure, high durability and low cost. However, since the starting torque is poor, there is a limit to be used in some fields.

Various researches have been studied to increase the starting torque, and the most representative method is the study of the rotor bar shape. The deep bar is a typical rotor slot shape in which the starting torque is high. However, since the reactance of the rotor is high, it causes a decrease in efficiency during operation. Therefore, a design of the rotor bar is required to raise the starting torque and increase the efficiency [1-3].

In this paper, the design of rotor shape proposed by considering the rotor reactance as well as the resistance. There are some advantages. Fist, since the rotor slots have the same area the cross-sectional, there is no change in the operating characteristics such as the rated torque and the maximum torque. Second, the starting torque is improved by designing to increase the rotor resistance during starting considering skin effect. Finally, the efficiency does not decrease, since the total amount of loss is similar. The above advantages are analyzed and verified through the equivalent circuit of the induction machine and 2D FEM analysis.

II. Resistance and Reactance of the Rotor

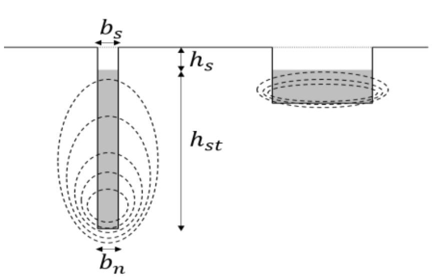

Fig. 1 Rectangular shaped rotor bars,

A. Rotor resistance

The rotor resistance is changed by the shape of the rotor bar and skin effect during starting operation. Fig. 1 shows two bars with different shape. When a rotor starts, a deep bar has a large resistance, while the shallow bar has a small resistance. This is because the current is concentrated at the surface due to the skin effect. Therefore, as the resistance of the deep bar increases, the starting torque also increases by (1).

$$T = \frac{3}{\omega_s}\frac{V_{1a}^2(R_2'/S)}{[R_1'' + (R_2'/S)]^2 + (X_1'' + X_{l2}')^2} \quad (1)$$

B. Rotor reactance

Rotor Reactance also affects the torque characteristics. Rotor reactance and leakage conductivity was determined by (2) and (3). The deep bar has an advantage that the starting torque is large, but since the leakage conductivity is large as in (3), there is a disadvantage in that the efficiency is inferior [4].

$$X_{l2}' = k z_{eff,2}\frac{\lambda_{n,2}}{q_2} \quad (2)$$

$$\lambda_{n,2} = 0.66 + \frac{h_{st}}{3b_n} + \frac{h_s}{b_s} \quad (3)$$

where k is the conductivity, $z_{eff,2}$ is the number of effective conductors per phase, $\lambda_{n,2}$ is the leakage conductivity, and q_2 is the number of the rotor slot.

III. New Design of Rotor Bar

In order to consider both start-up and operation characteristics, the rotor bar was divided into two parts as shown in Fig. 2. At start-up, current is concentrated at the top of the bar due to the skin effect. Therefore, by adjusting the shape of this part to increase resistance, it is possible to improve the starting torque. Compared with the conventional model, the new model shows a 55.78% reduction in the cross- sectional

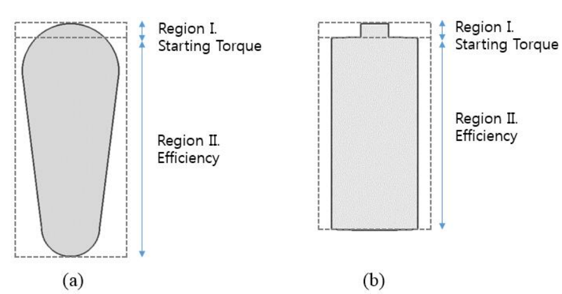

Fig. 2 The shape of rotor bar. (a) Conventional model. (b) New model.

area of the upper part and this is an important factor in increasing the starting torque. In addition, considering the reactance of the rotor, the rotor was designed so as not to reduce the efficiency. Fig. 2 (b) shows that the rotor reactance doesn't increase compared to conventional model as the length of the bar is maintained and the efficiency also can be prevented from decreasing.

IV. SIMULATION RESULT

A. *Starting Torque*

The new model was analyzed by 2D FEM simulation. Fig. 3 shows the comparison of the magnetic flux density, current density and torque distribution in the conventional bar and proposed bar. It can be seen that the magnetic flux density and the current density are more distributed in the surface.

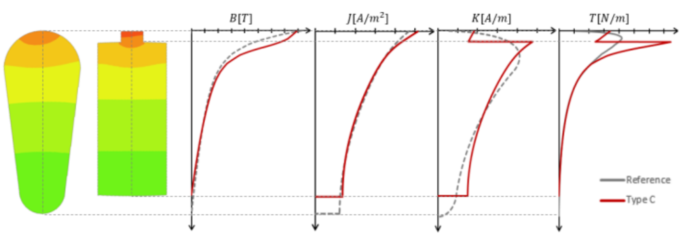

Fig. 3. Distribution of magnetic flux density, current density and torque in the middle line of rotor bars.

Torque is determined by the radius, current density and magnetic flux density by (4). Therefore, in the proposed model, the starting torque will becomes larger. Table I shows the surface area and starting torque results from the FEM analysis to verify. The starting torque in the proposed model increased by 11.6%.

$$T = \sum_{i=1}^{n} \left[\vec{r_i} \times \int_{vol} \vec{J} \times \vec{B} dv \right] \tag{4}$$

TABLE I
THE CROSS-SECTIONAL AREA OF THE UPPER PART AND STARTING TORQUE

	Cross-sectional area of the upper part	Starting Torque
Conventional Model	$2.291mm^2$	3.35 N·m
New Model	$1.013mm^2$	3.74 N·m

B. *Operation Efficiency*

Efficiency is affected by iron loss, and copper loss of the stator and rotor. Fig.4 shows the iron loss in conventional and proposed model. It can be seen the iron losses in both models have similar distribution and size. In order to calculate the copper loss of the rotor bar, the current density and copper loss distribution in the middle line are shown in Fig. 5. The current loss in the rotor bar was calculated by (5).

$$W_r = \frac{1}{\sigma} \int_{vol} J^2 dV \tag{5}$$

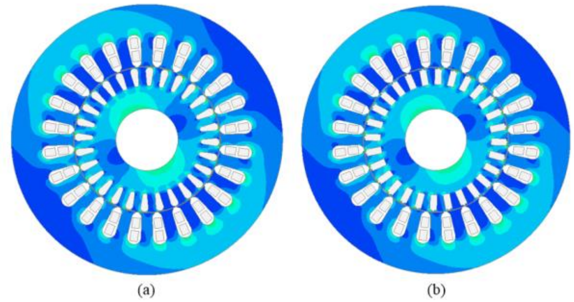

Fig. 4 The iron loss of the stator and rotor. (a) Conventional model. (b) New model.

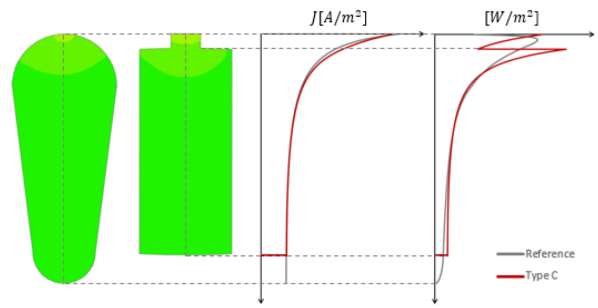

Fig. *5* The current density and copper loss of the rotor bar during operation.

Table II shows the various losses in both rotor bars. Overall, the losses in both models are similar, so there is no change in the efficiency of 88%.

TABLE II
Various Losses OF THE REFERENCE AND PROPOSED MODEL

	Core Loss	Stator Copper Loss	Rotor Copper Loss	Efficiency
Conventional model	44.2W	53W	12.6W	88.00%
New model	44.0W	53W	12.8W	88.01%

V. CONCLUSION

In this paper, shape design of rotor bar was presented to increase the starting torque and efficiency of induction motor. By designing the shape of the rotor bar considering the resistance and reactance of the rotor, the induction motor is designed to raise the starting torque without affecting the efficiency. Experimental results support the verifications of this design.

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