# Design and Analysis of Rotor with New Novel Shape by Inductance Changes for Power Improvement

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## Abstract

This study shows the novel rotor shape of the spoke-type PMSM to improve power by changes of permeance in the rotor and air-gap. Applying a wedge-shape barrier to the rotor results in a permeance change in some areas of the rotor, in which saturated magnetic flux density existing, which in turn changes the magnetic reluctance in the air-gap. As the magnetic reluctance changes, the inductance of the rotor d-axis decreases and the q-axis inductance increases to improve the reluctance torque. We investigated to maximize the reluctance torque and air-gap magnetic flux density with a wedge-shape barrier. In other words, magnetic flux density saturation area, which can help rarely torque increase, was subtracted. In addition, it also can change inductances of d-axis and q-axis. Accordingly, it was confirmed that average torque improves as magnetic flux density saturation was removed.

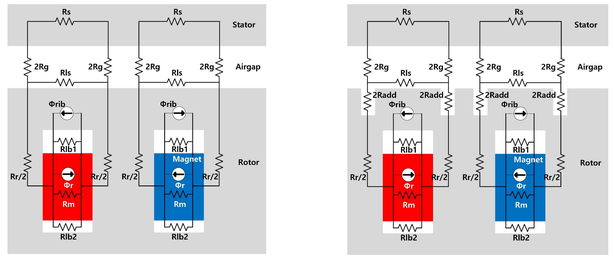
## Conclusion

It is investigated the wedge-shape barrier for higher power from removing the magnetic flux density saturation through RSM. The air-gap permeance was changed and d-axis and q-axis inductances were changed when the wedge-shape barrier applied. As a result, torque improves by 4.4%. Especially, reluctance torque was greatly increased because of the increased saliency. The spoke-type PMSM with wedge-shape barrier has been manufactured and no-load back electromotive force was verified which is equal to the FEM result. Finally, the test environment was built up and the machinability and performance were verified through the motor test. For the further work, research will be undertaken to improve motor control and further improvement of the wedge-shape barrier.

## Introduction

❖ This study investigates the wedge-shape barrier of the spoke-type PMSM to maximize the reluctance torque by permeance changes. Some area of rotor is needless, in which it has the magnetic flux saturation. If the wedge-shape barrier is designed without considering the workability of the motor, the output can be maximized [7]. That is why the wedge-shape barrier with proper machinability are designed in this study and a prototype model has been manufactured. Furthermore, the area is related to inductances of d-axis and q-axis. We found out the areas and improve the power in this study.

## Investigation of Wedge shape barrier




(a) (b)

Magnetic equivalent circuit (a) basic model (b) wedge-shape model

❖ Air gap permeance

$$\Lambda_r(\alpha)=\frac{B_r(\alpha)f_{mf_r}(\alpha)+B_\theta(\alpha)f_{mf_\theta}(\alpha)}{f_{mf_r}^2(\alpha)+f_{mf_\theta}^2(\alpha)}$$

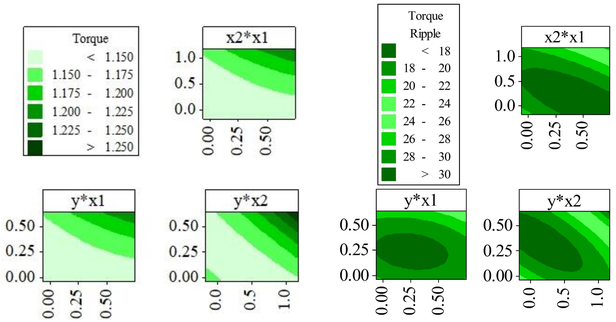
$$\Lambda_\theta(\alpha)=\frac{B_r(\alpha)f_{mf_\theta}(\alpha)-B_\theta(\alpha)f_{mf_r}(\alpha)}{f_{mf_r}^2(\alpha)+f_{mf_\theta}^2(\alpha)}$$

❖ Torque

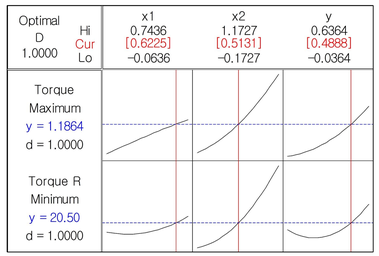
$$T=\frac{3}{2}p\lambda_{pm}I_a\cos\beta+\frac{3}{4}p(L_q-L_d)I_a^2\sin 2\beta \quad [Nm]$$
$$=\left(\frac{\pi}{4}k_w\hat{B}_{g1}ac\cos\beta\right)D_g^2L_{stk}$$
$$+\left(\frac{\pi}{16}\frac{1}{p}k_w^2ac^2G_{a1}\sin 2\beta\right)D_g^3L_{stk} \quad [Nm]$$

$$T_r=-\frac{1}{2}\frac{(Ni)^2}{R^2}\frac{\partial R}{\partial\theta}=-\frac{1}{2}\phi^2\frac{\partial R}{\partial\theta} \quad [Nm]$$

## Response Surface Method




(a) (b)



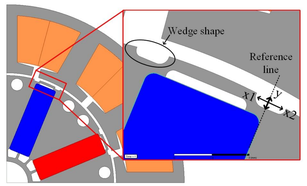

(c)

Contour plots by x1, x2 and y of wedge-shape barrier (a) torque (b) torque ripple (c) Response optimization

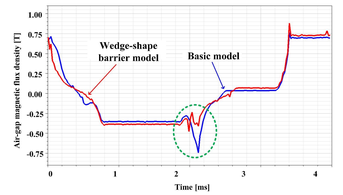
❖ Optimizing for higher torque and lower torque ripple

$$Torque = 1.10+0.0424(x1)+0.0417(x2)+0.0793(y)$$

$$Torque\ Ripple = 16.1+1.73(x1)+3.26(x2)+3.81(y)$$

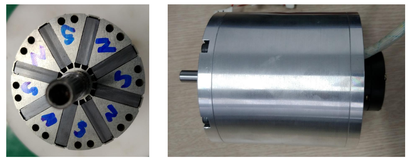



Final model with wedge shape barrier




Air-gap magnetic flux density at load

※ The air-gap magnetic flux density wave becomes more uniform.



Prototype of spoke-type PMSM

Comparison of FEA and Experimental

| | FEA | Experimental |
|---|---|---|
| Rated torque [Nm] | 1.157 | 1.12 |
| Maximum speed torque [Nm] | 0.368 | 0.374 |

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