

# Design of High Torque Density Ferrite Permanent Magnet Motor Using Scale Factor

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Rare earth permanent magnet (PM) motors have high efficiency and torque density, but they have the drawback of a high material cost. There is a great interest in designing PM machines without adopting such rare earth PMs. Thus, this paper proposes the use of ferrite instead of rare earth PMs to decrease the material cost. The models with structures are discussed that increase the Torque density. Discussed model is considered efficiency, reduce costs and winding temperature of the motor using scale factor. Thus, a motor using ferrite with the proposed structure can replace a motor using rare earth PMs. And the motor is fabricated and tested in order to verify its feasibility.

*Index Terms*— Torque density, concentrated flux type motor, ferrite magnet motor, efficiency.

## INTRODUCTION

The rare earth permanent magnets are commonly used in many industrial applications. They studied other type of PM motor owing to improve torque density and efficiency [1]-[3]. In particular, interior permanent magnet synchronous motors (IPM) and surface mounted permanent magnet motors (SPM) are the convenience of adopting rear earth PMs so as to improve the torque density and efficiency [4]-[6]. In particular, interior permanent magnet synchronous motors (IPMs) that use rare-earth permanent magnets have attracted considerable attention. However, the drive to minimize or eliminate the use of rare-earth permanent magnets has been accelerated because of their significant price fluctuations and the potential restrictions on their future supply [7]-[8]. Two methods can be used to increase the torque density in motors: increasing the flux per pole and improving the saliency ratio. There are two methods to increase the flux per pole: expanding the cross-sectional area of the permanent magnets and expanding the cross-sectional area of the gaps. To increase the saliency ratio, a method that increases the permanent magnet layers can be used. This paper discusses the characteristics of motors with various structures such as a model with a rotor structure where the cross-sectional area of the permanent magnets is increased, a model where the cross-sectional area of the gaps is increased, and a model where the permanent magnet layer is increased. Furthermore, the characteristics of motors with the proposed structure are compared. This paper proposes a motor structure to replace motors using rare earth magnets and uses a characteristic analysis to determine whether a motor with the proposed structure can replace motors using rare earth magnets. In the end, the motor is fabricated and tested in order to verify its feasibility.

## MAGNET TYPE

The rare earth magnets are used in several industrial applications. Because they have high efficiency and torque density but they have drawback of a high price and significant fluctuations in their prices over the past few years. Fig. 1. Shows the B-H curve of both high grade ferrite and NdFeB PMs. NdFeB has a

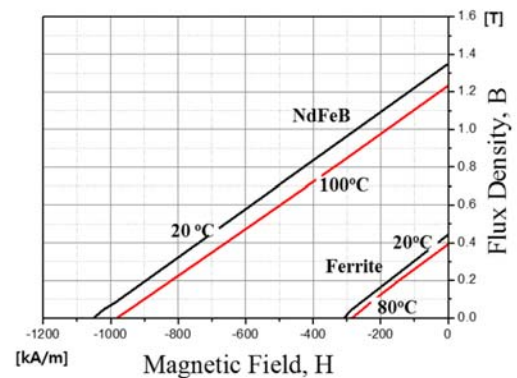


Fig. 1. B-H curves of NdFeB and ferrite PMs

higher remanence and coercivity than ferrite magnets. It is practically ten times higher than that of the ferrite PMs. On the other hand Advantages of ferrite magnets are low cost and price fluctuations, compared with the rare earth PMs.

## INDUSTRIAL MACHINE USING REAR EARTH MAGNET

The geometry of an actual 5kW industrial SPM machine has been adopted as a NdfeB machine. The pupose of this study is to replace concentrated flux type motor (CFM) using ferrite PMs achieving the same average torque, efficiency and power. The design methodology of both stator and rotor is required to maximize the performance.

This SPM machine exploits an electromagnetic torque. The NdfeB PMs have a parallel magnetization and the remanent flux density  $B_r=1.2T$  at  $20^\circ C$ . Table I reports the main geometrical dimension of the SPM machine. And NdfeB machine is shown in Fig. 2.

## COMPARISON OF THE CFM STRUCTURE

### Numerical Approach

The parameters were deduced in order to review the structure of increasing the torque density. The back electro motive force (EMF) can be written as

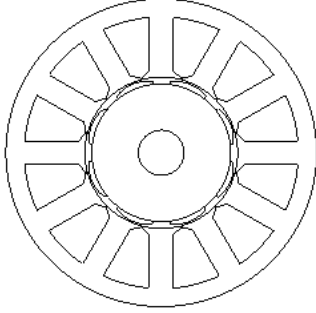


Fig. 2. Nd model Geometry

TABLE I. ND MODEL GEOMETRIC DATA

Item	Value
Stack length	120 mm
Stator external diameter	170 mm
Stator inner diameter	83.6 mm
Effective air-gap	0.8 mm
Rotor external diameter	82 mm
Rotor inner diameter	25 mm
Br	1.2 T

$$E = \omega \frac{4 k_w N}{\pi 2p} DL_{stk} \frac{B_r}{\frac{\pi D}{4ph_m} + \frac{2g\mu_{rec}}{t_m}}$$

It was investigated using the inductance equation to review the reluctance torque. The inductance is independent of the speed change only depending on the size and phase of the current. d-axis inductance can be written as

$$L_d = \frac{3}{\pi} \mu_0 \left( \frac{k_w N}{2p} \right)^2 \frac{DL_{stk}}{g} \left[ \frac{2\alpha_m + \sin 2\alpha_m}{\pi} - \frac{\frac{4}{\pi}}{\frac{\pi}{2} + 4p \frac{g\mu_r h_m}{t_m D}} \right]$$

d-axis inductance can be written as

$$L_q = \frac{3}{\pi} \mu_0 \left( \frac{k_w N}{2p} \right)^2 \frac{DL_{stk}}{g} k_p$$

Where  $E$  is the phase back electro motive force,  $\omega$  is the electrical angular velocity,  $k_w$  is the winding factor,  $N$  is the series number of turns per phase,  $p$  is the number of pole pair,  $g$  is the air gap length,  $D$  is inner diameter of stator,  $L_{stk}$  is the stack length of motor actual part,  $\mu_{rec}$  is the recoil permeability,  $t_m$  is the thickness of PM,  $h_m$  is the cross-sectional area of the permanent magnet,  $L_d$  is the d-axis inductance,  $L_q$  is the q-axis inductance.

There are ways to increase the flux per pole and ways to increase saliency ratio in the design plan for the torque density improvement and cost reduction. To increase the flux per pole, an increase in the thickness and/or area of the permanent magnet or an increase the cross section of the air gap is needed. To increase the saliency ratio, a decrease in the thickness and/or area of the permanent magnet or an increase the cross section of the air gap is needed, and increase in the number of permanent-magnet layers.

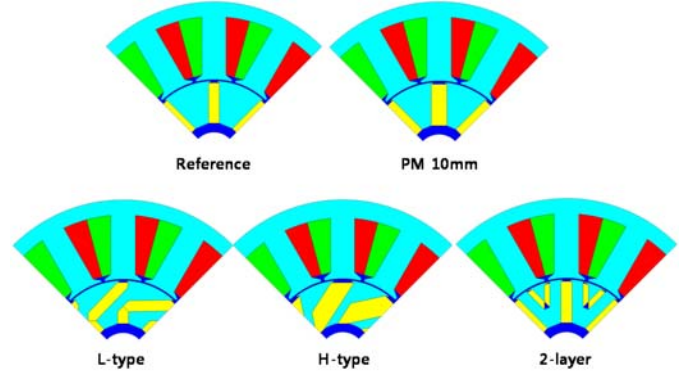


Fig. 3. Concentrated-flux-type ferrite magnet motor

Fig. 3 shows the review models for CFM structures. The ferrite residual magnetic flux density is 0.38T. The traditional shape of CFM was selected as the reference motor for comparison. Review the model was to increase the flux per pole as discussed above in formula. H-type model can increase the electromotive force than the other models and can reduce the material cost.

## CONCLUSION

A H-type motor with the various rotor structures is investigated for industrial servo motors. Moreover, this paper proposes a H-type motor that can increase torque density and reduce material cost.

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