COMPUMAG Shenyang, China June 26 - 30, 2005

Characteristic analysis of the Axial-Flux Type Brushless DC Motor Using Image method

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Abstract—**An analytical method of images using magnetic charge is applied to analyze the field distribution and force distribution of axial-flux type BLDC motors in this paper. Using the method, flux density distribution is calculated and verified by 3D FEA. Flux density distribution is used for the calculation of axial force distribution. The distribution of the axial force, the output torque, and harmonic component of axial force according to the driving method are presented.**

I. Introduction

Axial-flux type brushless dc (BLDC) motors have the flux along the axial direction contributing to output torque. Since the motors are generally air-cored, the energy density in air-gap is lower than that in cored motors. However, the air-cored axial-flux BLDC motor have little cogging torque, and torque ripple is so small that they are suitable for the application such as VCR, CD players and Floppy disc driver.

For the analysis of axial-flux type BLDC motor, 3-dimensional finite element analysis (3D FEA) is general, because the flux distribution of the motor is 3 dimensional [1]. However, 3D FEA requires large time for computation and pre-processing. Therefore, an analytical method of image using magnetic charge is used for the characteristic analysis of the axial-flux type BLDC motor in this paper [2]. The analysis result is verified by comparing the flux distribution in the air gap to that from 3D FEA.

The characteristics of the motor, such as speed, torque, current, and efficiency are calculated from the results of image method and these results are considered to the design of the motor [3]. Also, the distribution of the axial force characteristics, the output torque, and harmonic according to driving method are analyzed.

II. Image method

Magnetic field is conveniently analyzed by analytical method in case that saturation is not significant. Generally axial-flux type BLDC motors hardly saturated due to large and constant air-gap length so the analytical solutions can give precise result for this kind of application [4].

The essence of the image method consists in replacing the effects of a boundary line, and the desired field being given

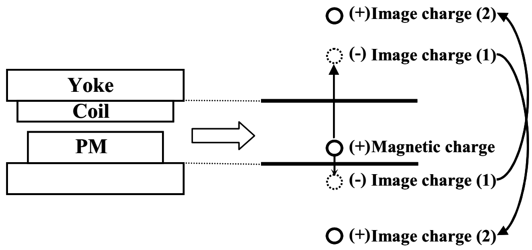


Fig. 1. Image model of axial-flux type BLDC motor

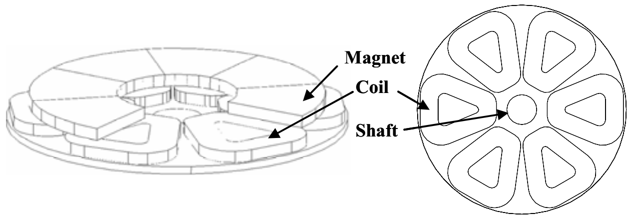


Fig. 2. Configuration of single sided axial-flux type BLDC motor

by the sum of the applied and the image fields [5]. The analysis model of image method for axi-flux type BLDC motor is shown in Fig. 1. Single sided axial-flux type BLDC motor configuration in Fig. 2 [6].

For the calculation of 3-dimensional flux distribution in axial-flux type BLDC motor, radial and circumferential component of stator current are considered in this paper because the axial component of current is negligible.

To get the flux density with image method, magnetization ($\boldsymbol{M}$) is replaced by magnetic charge ($\pm Q_m$) and this is shown in Fig. 2. Differential magnetic field strength ($d\overrightarrow{H}$) on the magnet surface can be represented by (1), and differential magnetic charge (dQ_m) can be expressed by B_r using (2).

$$d\overrightarrow{H} = \frac{dQ_m}{4\pi r^2}\overrightarrow{a_r} \tag{1}$$

$$dQ_m = \frac{B_r}{\mu_0}dS \tag{2}$$

where, B_r, μ_0, and dS are the remanent flux density of permanent magnet, the relative permeability of vacuum, and differential area. If the distributions of flux density in air gap are estimated, the axial force and output torque can be calculated by (3).

$$d\vec{f} = (\vec{J} \times \vec{B}) \cdot dv \tag{3}$$

Therefore, by integrating force density in air gap, force distribution and torque are calculated.

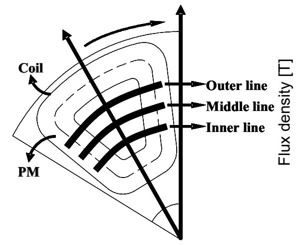
III. ANALYSIS RESULT

Contour lines to air-gap flux density and three component of air-gap flux density from analytical method and 3D FEA are compared in Fig. 3 and the comparison shows good agreements. In Fig. 3, b is the axial component of flux producing torque, c and d are the components producing axial vibration and noise. The axial force, harmonic component of force, and output torque calculated by image method according to driving method are presented in Fig. 4, Fig .5, and Fig.6 respectively.

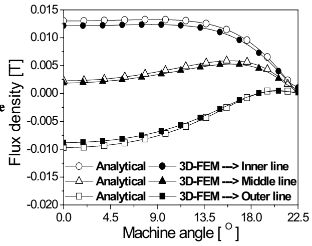
From Fig.4 ~ Fig. 6, it is evident that sine-wave drive produces more stable distribution of axial force than 6-step drive. In addition, the design to reduce axial force, image method can be practically applied, because it does not require geometrical modeling and provides accurate result rapidly.

III. CONCLUSIONS

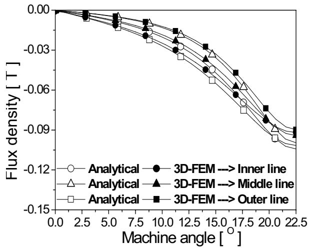
In this paper, image method, where the magnetization of permanent magnet is replaced by magnetic charge, is applied to the analysis of the axial-flux BLDC motors having 3-dimensional flux distributions. With the method, the flux distribution is calculated, and axial component of force and output torque are calculated according to driving method.



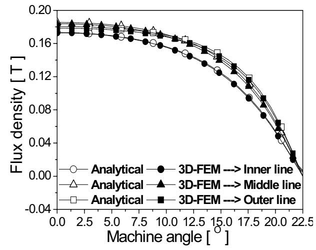
a. Contour line



b. Radial component

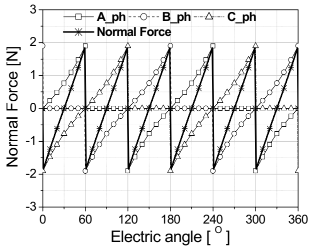


c. Peripheral component

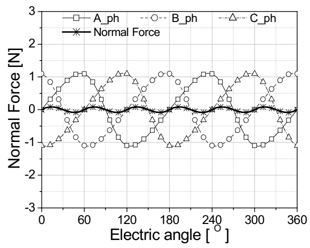


d. Axial component

Fig. 3. Flux density from analytical method and 3D FEA along contour lines.

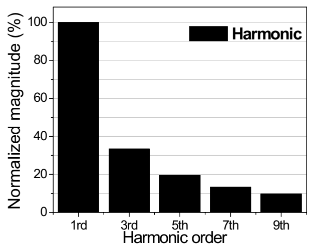


a. 6-Step drive

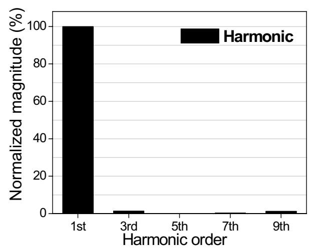


b. Sine-wave drive

Fig. 4. Axial component of force by 6-Step and Sine-wave drive

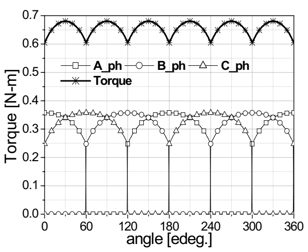


a. 6-Step drive

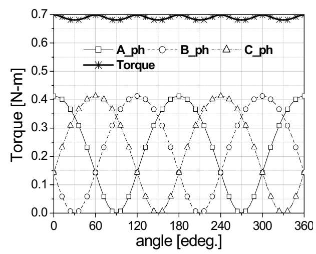


b. Sine-wave drive

Fig. 5. Harmonic components of normal force



a. 6-Step drive



b. Sine-wave drive

Fig. 6. Output torque of 6-Step and Sine-wave drive

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