Modeling and Analysis on Quasi-parallel Magnetic Field Created by Magnetic Rings Array

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This paper presents a quasi-parallel magnetic field created by magnetic rings array for a VCM (voice coil motor), which consist of six permanent magnetic rings arranged coaxially, and an aluminium ring is inserted between two magnetic rings for heat dissipation. The magnet rings are magnetized the inside as S pole and the outside as N pole, and consists of four same pieces. In this paper, firstly, the structure of magnetic ring array is introduced; Secondly, a mathematical model of the quasi-parallel magnetic field is established and its characteristics are analyzed. Finally, the characteristics of the quasi-parallel magnetic field using magnetic rings array is verified by FEM (Finite Element Method) analysis.

***Index Terms*—FEM, Magnetic ring array, Mathematical model, Quasi-parallel magnetic field.**

I. INTRODUCTION

Analytic calculation of the magnetic field is very important for designing motors and some magnetic devices. Until now, the researchers have proposed the various analytic calculations of the magnetic field created by permanent magnets [1]-[2]. In this paper, the authors propose a quasi-parallel magnetic field created by magnet rings array for a voice coil motor. The mathematical model of the proposed magnetic field is built, and the magnetic flux density is calculated using the mathematical model. Finally, the calculated results are verified by FEM analysis.

II. STRUCTURE AND PRINCIPLE

The structure of the proposed VCM and the dimensional parameters are respectively shown in Fig. 1 and Table I. The VCM consists of two major parts: mover and stator. The mover is coil and moves along the axis of VCM.

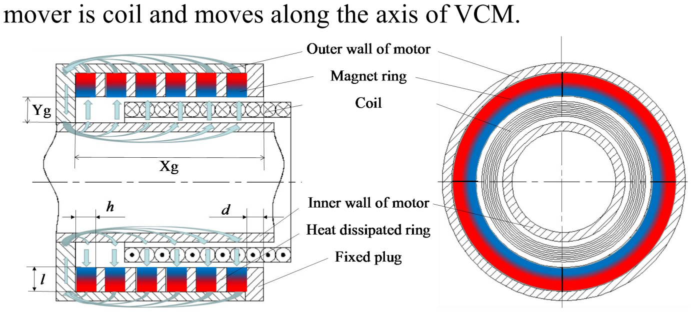

Fig. 1. Structure of the VCM.

TABLE Ⅰ
PARAMETER TABLE

Parameter	Value
Width of magnet ring $h(mm)$	12.5
Length of magnet ring $l(mm)$	12
Width of heat dissipated ring $s(mm)$	3
Length of the rotor gap x_g(mm)	95.5
Width of the rotor gap y_g(mm)	18
Current line density k_v	10^9
Width of fixed plug d(mm)	5.5
Permeability of vacuum μ_0(H/m)	$4\pi*10^{-7}$

The stator consists of the inner wall of motor, outer wall of motor, six magnet rings, heat dissipated ring and the fixed plug. Each magnet ring is composed of four same pieces, and its material is Nd-Fe-B, the magnet rings are magnetized the inside as S pole and the outside as N pole. Heat dissipated ring is used for dissipating heat between two magnet rings to avoid some phenomenons of heat accumulation and magnet overheating. Fixed plug plays a role of fixing magnet rings and heat dissipated rings.

The stator can generate the quasi-parallel magnetic filed as shown in Fig. 1. The magnetic flux is generated by the N pole of magnet rings, through outer wall of motor and inner wall of motor, passed air gap of motor, and finally closed itself through the S pole of magnet rings. It is worth mentioning that the number of magnet rings can be changed according to the requirements of users. When the inner wall, outer wall, and the magnetic rings form the parallel magnetic field, and the control current flows through the coil, the lorentz force drives the mover moving along the axial direction of the motor.

III. MATHEMATICAL MODEL OF MAGNETIC FIELD

In order to analyze quasi-parallel magnetic field in the air gap between magnetic rings array and inner wall of motor, the mathematical model of the magnetic flux intensity of the magnet field is built in Y direction according to Ampere molecular circulation hypothesis, as shown in Fig. 2.The description of the variables in the formula is shown in Table Ⅱ.

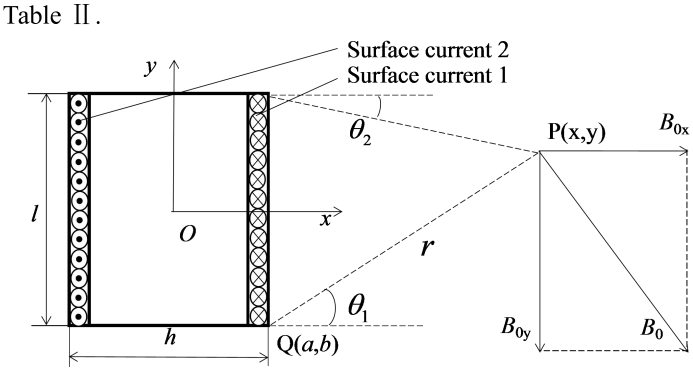

Fig. 2. Schematic Diagram of the Magnetic Field of Single Magnet Ring.

Table II

VARIABLE TABLE

Variable	Description
Q(a, b)	Horizontal and vertical coordinates of any current source
P(x, y)	Horizontal and vertical coordinates of any point in a plane
j	Ring number from left to right, j=1~6
θ_1, θ_2	Angle between the upper and lower points of surface current 1
θ	Angle between the line of point Q and point P and the horizontal line
r	Distance between point Q and point P
B_{yj1}	Magnetic flux intensity of surface current 1
B_{yj2}	Magnetic flux intensity of surface current 2
B_y	Magnetic flux intensity of the magnetic rings array

B_{y11} can be expressed as Equation (1), according to B_{y11}, B_{y12} can be obtained.

$$B_{y11} = -\int_{\theta_1}^{\theta_2} \frac{\mu_0 k_v}{2\pi r} \cos\theta \, \mathrm{d}b$$
$$= \frac{\mu_0 k_v}{2\pi}[\arctan(\frac{y-l/2}{x-h/2}) - \arctan(\frac{y+l/2}{x-h/2})] \quad (1)$$

$$r = \frac{x-h/2}{\cos\theta} \quad (2)$$

$$\theta_1 = \arctan(\frac{y+l/2}{x-h/2}); \theta_2 = \arctan(\frac{y-l/2}{x-h/2})$$

In order to analyze the magnetic fields of the six magnetic ring arrays, the magnetic flux intensity B_y of the magnetic rings array in the air gap in Y direction can be expressed as Equation (3):

$$B_y = \sum_{i=1}^{6} B_{yj1} + \sum_{i=1}^{6} B_{yj2} \quad (3)$$

$$B_{yj1} = \frac{\mu_0 k_v}{2\pi} \arctan(\frac{y-h/2}{x-(j-1)\cdot(l+s)-l/2})$$
$$- \frac{\mu_0 k_v}{2\pi} \arctan(\frac{y+h/2}{x-(j-1)\cdot(l+s)-l/2}) \quad (4)$$

$$B_{yj2} = \frac{\mu_0 k_v}{2\pi} \arctan(\frac{y+h/2}{x-(j-1)\cdot(l+s)+l/2})$$
$$- \frac{\mu_0 k_v}{2\pi} \arctan(\frac{y-h/2}{x-(j-1)\cdot(l+s)+l/2}) \quad (5)$$

IV. VERIFICATION OF FEM AND THEORETICAL ANALYSIS

A. FEM analysis on magnetic field.

FEM analysis verifies the characteristics of the quasi-parallel magnetic field using magnetic ring array. Fig. 3 shows FEM analysis on magnetic field for a half of the VCM stator, and indicates that the magnetic flux is nearly parallel in the air gap. This proves that when it moves in the air gap, the coil moves though cutting the parallel magnetic flux.

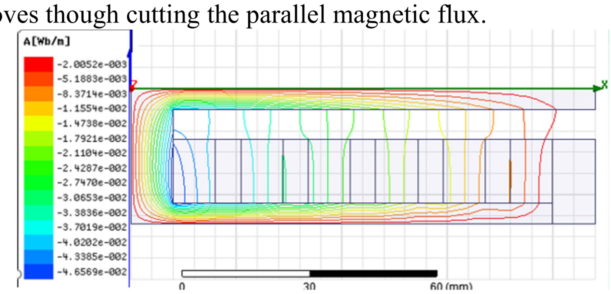

Fig. 3. FEM analysis on magnetic field for a half of the VCM stator.

B. Theoretical and FEM result of the quasi-parallel magnetic field characteristics.

In order to analyze the characteristics of the quasi-parallel magnetic field created by the magnetic rings array, the calculation analysis was carried out basing on the mathematical model Eq.(3). The calculation positions are the middle positions of the stator's air gap in radial direction, and are from left to right in the stator's air gap in axial direction shown in the left figure of Fig. 1.

Fig.4 shows theoretical result and FEM result of the total magnetic flux intensity B_y in the stator's air gap. The position x=0mm is the center of the first magnetic ring from left side. The solid and dotted line in Fig. 4 are shown as theoretical and FEM result of the total magnetic flux intensity B_y. When x=0~80mm, the flux indensity is regularly fluctuated, the moving mover can produce Lorentz force in this parallel magnetic field. The FEM results are similar to the theoretical results, although the value of the flux indensity is different since the lateral end effect, the eddy currents and hysteresis losses in ferromagnetic materials can be ignored in the theoretical calculations.

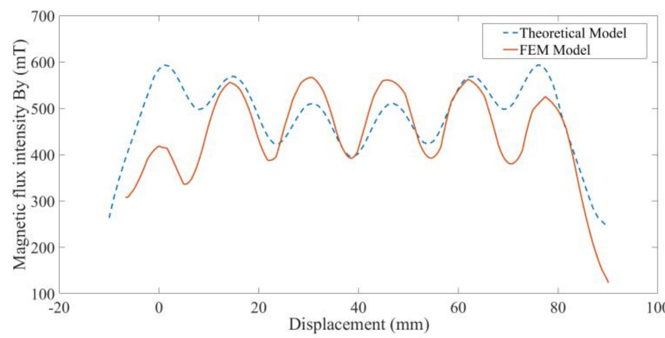

Fig. 4. Theoretical and FEM result of the quasi-parallel magnetic field characteristics.

V. CONCLUSION

This paper proposed a quasi-parallel Magnetic Field created by magnetic rings array for a VCM. The mathematical model of the quasi-parallel magnetic was built, and the magnetic flux indensity was calculated by the mathematical model and FEM model. The results indicate that the magnetic filed is nearly parallel and the mathematical model is correct.

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