THE PERMANENT MAGNET OVERHANG EFFECT ON THE RADIAL FORCE DENSITY IN BRUSHLESS DC MOTOR

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Abstract : *This paper investigates the permanent magnet(PM) overhang effect on the radial force density in brushless DC motor(BLDCM). The overhang effect has been used to enlarge the performance of the radial flux density in BLDCM and balance the force in the axial direction for the reduction of the vibration. 3-D equivalent magnetic circuit network method(3-D EMCNM) is used for the accurate and efficient analysis of radial force density. The radial force densities are calculated by Maxwell stress tensor and the frequency spectra are analyzed by the discrete Fourier transform. From the analysis results, appropriate PM length in overhang structure and the magnetization pattern for the reduction of the vibration are proposed.*

Key words: *Eddy current brake, Convective-diffusion equation, Galerkin-FEM, Upwind-FEM*

1. Introduction

BLDCM in computer hard disk drive has the overhang structure in which PM length is longer than the stator stack in the axial direction. The overhang effect has been used to enhance the performance of radial flux in BLDCM, but its precise contribution to performances is not well known [1]-[2].

In addition, the electromagnetic load per volume ratio in BLDCM becomes larger owing to the development of the motor design technology and the use of high energy magnet. Accordingly, the problems of vibration and subsequent noise emission can be significantly increased in BLDCM.

The most frequent source of vibration in BLDCM is caused by radial force due to the electromagnetic force. The problems of vibration and noise are extremely troublesome when the forcing frequencies of the radial force match one or more of the mechanical or structural resonant frequencies in the machine[3]. Therefore, it is important to know the airgap flux density distribution accurately for the prediction of back-emf waveform, cogging torque and radial force.

In this paper, 3D EMCNM is used for the radial force density analysis considering the overhang effect and various magnetization patterns such as sinusoidal, square and trapezoidal. 3D EMCNM supplements magnetic equivalent circuit by numerical technique using distributive magnetic circuit parameter, permeance [4]. Appropriate PM length in overhang structure is proposed based on the analysis results. The frequency spectra of the radial force densities have been also investigated by using the discrete Fourier transform with respect to the variation of overhang ratio.

2. Analysis method

3-D equivalent magnetic circuit network is constructed by connecting the centroids(nodes) of adjacent elements through the permeance as shown in Fig. 1.

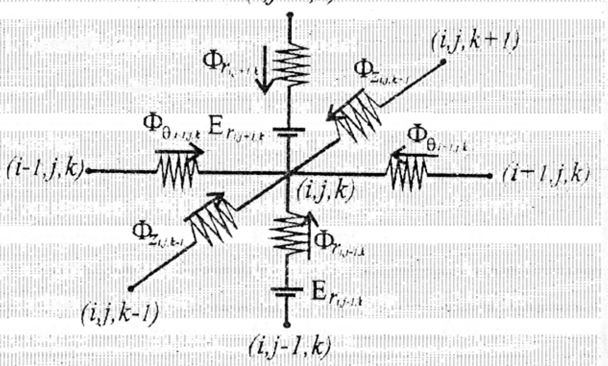


Fig. 1. 3-D equivalent magnetic circuit at node (i,j,k)

The field variable of the centroids, magnetic scalar potential(MSP), is decided by the permeance and magneto-motive force(MMF) involved with them. The magnetic flux and magnetic flux density in r direction between node (i,j,k) and node $(i,j\text{-}1,k)$ are calculated as follows[5]:

$$\Phi r_{i,j-1,k} = P r_{i,j-1,k}(U_{i,j,k} - U_{i,j-1,k} + E_{i,j-1,k})$$

$$B r_{i,j-1,k} = \Phi r_{i,j-1,k} / S r_{i,j,k} \qquad (1)$$

where $U_{i,j,k}$ is unknown MSP and $E_{i,j-1,k}$ is MMF of the PM or stator winding.

The magnetic flux continuity condition at a node(i,j,k) is given by

$$\Phi_{\theta\, i-1,j,k} + \Phi_{\theta\, i+1,j,k} + \Phi_{r\, i,j-1,k} + \Phi_{r\, i,j+1,k} + \Phi_{z\, i,j,k-1} + \Phi_{z\, i,j,k+1} = 0 \qquad (2)$$

The system matrix equation is obtained by (1) and (3) for all nodes, such that

$$[\mathbf{P}]\{\mathbf{U}\} = \{\mathbf{F}\} \qquad (3)$$

where $[\mathbf{P}]$ is the permeance coefficient matrix, $\{\mathbf{U}\}$ is matrix of node MSP, and $\{\mathbf{F}\}$ is forcing matrix (=Permeance × MMF of stator current or PM).

The distribution of magnetic flux density in BLDCM is calculated by (1), and the radial force density acting on the surface of the teeth are calculated using the Maxwell stress tensor as follows:

$$f_n = \frac{1}{2\mu_o}(B_n^2 - B_t^2)$$

$$f_t = \frac{1}{2\mu_o} B_n B_t \qquad (4)$$

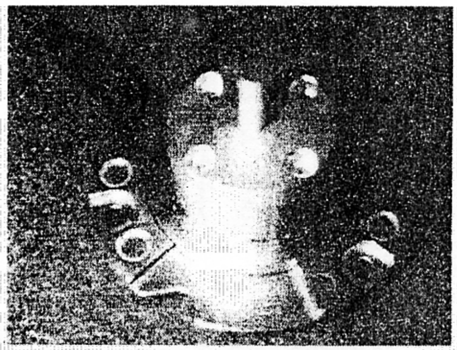
where f is force per unit area, B is the flux density, n is the normal component, t is the tangential component and μ_o is the permeability.

3. Analysis model

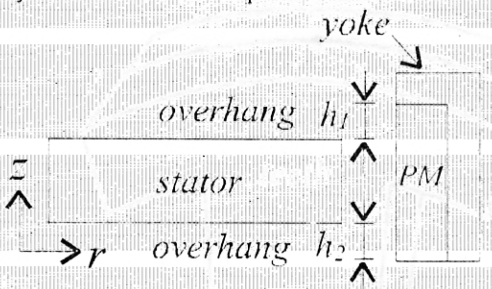
Fig. 2 shows the spindle BLDCM model and r-z plane with overhang structure for hard disk drive. The motor is exterior-rotor type with 8 poles, 12 teeth and 3 phase full bridge circuit. The magnetization pattern of PM, ring type plastic Nd-Fe-B, is assumed to be sinusoidal, square and trapezoidal respectively.

The BLDCM model has asymmetric structure magnetically in the axial direction. Therefore, in 2D analysis, it cannot consider the flux fringing and the leakage flux effect in the axial direction because the 2D analysis assumes that the physical quantity such as linkage flux is constant or the analysis region has constant structure in the axial direction. Consequently, in the BLDCM with axial overhang structure, 3D analysis is necessary, although 2D analysis is much easier and faster than 3D analysis in modeling and computation time. Table I presents the specification of the analysis model.

Fig. 3 shows the mesh of analysis model. The analysis model is divided into elementary volumes(elements) of hexahedral shape. The node number and element number are 38,280 respectively.



(a) Analysis model for HDD spindle motor drive



(b) r-z plane

Fig. 2. The BLDCM model and r-z plane with overhang structure

Table I. Specification of analysis model

Stator		Rotor	
Slot number	12	Outer radius	15.25(mm)
Phase	3	Magnet thickness	1.2(mm
Phase resistance	5.9(Ω)	Magnet height	3.7(mm
Turns per phase	57	Remanent	0.7(T)
Stack height	2.5(mm)	Coercivity	5(kA/m)
Inner radius	7.25(mm)	Airgap length	0.25(mm)
Outer radius	13.8(mm)	Overhang	0.8(mm)

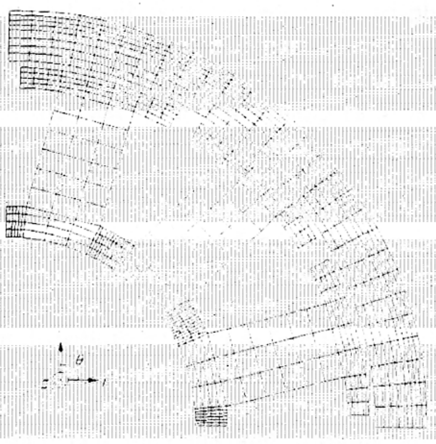


Fig. 3. Mesh of analysis model

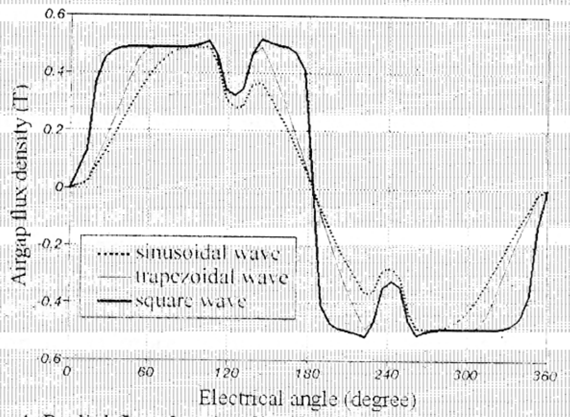


Fig. 4. Radial flux density distributions with variation of the magnetization distribution of PM in BLDCM

For the considering the movement of the rotor, the magnetization distribution is represented by the function using the Fourier series which changes according to relative position of the PM. Consequently, 3D-EMCNM need not remesh process for the analysis region and more efficient than 3D finite element analysis.

4. Analysis results

The value of the overhang ratio (h_2/h_1) is varied such as 0.5, 1 and 2 respectively for the investigation of the overhang structure effect on the radial force density in BLDCM. At no load condition, the radial flux distributions in the airgap center according to the variation of magnetization distribution of PM are shown in Fig. 4. Due to the teeth and slot structure, the dip appears in the radial flux distributions of the airgap.

Fig. 5 shows the vector distribution of the flux density in r-z cross section using 3-D EMCNM. The remarkable leakage flux in overhang section of the PM can be seen, which cannot be considered by 2-D analysis. It is known that the radial flux distribution over the stator surface is enhanced due to the overhang structure in PM.

The fixed 3 points on the center line of the surface of the teeth is selected in order to investigate the radial force density at the different positions of the teeth because the radial force density does not act on the surface constantly. The Fig. 6 presents the fixed 3 points of the teeth.

Fig. 7 shows the radial force density at the center point of the teeth when the overhang ratio(h_2/h_1) is 0.5, 1 and 2, respectively in trapezoidal magnetization distribution.

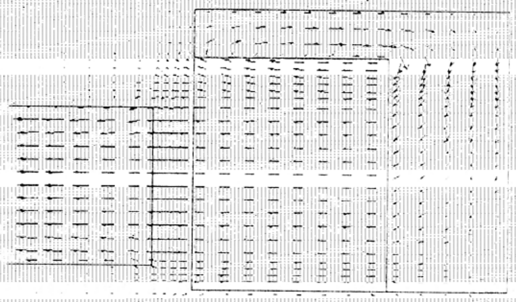


Fig. 5. The flux density in r-z cross section

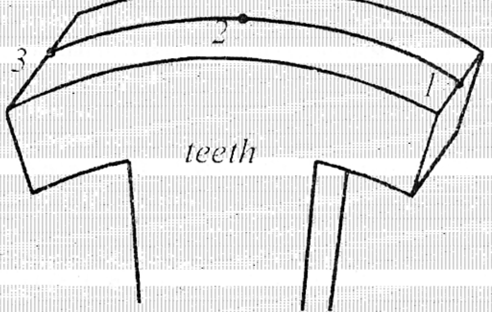


Fig. 6. Fixed 3 points on the surface of the teeth.

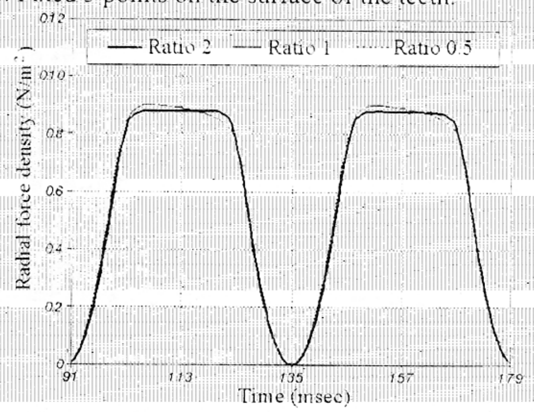


Fig. 7. Radial force density acts on the point 2 according to the overhang ratio in trapezoidal distribution.

The winding of coil is assumed as Y tri-phase connection and the shape of end part in coil is not considered. As shown in Fig. 7, the radial force distribution of the case with 2 overhang ratio is the symmetric but others are less symmetric. Consequently, in case of 2 overhang ratio, it is better than others in vibration reduction of the BLDCM.

Fig. 8 shows the comparison of radial force density distribution acting at the fixed 3 points on the center line of the surface of the teeth in trapezoidal magnetization distribution. For a period force density distribution of the middle point 2 is relatively symmetric but other points are less symmetric due to flux leakage between magnets and fringing at the stator slot-openings.

Fig. 9 represents the comparison of radial force density distribution at point 2 according to the variation of magnetization patterns such as sinusoidal, square, and trapezoidal respectively. In case of the square, the radial force density distribution is the most asymmetric and has a bad effect on the vibration and noise.

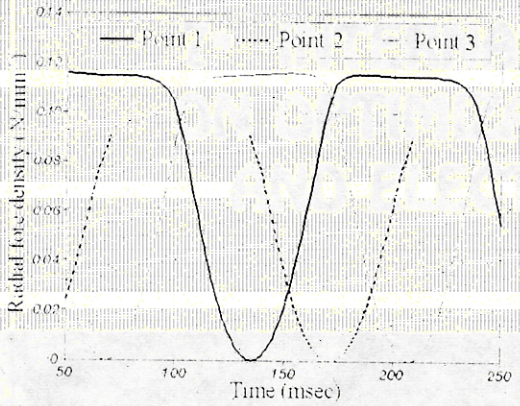


Fig. 8. Radial force density distribution at points 1, 2, and 3 in trapezoidal distribution (overhang ratio 1).

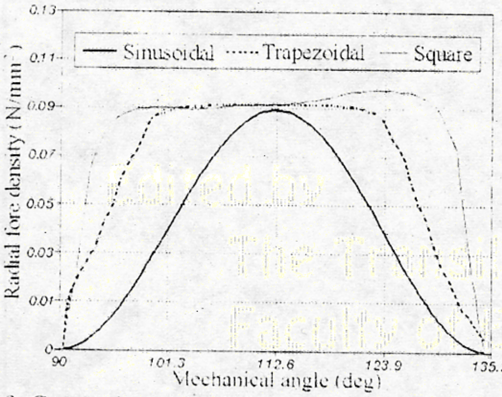


Fig. 9. Comparison of radial force density distribution at point 2 with respect to magnetization patterns (overhang ratio 1).

Fig. 10 shows the spectra analysis of the radial force density in Fig. 7. The excitation frequencies are integer multiple of 720 Hz which is the value of multiplication pole number and rotation frequency.

5. Conclusion

In this paper, the radial force density acting on the surface of the teeth in BLDCM is analyzed considering the overhang effect and various magnetization patterns by 3-D EMCNM. In case of overhang ratio 2, the radial force density is more symmetric than those of the ratio 0.5 and 1.

The magnetization patterns having effect on the radial force density are also investigated. In case of the square, the radial force density distribution is the most asymmetric and has a bad effect on the vibration and noise.

References

1. Wang, J. P., Lieu, D. K., Lorimer, W. L., Hartman, A. : *Influence of the permanent magnet overhang on the performance of the brushless dc motor.* In: Journal of Applied Physics(1998), Vol. 83, No. 11, 1998, p. 6362-6364, U.S.A.
2. Jang, G. H., Yoon, J. W., Ro, K. C., Park, N. Y., Jang S. M. : *Performance of a brushless DC motor due to the axial geometry of the permanent magnet.* In: IEEE. Transactions on Magnetics(1997), Vol. 33, No. 5, 1997, p. 4101-4103, U.S.A.
3. Rahman, B. S., Lieu, D. K. : *The origin of permanent magnet induced vibration in electric machines.* In: ASME. Journal of Vibration and Acoustics(1991), Vol. 113, No. 4, 1991, p. 476-481, U.S.A.
4. Vlado Ostovic, *Dynamics of Saturated Electric Machines,* Springer-Verlag, 1989.
5. Hur, J., Yoon, S. B., Hwang, D. Y., Hyun, D. S. : *Analysis of PMLSM using 3 dimensional equivalent magnetic circuit network method.* In: IEEE. Transactions on Magnetics(1997), Vol. 33, No. 5, 1997, p. 4143-4145, U.S.A.

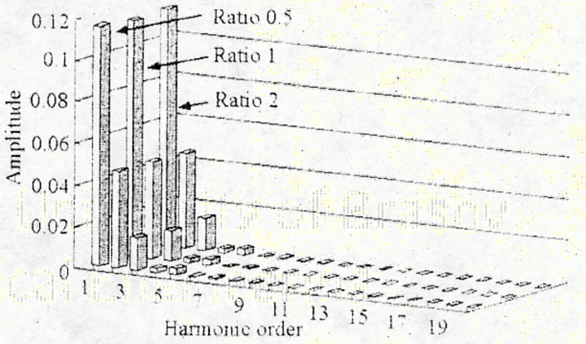


Fig. 10. Comparison of spectra analysis of the radial force densities at point 2 with respect to the overhang ratio.

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