3D INFLUENCE OF UNBALANCED MAGNETIC PULL INDUCED BY MISALIGNMENT ROTOR IN PMSM MOTOR

A. Yinquan Yu, B. Chao Bi, C. Phyu Nu Hla, D. Quan Jiang, E. Song Lin, F. Nay Lin Htun Aung, and G. Abdullah Al MAMUN, *Member, IEEE*

***Abstract*-- This paper presents the Permanent Magnetic Synchronous Motor (PMSM) with the rotor misalignment; the asymmetric motor magnetic field in each section is varied due to varied eccentricity in axis direction. This asymmetric field generates Unbalanced Magnetic Pull (UMP), and the analysis shows that, the UMP value varies in the motor operation. The paper presents an analytical model for analyzing the 3D effects of the UMP induced by the misalignment rotor. The Simulation results done by ANSOFT prove the effectiveness of the proposed analytic method.**

Index Terms—**PMSM, misalignment, UMP, MMF**

I. INTRODUCTION

The spindle motor used in hard disk drive uses one end fixed Fluid Dynamic Bearing (FDB) which structure likes slender cantilever beam to support the rotor; see Fig. 1. However, this type of structure will generate the motor uneven UMP in Axis direction due to slender shaft bending. Although fluid dynamics bearing replaced ball bearing in current hard-disk spindle motor to increase running stiffness of FDB and reduce noise, the stiffness of FDB is very low and whole rotor system misalignment at the rest point, see Fig. 2. This status will generate uneven UMP on the rotor and reaction force on FDB which can significantly reduce FDB lifecycle and increase Repeatable Run-Out (RRO) and None Repeatable Run-Out (NRRO) of hard disk. For general motor case, there are four types of misalignment which shown in Fig. 3.

In this paper, we will concentrate on analyzing the effects of the UMP caused by rotor uneven misalignment in axial direction in the general motor. In the following analysis, we assume the permeability of the rotor yoke and stator core are infinite. Because the axis direction misalignment angle is quite small, see Fig.3. The air-gap field is also assumed to alignment in radial direction.

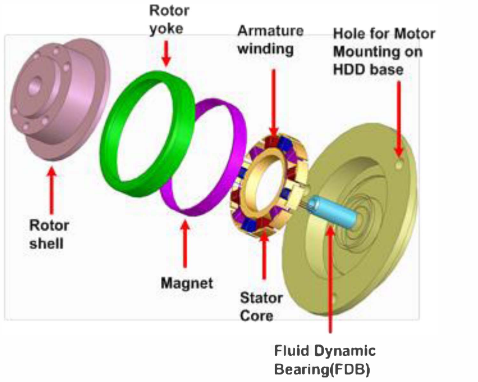

Fig. 1 The structure of spindle motor used in hard disk drive

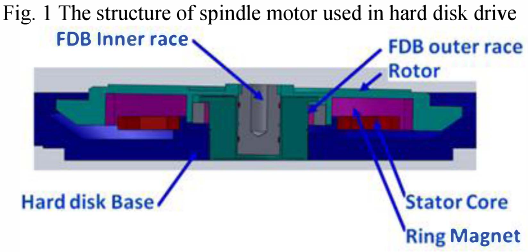

Fig. 2 The start-up condition of spindle motor with FDB in hard disk

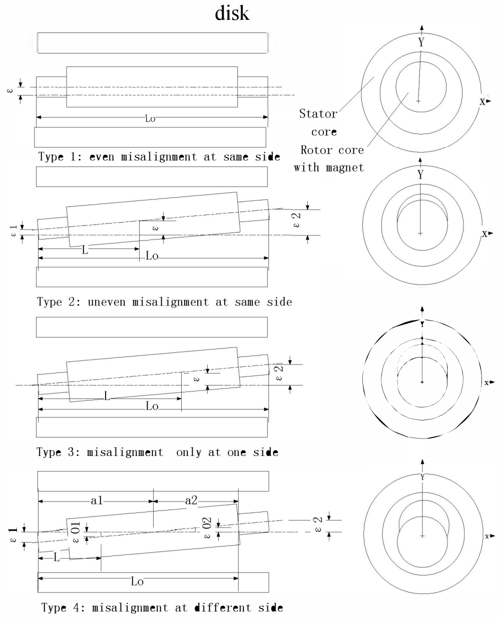

Fig. 3 The PM-BLDC motor with the rotor varied air-gap in axial direction

II. UMP Induced by Rotor Uneven Misalignment in Axial Direction

There are many kinds of PMSM motors. In this paper, the analysis concentrates on the motors with surface PM ring. This kind of motor is widely used in low power applications, e.g., Except the UMP of type1 (in Fig. 3) which is fully studied in [1], the

A~F.Authors are from Data storage Institute, A-star, Singapore. 5, Engineering Drive I, Singapore 117608. The corresponding author is Yinquan Yu (phone: 65-68745219; fax: 65-65160900;e-mail: yu_yinquan@ dsi.a-star.edu.sg).

G. Author is with the Department of ECE, National University of Singapore, 4 Engineering Drive 3, Singapore 117576 (e-mail: eleaam@nus.edu.sg).

UMP of other types will be deducted in this paper.

For the global radial UMP of the motor with the even misalignment rotor of type1 in Fig. 3, it can be expressed as

$$
\begin{aligned}
&P_{AE\_G}(\alpha) \\
&= \frac{\varepsilon L_0 R_A \pi}{2\mu_0} \sum_{m=0} \square l_{Am} [\sum_{n=0} f_{A2n} Cos(2np\alpha)] \square \Big|_{mZ-1=2np} \\
&+ \frac{\varepsilon R_A L_0 \pi}{2\mu_0} \sum_{m=0} \square l_{Am} [\sum_{n=0} f_{A2n} Cos(2np\alpha)] \square \Big|_{mZ+1=2np}, \quad (1)
\end{aligned}
$$

The global UMP, $P_{AE\_G}(\alpha)$ in Type 2, can be calculated by using the following equation,

$$
\begin{aligned}
&P_{AE\_G}(\alpha) \\
&= \frac{\varepsilon_1 L_0 R_A \pi}{2\mu_0} \sum_{m=0} \square l_{Am} [\sum_{n=0} f_{A2n} Cos(2np\alpha)] \square \Big|_{mZ-1=2np} \\
&+ \frac{\varepsilon_1 R_A L_0 \pi}{2\mu_0} \sum_{m=0} \square l_{Am} [\sum_{n=0} f_{A2n} Cos(2np\alpha)] \square \Big|_{mZ+1=2np} \\
&+ \frac{L_0 R_A \pi}{4\mu_0} (\varepsilon_2 - \varepsilon_1) \sum_{m=0} \square l_{Am} [\sum_{n=0} f_{A2n} Cos(2np\alpha)] \square \Big|_{mZ-1=2np} \\
&+ \frac{R_A L_0 \pi}{4\mu_0} (\varepsilon_2 - \varepsilon_1) \sum_{m=0} \square l_{Am} [\sum_{n=0} f_{A2n} Cos(2np\alpha)] \square \Big|_{mZ+1=2np}, \quad (2)
\end{aligned}
$$

Let ε_1 equal to zero, the global UMP, $P_{AE\_G}(\alpha)$ in Type 3, can be easily obtained. We assume ε2>ε1, therefore, the global UMP, $P_{AE\_G}(\alpha)$ in Type 4, can be calculated by using the following equation,

$$
\begin{aligned}
&P_{AE\_G}(\alpha) \\
&= -\frac{R_A \pi}{2\mu_0} \int_0^{a_1} \frac{a_1 - L}{a_1} \varepsilon_1 dL \sum_{m=0} \square l_{Am} [\sum_{n=0} f_{A2n} Cos(2np\alpha)] \square \Big|_{mZ-1=2np} \\
&+ \frac{R_A \pi}{2\mu_0} \int_{a_1}^{L_0} \frac{L - a_1}{a_2} \varepsilon_2 dL \sum_{m=0} \square l_{Am} [\sum_{n=0} f_{A2n} Cos(2np\alpha)] \square \Big|_{mZ+1=2np} \\
&= -\frac{R_A \pi \varepsilon_1^2 L_0}{4\mu_0(\varepsilon_1 + \varepsilon_2)} \sum_{m=0} \square l_{Am} [\sum_{n=0} f_{A2n} Cos(2np\alpha)] \square \Big|_{mZ-1=2np} \\
&+ \frac{R_A \pi (2\varepsilon_1 - \varepsilon_2) L_0}{4\mu_0(\varepsilon_1 + \varepsilon_2)} \varepsilon_2 \sum_{m=0} \square l_{Am} [\sum_{n=0} f_{A2n} Cos(2np\alpha)] \square \Big|_{mZ+1=2np} \quad (3)
\end{aligned}
$$

III. Numerical Analysis on The UMP

For verifying the analytical results obtained in the Section II, a misalignment PMSM motors is calculated with 3D finite element method (FEM), and the FEM results will be verified that the fundamental frequency of UMP will be 2P times rotating frequency. Fig. 4 shows the magnetic field of PMSM motor which has 5 magnetic pole-pairs obtained with 3D FEM. The result shows that the cycle width of fundamental harmonic of the UMP is 36 degree. In Fig. 5~Fig. 7, it can be seen that the frequency of Incline Unbalance Pull (IUMP) is 10(2 times of pole-pairs) orders of rotor rotating frequency. Fig. 5 also shows that IUMP not only repeat 10 times in one rotor full cycle but also has DC offset. The reason is the Incline eccentricity is also a type of rotor static eccentricity. Fig. 6 shows the UMP in Y direction is smaller than that in X direction because there is no rotor eccentricity in Y direction. The UMP in Z direction is shown in Fig. 7. It can be seen that there is ending effective of the UMP in Z direction.

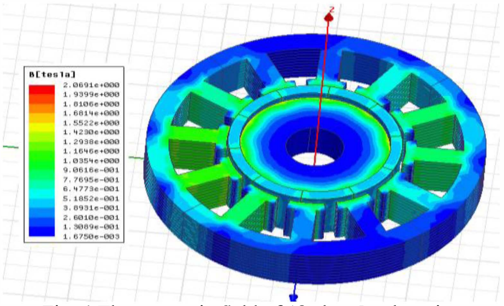

Fig. 4 The magnetic field of 12 slot, 5 pole-pair motor

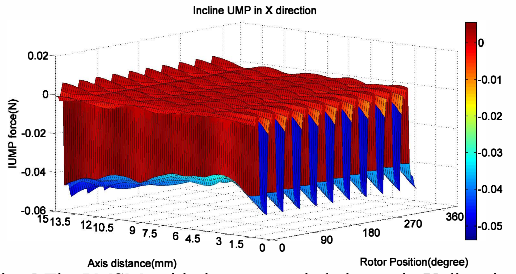

Fig. 5 The PMSM with the rotor varied air-gap in X direction

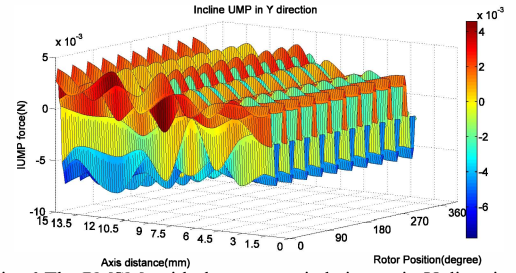

Fig. 6 The PMSM with the rotor varied air-gap in Y direction

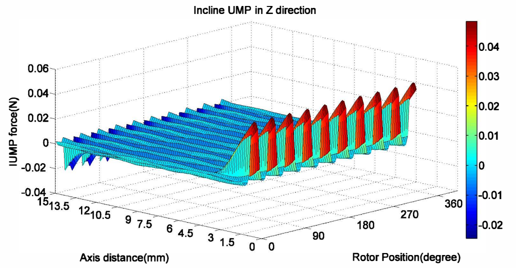

Fig. 7 The PMSM with the rotor varied air-gap in Z direction

IV. Conclusion

Though the UMP may induce serious vibration, acoustic noise and run-out in the motor operation, the influences of the UMP generated by misaligned rotor have not been perceived well in many applications. The paper presents an analytical model to analyze this kind of UMP. These analytical deductions have been confirmed by the numerical results, and they can be used to analyze and realize high performance permanent magnetic Synchronous Motor, and can also be used in motor misalignment failure diagnosis.

REFERENCES

[1] Chao BI, Nay Lin Htun Aung, Quan JIANG, and Song LIN, Influence of Rotor Eccentricity to Unbalanced-Magnetic-Pull in PM Synchronous Motor, ICEMS06, November 20-23, 2006, Nagasaki, Japan