Analysis of Force and Torque Variation on VCM Actuator for Ultrahigh TPI Magnetic Recording System

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Abstract — To realize ultrahigh TPI magnetic recording system of a modern hard disk drive, very high servo bandwidths are required to minimize the position error signal (PES) and to avoid track-misregistration (TMR). However, the expansion of the servo bandwidth is limited by the structure and performances of an actuator-suspension system (which includes the arm, voice coil motor (VCM) and ball bearing pivot). In this work, the affect of force and torque variation of the VCM to the actuator-suspension system is analyzed. 3D finite element method is conducted to extract the required parameters. Analysis data are crucial to optimize VCM design to improve dynamic performances and to reduce the mechanical resonances, so as to increase the servo bandwidth of the head position system.

I. Introduction

The continuous increase of data storage capacity and high speed data access in modern HDDs, track density is getting higher and higher. When the number of tracks increases, the width of tracks are decreased consequently. As the track pitch reduces, sophisticated servo scheme is needed for accurate head positioning. An actuator design should provide high performance and precise head positioning capability to minimize the position error signal and to avoid TMR. In general, servo bandwidth is limited by the mechanical resonances of actuator-suspension system (which includes the arm, VCM and ball bearing pivot) [1]. In this study, detailed analysis of the effect of force and torque variation of the VCM to the actuator-suspension system is analyzed. To include axial field distribution and VCM coil ending effect, 3D modeling and simulation is a preferred method to satisfy the precise determinations of motor performances.

II. 3D FEM Model

Fig.1 shows the structure of VCM actuator-suspension system. Top cover is removed in Fig. 1 to get clear picture of VCM structure. When current is fed to the VCM coil, electromagnetic field (EM) generated by a driving current and another EM field generated by the permanent magnets produces a driving force to position a magnetic head. Hence, an accurate modeling of VCM structure requires 3D model to include the effect of 3D EM field behaviour of the motor. The nonlinear EM field in a VCM structure can be represented by applying the Maxwell's equation as:

$$\nabla \times (\nu \nabla \times A) = J_s + \nabla \times (\nu B_r) \qquad (1)$$

In (1), A is the magnetic vector potential, ν is the reluctivity of the material, J_s is the current density of VCM coil and B_r is the remanence flux density of the permanent magnet. The magnetic solver calculates the magnetic field distribution produced by a combination of know DC current density vector distribution and a spatial distribution of objects with permanents magnetization. In FEM formulation, edge-based elements with a discontinuous normal component of magnetic vector potential is used to avoid the inaccuracy associated with node-based formulation [2]. Newton Raphson iterative solution process is carried out to handle nonlinear EM field of ferromagnetic material such as based plate and top cover (upper and lower yokes) of VCM. Force and torque is calculated by virtual work method based on magnetic co-energy of a system.

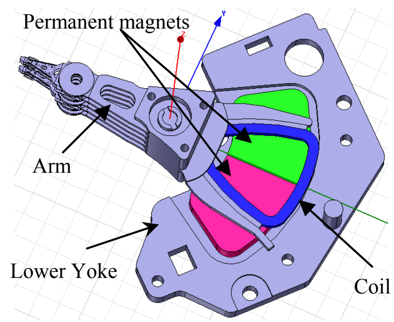

Fig.1 VCM actuator-suspension system

III. Effect of Force and Torque Variation on VCM Operation

VCM is expected to produce an orthogonal force or pure torque to reduce the impact from VCM force. However, VCM cannot generate a constant torque within its entire moving range because of the uneven distribution of flux density of the permanent magnet (PM) as shown in Fig.2 and Fig.3. The field interval between the north and south poles of the magnet is unavoidable. Even if the constant current flows through the coil, the generated electromagnetic field will vary with the position of the coil in the air gap. See Fig.4. This may cause the torque constant, K_t of the VCM to vary at different positions and it directly affects to the servo control system [3]. In addition, the time constant of the control system is determined by an average torque level (ΔT) as shown in Fig. 5. When the torque deviates from its average, positioning to a target position takes a long time which leads to serious TMR.

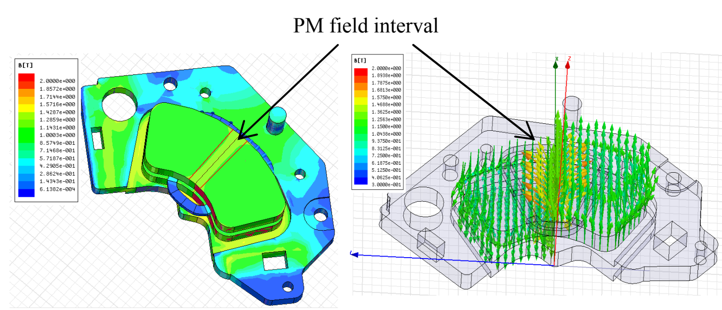

Fig. 2 3D EM Field distribution of VCM and PM field interval

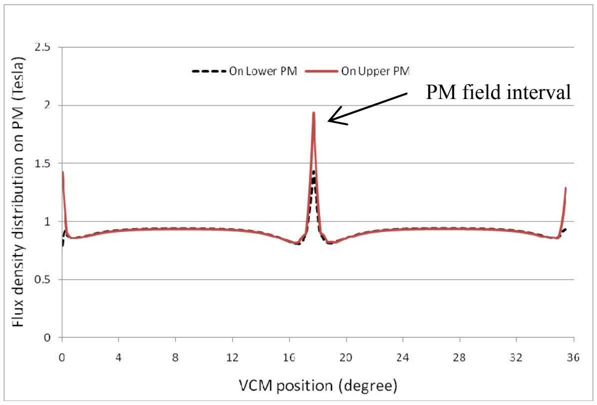

Fig.3 Field distribution on the upper and lower surfaces of PM

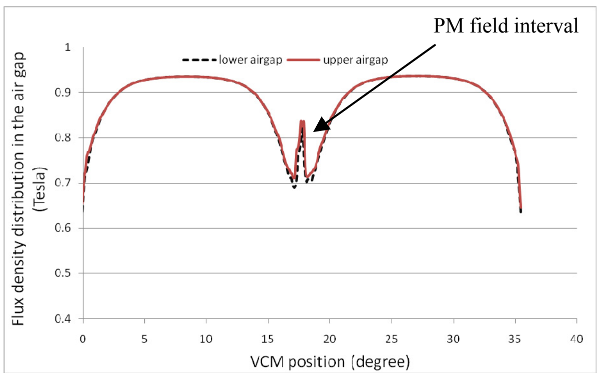

Fig. 4 Field distribution at the middle of upper and lower air gaps

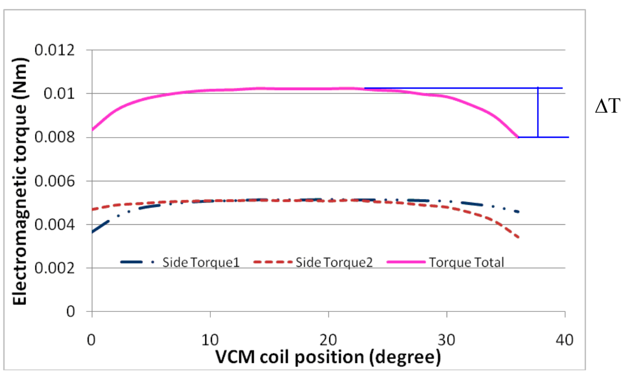

Fig. 5 EM torque where constant current flows to the VCM coil

Besides the EM forces acting on the effective sides of the coil in planar XY directions, there are also electromagnetic forces acting on the ends because of the stray field as shown in Fig.6. VCM stray field induced unbalance magnetic pull that cause Head-Suspension-Actuator assembly to vibrate undesirably during track following operation. As seen in Fig. 7, force acting on the coil ends cannot be negligible. In addition, when a driving force is excited in the same seeking direction during operation, a substantial reaction force on the pivot bearing is generated. This bearing reaction force can produce quasi-rigid body vibration mode (QR mode) in the cross-tracking direction and potentially affects the accurate tracking of the head position system [4]. Fig.8 shows the total driving force acting on the pivot with different VCM positions. It is found that force is varied with the position of the coil where same current flows through the coil.

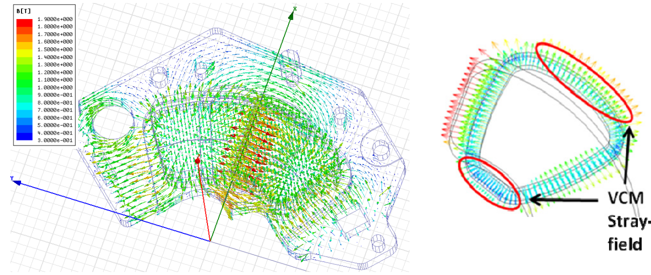

Fig. 6 VCM stray field

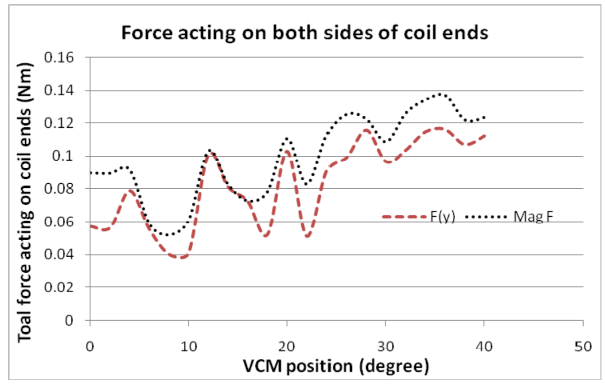

Fig. 7 Force acting on coil ends

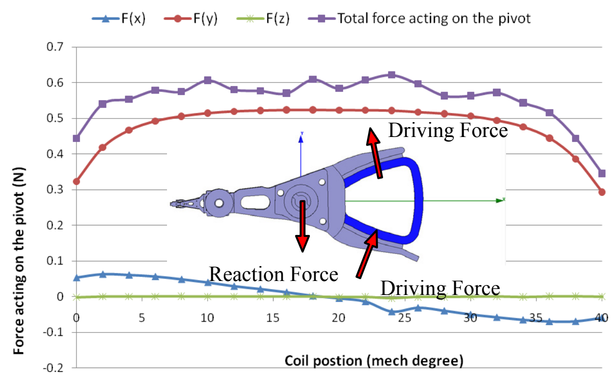

Fig. 8 Force acting on the pivot

IV. Conclusions

Increasing track density has revealed the importance of many kinds of disturbance which were considered negligible in the past such as torque constant variation, stray field at the end of the coil and bearing reaction force in the cross-tracking direction. Hence, detailed investigation of the effect of force and torque variation of the VCM to the actuator-suspension system is crucial and results are useful to optimize high performance actuator design.

V. References

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