FDB Spindle Motor Design for Vibration Suppression

Thitima JINTANAWAN
Mechanical Engineering Department, Chulalongkorn University
Bangkok, Thailand 10330, Email: thitima.j@chula.ac.th

***Abstract*—This paper aims at investigating the effects of variation in parameters of the FDB spindles on the total in-plane vibration of the disk-spindle systems in HDDs. For the parametric study, the in-plane FRF of the disk-spindle system subjected to the inplane base excitation is presented for each set of the varying parameters such as: the stiffness and damping coefficients of the radial FDBs, the radial bearing locations, and the stiffness coefficient of the tosional spring representing the hub flexibility. The parametric study reveals that an increase in the radial FDB coefficients significantly suppresses the amplitude of the half-speed whirls. Moreover, the spindle hub design with higher rigidity can reduce the amplitude of the rocking modes.**

I. Introduction

Fluid dynamic bearing (FDB) spindles are currently used in the new HDDs because of their capabilities for vibration suppression and acoustic noise reduction. Design criteria for the FDB spindles are reliability, low power consumption, and low vibration and shock responses. To meet the vibration criteria, the parametric study and optimization of the axial stiffness and damping coefficients in thrust FDB for minimizing the axial vibration of the spindle systems were proposed in [1]. Among the vibration components of the disk-spindle systems, the vibration in the disk plane or the in-plane vibration is a major problem of track misregistration in HDDs. Hence suppression of this in-plane vibration through an optimization of parameters in the FDB spindles can be a practical and inexpensive solution. As a feasibility study, this paper aims at investigating the effects of variations in parameters of the FDB spindles (such as bearing parameters, bearing locations, and flexibility of the hub) on the in-plane vibration.

II. Model Description

Figure 1 shows a physical model of a disk-spindle system with the FDBs. The system consists of multiple and identical elastic disks clamped to a deformable hub that allows infinitesimal rigid-body translation and rocking. The hub is press-fit onto a rotating, flexible shaft. For this rotating-shaft design, the hub deformation is critical at the press-fit interface [2]. Thus, to compensate for this

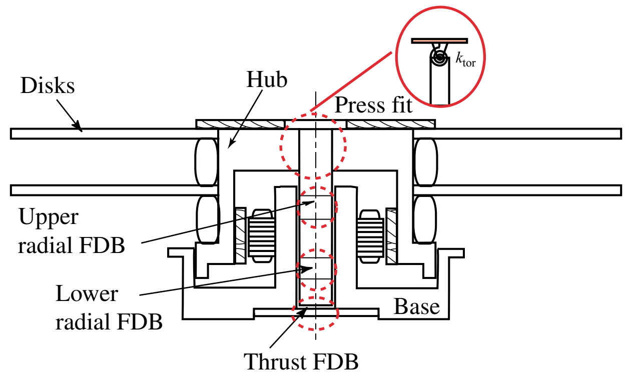

Fig. 1. A disk-spindle system with the FDBs

deformation, the boundary condition of the flexible shaft at the press-fit end is modeled as a hinged support with a torsional spring as shown in Fig. 1. The coefficient of the torsional spring, denoted by k_{tor}, determines flexibility of the hub at the press-fit interface. Specifically, if the value of k_{tor} is lower, the hub is more flexible at the interface. Furthermore, the shaft is mounted to the base through radial and thrust FDBs. The radial FDBs are modeled as restoring and damping forces with in-line and cross stiffness and damping coefficients (denoted by k_{r1}, k_{r2}, c_{r1}, and c_{r2}, respectively). The locations of the lower and upper radial FDBs, measured from the low end of the shaft, are z_a and z_b, respectively. In this model, the thrust FDB provides infinitesimal restoring and damping moments against the spindle rocking. Finally, the spindle system is subjected to base excitations along the disk-plane (in-plane) direction. Equations of motion of this system were derived in [2] and [3]. The total in-plane motion of the disk-spindle system consists of two major components: a rigid-body translation of the hub along the radial or disk plane direction and the rigid-body rocking of the hub. This model is used for the parametric study in the next section.

III. Parametric Study

In this section, we investigate the effects of variations in parameters of the FDB spindles on the total in-plane vibration of the spindle system, using the analytical simulation. For the parametric study, the mathematical model [2], [3] is further developed to predict frequency response function (FRF) of the total in-plane vibration of the disk-spindle system subjected to the in-plane base acceleration

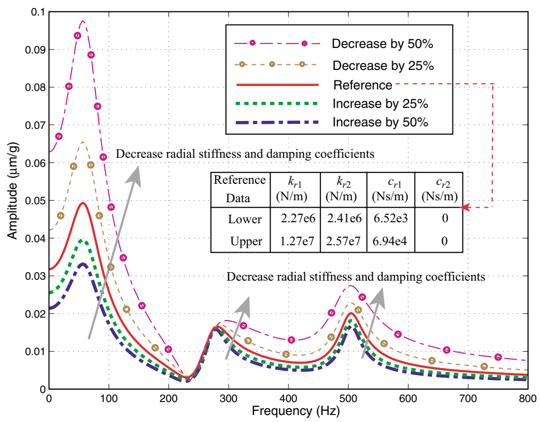

Fig. 2. Effect of radial FDBs on response amplitude

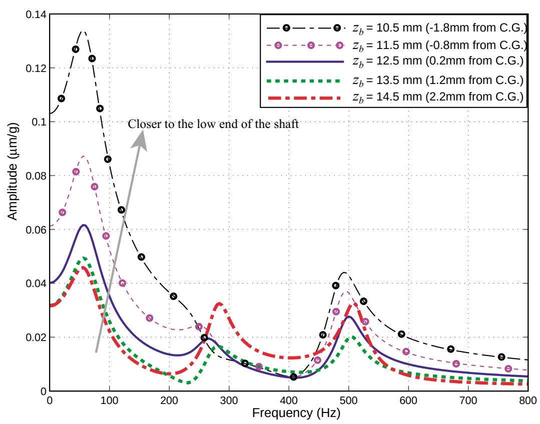

Fig. 3. Effect of the upper bearing location on response amplitude

of $1g$, for each set of the varying parameters. In addition, the FDB spindle used in the simulation carries two identical disks of 1.27 mm thickness, and is operated at 7,200 rpm. Effects of variation in different parameters of the FDB spindles such as the stiffness and damping coefficients of the radial FDBs, locations of the radial FDBs, and Hub flexibility at the press-fit end (k_{tor}) are discussed as follows.

Figure 2 shows the total response amplitude of the inplane vibration at various excited frequency, when the stiffness and damping coefficients of both radial FDBs are varied. The resonances at 60, 280, and 500 Hz are the half-speed whirl mode, the backward rocking mode, and the forward rocking mode, respectively [3]. An increase in the radial bearing coefficients significantly reduces the amplitude of the half-speed whirl but slightly suppresses the amplitude of the rocking modes. From Fig. 2, when the bearing coefficents is increased by 50%, the forward rocking amplitude is reduced by only 28%.

Figure 3 shows the total response amplitude of the inplane vibration when the location of the upper radial FDB is varied. Similar to the result shown in Fig. 2, the upper bearing location has a major effect on the amplitude of the half-speed whirls but slightly changes the amplitude of the rocking modes. If the upper bearing is located closer to the lower end of the shaft, the bearing system is more

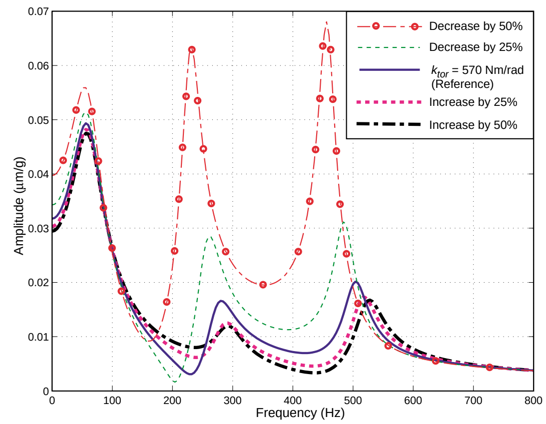

Fig. 4. Effect of k_{tor} on response amplitude

flexible. As a result, the amplitude of the half-speed whirl is larger. Moreover, $z_b = 13.5$ mm (1.2 mm from the disk pack C.G.) is the optimized location of the upper bearing for minimizing the rocking mode vibration for this case. The variation in the lower bearing location causes a minor change in the response amplitude, when compared with the result in Fig. 3, and the result is not shown here due to a limited space.

Figure 4 shows the total response amplitude of the inplane vibration when k_{tor} is varied. The higher value of k_{tor} indicates the less flexibility of the hub at the press-fit end. In the FDB spindle design, k_{tor} can be varied through a change of shaft diameter, depth of the press-fit interface, or spindle material. Fig. 4 shows that an increase in k_{tor} slightly reduces the amplitude of the half-speed whirl but significantly suppresses the rocking mode amplitudes. The higher value of k_{tor} also increases the resonance frequencies of the rocking modes.

IV. Discussion and Conclusions

The coeffiencts of the radial FDBs and the bearing locations mainly affect the amplitude of the half-speed whirls. Nevertheless, a correction of this half-speed whirl vibration can be achieved by the servo system in HDD. Thus, for suppression of the total in-plane vibration, the spindle designers more focus on reducing the vibration of the rocking modes. The parametric study reveals that the amplitude of the rocking modes are significantly decreased by the spindle hub design with higher rigidity.

References

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