

## EFFECTS OF DISTRIBUTED BEARING FORCES AND BEARING LOCATIONS ON ROCKING VIBRATION OF FDB SPINDLE SYSTEMS

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### Introduction

Fluid dynamic bearings (FDB) are currently used in hard disk drive (HDD) spindles because of their capability in vibration and acoustic reduction. The spindle vibration in transverse direction, as known as rocking vibration, is the main cause of the track misregistration that limits the performance of storage density in HDD. The property and locations of the radial FDBs, which are the herringbone-grooved journal bearing (HGJB) type, play an important role in optimizing such unwanted rocking vibration [1]. To accurately predict the rocking vibration and optimize the bearing locations in HDD spindles, the unique geometry of the bearing-spindle in HDD needs to be considered. For disk drives with small form factors, e.g., 0.85-inch drive to be used in cell phones, most of the shaft length is supported by the bearings. In this case the aspect ratio of the bearing width to the shaft length is significant. Moreover the shaft in the rotating-shaft design spindles is likely flexible. With these observations, the HGJBs in HDD spindles would rather function as a continuous support providing *distributed* restoring and damping forces.

This paper is to investigate the effects of distributed bearing forces and locations of HGJBs on the rocking vibration of the FDB spindle systems. In addition the discrepancy in predicting the rocking vibration with the model of distributed bearing forces is investigated by comparing the natural frequencies, modal damping, and frequency response functions predicted by this model to the values from the conventional model of discrete bearing forces.

### Dynamic Model

Figure 1 shows the physical model of the disk-spindle system with distributed bearing forces in HDD. The mathematical model is developed to predict the rocking

vibration of this spindle system. The model is mainly based on the existing dynamic model [2], consisting of the rotating and flexible shaft that pressed fit to the rigid spindle hub, and the rotating flexible disks clamped on the outer rim of the hub. The HGJBs are however modeled as *distributed* direct and cross-coupled, linear spring and damping forces through the distribution functions of dynamic coefficients.

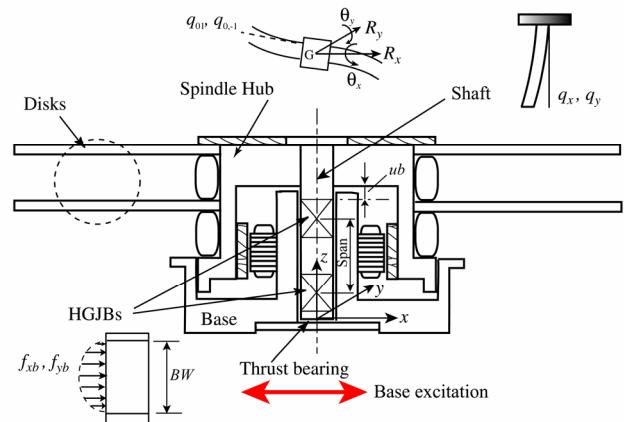


Fig.1 Physical model of disk-spindle system

### Free Vibration Analysis

A standard 3.5-inch drive with two identical HGJBs and two disks is the case for study. The rocking modes predicted by the distributed bearing model can be divided into two groups: 1) half-speed whirl (HSW) modes, and 2) two pairs of (0,1) unbalanced backward and forward modes (denoted by  $B1$ ,  $F1$ ,  $B2$  and  $F2$ ). Natural frequencies and modal damping of the rocking modes that predicted by both models of distributed and discrete bearing forces are compared in Table 1 for two spindles with bearing widths ( $BW$ ) of 2.8 and 5.0 mm, and at zero and 7200 rpm speed. Compared to the conventional model, the spindle model with distributed bearing forces

predicts the same natural frequencies for all rocking modes but predicts higher modal damping of  $B1$ ,  $F1$ ,  $B2$  and  $F2$ . The difference in damping prediction of these modes is clearer for the case of larger bearing width ( $BW = 5.0$  mm).

@ stationary (zero speed)

Mode	$BW = 2.8$ mm		$BW = 5.0$ mm	
	$\omega_n$ (Hz)	$\zeta$ (%)	$\omega_n$ (Hz)	$\zeta$ (%)
B1&F1	383/383	3.16/2.52	381/380	5.99/1.65
B2&F2	1977/1977	1.81/1.23	1982/1987	5.01/1.18

@ 7200 rpm

Mode	$BW = 2.8$ mm		$BW = 5.0$ mm	
	$\omega_n$ (Hz)	$\zeta$ (%)	$\omega_n$ (Hz)	$\zeta$ (%)
HSW	63/63	60/60	62/62	32/34
B1	285/285	3.99/3.23	283/282	7.09/1.97
F1	515/515	2.33/1.78	514/513	5.01/1.29
B2	1893/1893	1.84/1.24	1897/1902	5.16/1.20
F2	2094/2089	1.75/1.20	2094/2100	4.78/1.15

(Note: #1/#2 in the table is the value predicted by distributed model per the value predicted by conventional discrete model)

**Table1** Predicted natural frequencies and damping

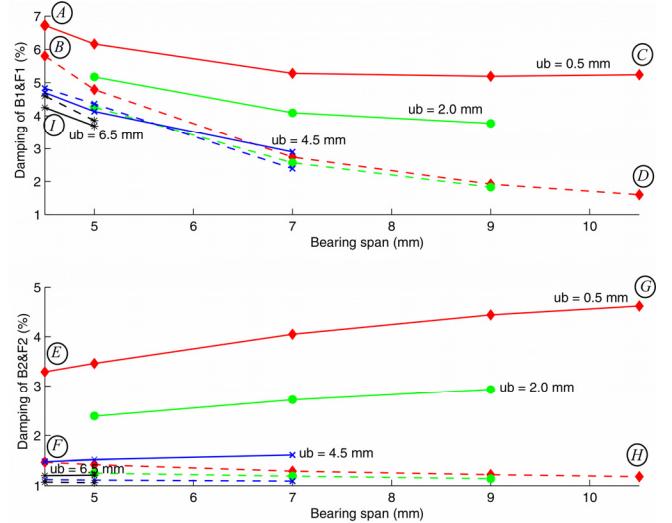
## Bearing Locations vs. Damping

Fig. 2 presents the damping values of  $B1-F1$  and  $B2-F2$  of the stationary drive with 4.0 mm bearing width at various HGJB locations. The locations of the two HGJBs as shown in Fig. 1 are indicated by two parameters: 1) bearing span and 2) position of the upper bearing ( $ub$ ) that measured from the top end of shaft. Comparing the dampings obtained from both distributed and discrete models, the discrepancy in damping prediction is greater when the span is wider and level of the upper bearing is higher ( $C$  vs.  $D$  and  $G$  vs.  $H$  in Fig. 2). The damping predicted by the distributed model depends on the locations of the bearings as described as follows. With a certain level of the upper bearing but wider span, the damping of  $B1-F1$  is decreased ( $A$  to  $C$ ) whereas the damping of  $B2-F2$  is increased ( $E$  to  $G$ ). Moreover with a fixed span but the upper bearing located at higher level, the dampings of both  $B1-F1$  and  $B2-F2$  are increased ( $A$  vs.  $I$  and  $E$  vs.  $F$ ).

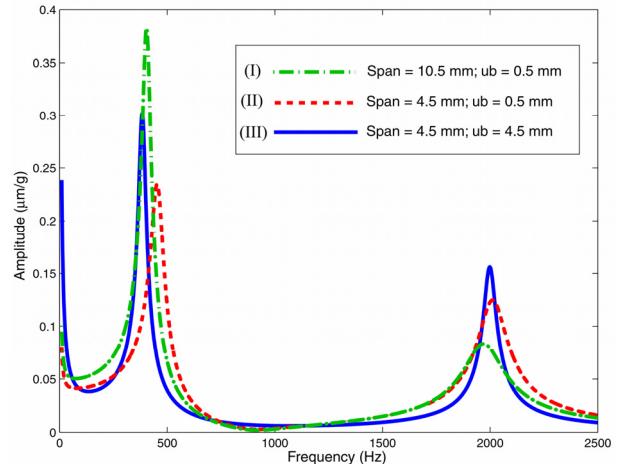
## FRF of Rocking Vibration

The modal dampings presented in Fig. 2 indicate the shape and the amplitude of the rocking resonance in the frequency response function (FRF) as shown, for examples, in Fig. 3. The peaks around 400 Hz and 2 KHz in Fig. 3 are the  $B1-F1$  and  $B2-F2$ , respectively. With the larger span or the decrease in level of the upper bearing, the system is more flexible as the natural frequencies are decreased. When the bearing span is wider (I vs. II in Fig.

3), the amplitude of  $B1-F1$  is increased while the amplitude of  $B2-F2$  is decreased. This respectively corresponds to the decrease and increase of damping by ~1%. In addition an increase in level of the upper bearing results in a more heavily damped peaks, and hence a decrease of the resonance amplitudes (II vs. III).



**Fig.2** Effects of HGJB locations to the damping of  $B1\&F1$ ,  $B2\&F2$  @ stationary (solid lines represent distributed model; dashed lines represent discrete model)



**Fig.3** Transverse FRF of the stationary drive with distributed bearing forces subjected to base excitation

## References

- [1] Park, J. S., Shen, I. Y. and Ku, C.-P. R., 2002, "A parametric study on rocking vibration of rotating disk/spindle systems with hydrodynamic bearings: rotating-shaft design," *Microsystem Technologies*, 8:427-434.
- [2] Jintanawan, T., Shen, I. Y. and Tanaka, K., 2001, "Vibration analysis of fluid bearing spindles with rotating-shaft design," *IEEE Trans. Magn.*, 37:799-805.