A MODEL OF DISTRIBUTED DYNAMIC FORCES IN HERRINGBONE GROOVED JOURNAL BEARING

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ABSTRACT

This paper proposes a new model of dynamic bearing forces for a journal-bearing spindle system in which an aspect ratio of the bearing width and the shaft length is significant, and the shaft is flexible. In this case the journal bearing functions as a continuous support, providing the *distributed* restoring and damping forces. The application can be found in the micro bearing spindle systems such as the herringbone-grooved journal bearing (HGJB) spindles for hard disk drives. To characterize the distributed dynamic forces of the HGJB, distribution functions of the stiffness and damping coefficients are determined along the bearing length.

INTRODUCTION

The dynamic forces provided by journal bearings are normally modeled as *discrete* direct and cross-coupled linear spring and damping forces acting at the bearing center [1, 2]. For the micro bearing spindles such as the spindle motors in hard disk drives, herringbone grooved journal bearings (HGJB) are currently used. The HGJB provides restoring and damping forces along the radial direction. In many researches, the HGJB is modeled as discrete dynamic forces through the direct and cross-coupled bearing coefficients [3, 4, 5]. In such HGJB spindle design for hard disk drives, the ratio of the bearing width and the shaft length is however significant compared to that in conventional rotordynamic systems, and the shaft is more likely flexible. Thus the HGJB would rather function as a continuous support, providing the *axially distributed* restoring and damping forces. This paper aims at a determination of distribution functions of dynamic coefficients that characterize the distributed dynamic forces of the HGJB.

ANALYSIS

Consider an arbitrary herringbone grooved journal bearing (HGJB). The bearing width is L, and the journal has a radius R and rotates with a constant angular speed Ω. For the spindles in hard disk drives, there exist two types of HGJB according to the location their grooves: a) the grooved-bearing (GB) type, and b) the grooved-journal (GJ) type, as shown in Figure 1. The GB type has grooves located at the bearing sleeve, while the GJ type has grooves located at the rotating journal. The patterns of groove angle for these two types are in opposite direction, in order to pump the fluid inward.

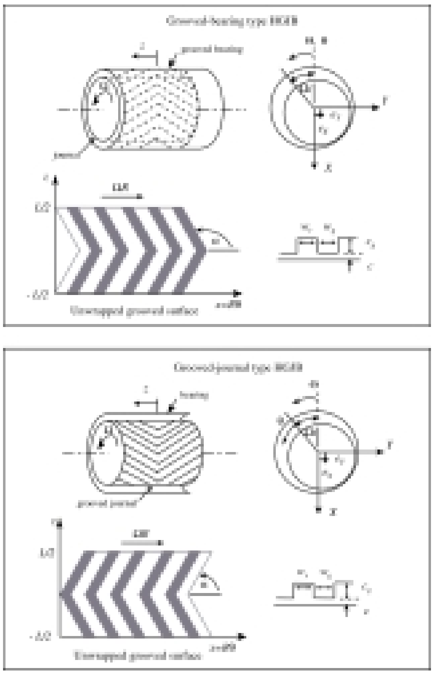

Figure 1: Two types of HGJB for a hard disk drive

To model the distributed dynamic forces in HGJB, Reynolds equation governing a pressure field of the bearing is formulated. The pressure perturbation arising from the dynamic perturbations of journal displacements and velocities is then analyzed using a variational approach [2]. The finite element method (FEM) is used to solve for the steady-state pressure field P_0, and the pressure perturbation P_X , P_Y , $P_{\dot{X}}$ and $P_{\dot{Y}}$.

Let the direct stiffness distributions be $k_{XX}(z)$ and $k_{YY}(z)$ and the cross-coupled stiffness distributions be $k_{XY}(z)$ and $k_{YX}(z)$. Similarly, let the direct damping distributions be $c_{XX}(z)$ and $c_{YY}(z)$ and the cross-coupled damping distributions be $c_{XY}(z)$ and $c_{YX}(z)$. These parameters are distribution functions of the bearing position z that measured from the bearing center along its length, defined as

$$\mathbf{k} = \begin{bmatrix} k_{XX}(z) & k_{XY}(z) \\ k_{YX}(z) & k_{YY}(z) \end{bmatrix} = \int_{\theta} \begin{pmatrix} -\cos\theta \\ -\sin\theta \end{pmatrix} \begin{bmatrix} P_X(z) & P_Y(z) \end{bmatrix} R\, d\theta$$

and

$$\mathbf{c} = \begin{bmatrix} c_{XX}(z) & c_{XY}(z) \\ c_{YX}(z) & c_{YY}(z) \end{bmatrix} = \int_{\theta} \begin{pmatrix} -\cos\theta \\ -\sin\theta \end{pmatrix} \begin{bmatrix} P_{\dot{X}}(z) & P_{\dot{Y}}(z) \end{bmatrix} R d\theta$$

where θ is the bearing angle. The stiffness and damping distributions are in units of N/m^2 and Ns/m^2, respectively. Note that total direct and cross-coupled stiffness and damping coefficients can be determined from an integration of $k_{XX}(z)$, $k_{XY}(z)$, $c_{XX}(z)$, and $c_{XY}(z)$ over z.

With the distribution functions of the dynamic coefficients, the distributed forces $f_X(z)$ and $f_Y(z)$ per unit length provided by HGJB are then:

$$\begin{pmatrix} f_X(z) \\ f_Y(z) \end{pmatrix} = -\begin{bmatrix} k_{XX}(z) & k_{XY}(z) \\ k_{YX}(z) & k_{YY}(z) \end{bmatrix} \begin{pmatrix} r_X \\ r_Y \end{pmatrix} - \begin{bmatrix} c_{XX}(z) & c_{XY}(z) \\ c_{YX}(z) & c_{YY}(z) \end{bmatrix} \begin{pmatrix} \dot{r}_X \\ \dot{r}_Y \end{pmatrix}$$

where $r_X(z)$, $r_Y(z)$ and $\dot{r}_X(z)$, $\dot{r}_Y(z)$ are radial displacement and velocity of the HGJB, respectively, expressing as functions of the bearing position z.

RESULTS & DISCUSSION

The GB-type HGJB in a hard disk drive is analyzed. The steady-state pressure and the distributions of direct and cross-coupled stiffness and damping calculated from the FEM program are present.

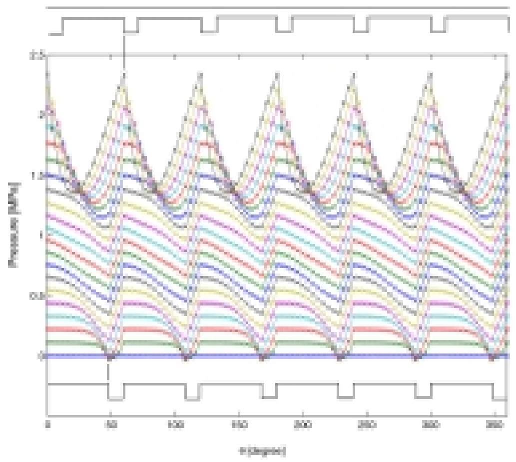

Figure 2: Steady-state pressure field

Figure 2 illustrates the steady-state pressure field generated in the HGJB. Each curve presents the pressure distribution along the circumference at various bearing distance z, $-L/2 \le z \le 0$. According to the bearing symmetry, the pressure distribution for the other half is identical to that presented in Fig.2. Comparing the pressure profiles for various z, the pressure increases from both ends and reaches maximum at the bearing center. However the pressure lightly drops below the atmospheric pressure at the bearing distance close to the sided ends and around the ridge-to-groove region. This dropped pressure causes the fluid to be pumped inward around this region. Hence the abrupt change of geometry in HGJB would help reduce the fluid leakage. Moreover, the pressure is a repetitive function of the bearing angle θ, as shown in Fig.2. A period of the repetition corresponds to the width of each groove and ridge. At the bearing center (z = 0), the pressure reaches maximum at the abrupt change of boundary from ridge to groove.

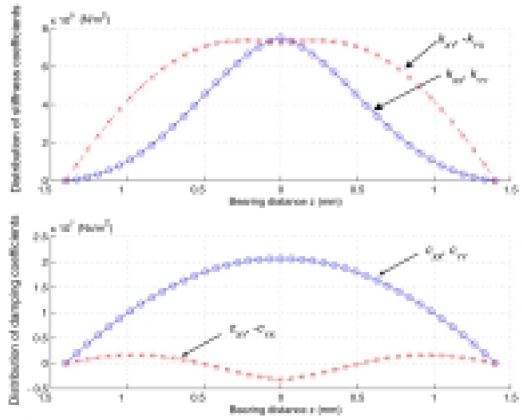

Figure 3: Distribution of dynamic coefficients of HGJB

Fig. 3 shows the distribution functions of dynamic coefficients for the HGJB with respect to the bearing distance z. The calculation yields $k_{XX}(z) = k_{YY}(z)$, $k_{XY}(z) = -k_{YX}(z)$, $c_{XX}(z) = c_{YY}(z)$, and $c_{XY}(z) = -c_{YX}(z)$. This so called isotropic property occurs in the lightly loaded bearing such as the HGJB for hard disk drives. In Fig. 3, the distributions of direct and cross-coupled stiffness $k_{XX}(z)$, $k_{XY}(z)$ and the distribution of direct damping $c_{XX}(z)$ are gradually increased from both sided-ends of the bearing, and reach maximum at the bearing center. In addition the cross-coupled stiffness $k_{XY}(z)$ is larger than the direct stiffness $k_{XX}(z)$. Note that a total cross-coupled damping coefficient, obtaining from an integration of $c_{XY}(z)$ over z, is about zero

CONCLUSIONS

A dynamic model of the distributed forces in a HGJB is presented. The distribution functions of direct and cross-coupled stiffness and damping coefficients characterizing the distributed dynamic bearing forces are determined. The proposed dynamic model of bearing forces is capable for applying to the bearing spindle system whose aspect ratio of the bearing width and the shaft length is significant and the shaft is flexible.

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