ENHANCEMENT OF MEMORY CAPACITY IN HDD MICRO- BEARING WITH HYPERBOLIC JOURNALS

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Abstract

The aim of the presented paper is presenting the shapes of HDD micro-bearing journal which have influence on the enhancement of memory capacity. Moreover the asymmetrically grooved lateral surfaces of journal bearings generate the asymmetric pressure distribution which leads to concentric rotation and eccentricity of a rotor. Most of the stiffness coefficient due to asymmetric grooves and hyperbolic shapes of lateral journal surfaces are bigger than those of the conventional cylindrical micro-bearings without grooves.

The damping coefficients and friction torque due to asymmetric grooves and hyperbolic shapes of lateral journal surfaces are slightly bigger than those of the conventional cylindrical micro-bearings without grooves.

The asymmetric grooves of hyperbolic micro journal bearings may have advantages in terms of small whirls radius and large dynamic coefficients occurring during the bearing exploitation.

The idea of seeking of the slide micro-bearings with optimum of the capacity memory was implied from the authors investigation of human joints which fulfill the role of intelligent bio-bearings.

This paper investigates the dynamic behavior of HDD micro-bearings with hyperbolic journal lateral shapes, by solving the proper Reynolds equation and the equation of a motion of a HDD spindle system.

This paper presents the friction forces calculation in hydrodynamic HDD micro bearing lubrication with hyperbolic shapes of journals.

Keywords: *HDD slide micro- bearings, hyperbolic journal shapes*

1. Introduction

The presented topic concerns determining the pressure and capacity distributions in a thin layer of non-Newtonian, visco-elastic lubricant inside the slide bio-bearing and slide micro-bearing gaps of a curvilinear orthogonal hyperbolic form. Non-isothermal, unsteady and random flow conditions and thermal deformations of the micro-bearing and its sleeve are taken into account. General analysis of this paper considerate the dynamic behaviour of micro-bearings and makes comparisons with recently obtained results of other authors [20]. The lubrication of micro-bearing surfaces is characterized by various geometries form and non-Newtonian lubricants. The aim of the presented paper is to generalize the recently calculation methods of the pressure distributions in a thin layer of non-Newtonian, visco-elastic lubricant of slide micro-bearing gaps [1-2, 4-5, 8-14, 18-20].

A coupled journal and thrust hydrodynamic bearing has been recently used in the precision spindle of a computer hard disk drive (HDD), replacing the conventional ball bearings, due to its outstanding low noise and vibration characteristics [12]. In this application, herringbone grooves have the advantage of self-sealing which causes the lubricant to be pumped inward, and therefore, reduces side leakage. They also prevent whirl instability that is observed in the plain journal bearings at concentric operating conditions. Fig. 1a,b,c,d show the spindle system of a HDD and a coupled hyperbolic journal and thrust hydrodynamic bearing used in the HDD spindle [2-3, 9], [12]. Cooperating surfaces in above devices are limited by the hyperbolic surfaces. Fig. 2a,b,c shows the geometries of hyperbolic bearing surfaces [2, 9, 12].

Random conditions are taking into account. Micro-bearing has application in medical drill bits and hard disc driver HDD spindle medical systems [11-12].

The HDB spindle samples have a shaft diameter 3.0 mm; rotational speed 20000 rpm; viscosity of 18 cP (0.018 Pas), radial clearance 3 micrometers, mass 27 g, mass moment of inertia 0.000167 kgm^2. The width of upper and lower journal bearing changes from 1.6 and 1.8 mm to 2.2 and 1.2 mm. The flow analysis of the viscoelastic lubricant, will be performed by means of the Helmholtz equation and the equations of continuity, motion and energy [6-7, 15-[16]. The lubricant flow in bearing gap is generated by rotation of a conical, or parabolic journal. Bearing sleeve is motionless.

The micro-bearing lubrication is characterized by the dynamic viscosity changes in thin gap- height direction.

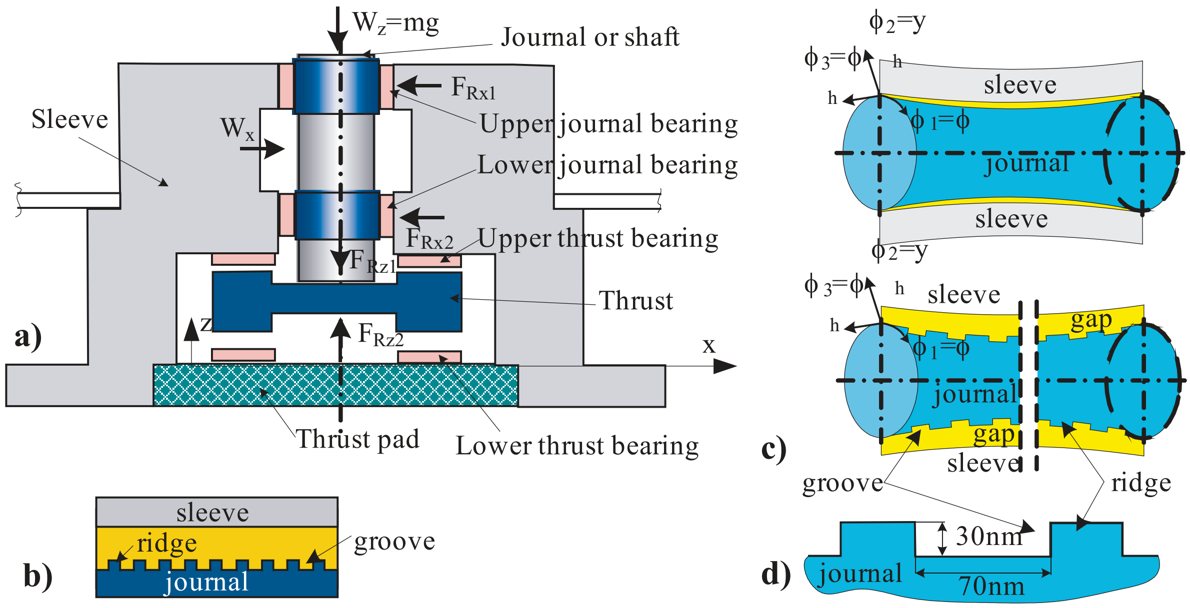

Fig. 1. Coupled journal and thrust hydrodynamic HDD micro-bearing (20000 rpm): a) after G.H. Jang and J.W. Yoon [12], b) classical ridges and grooves on the HDD journal surface, c) hyperbolic journals after Wierzcholski, d) height of ridge

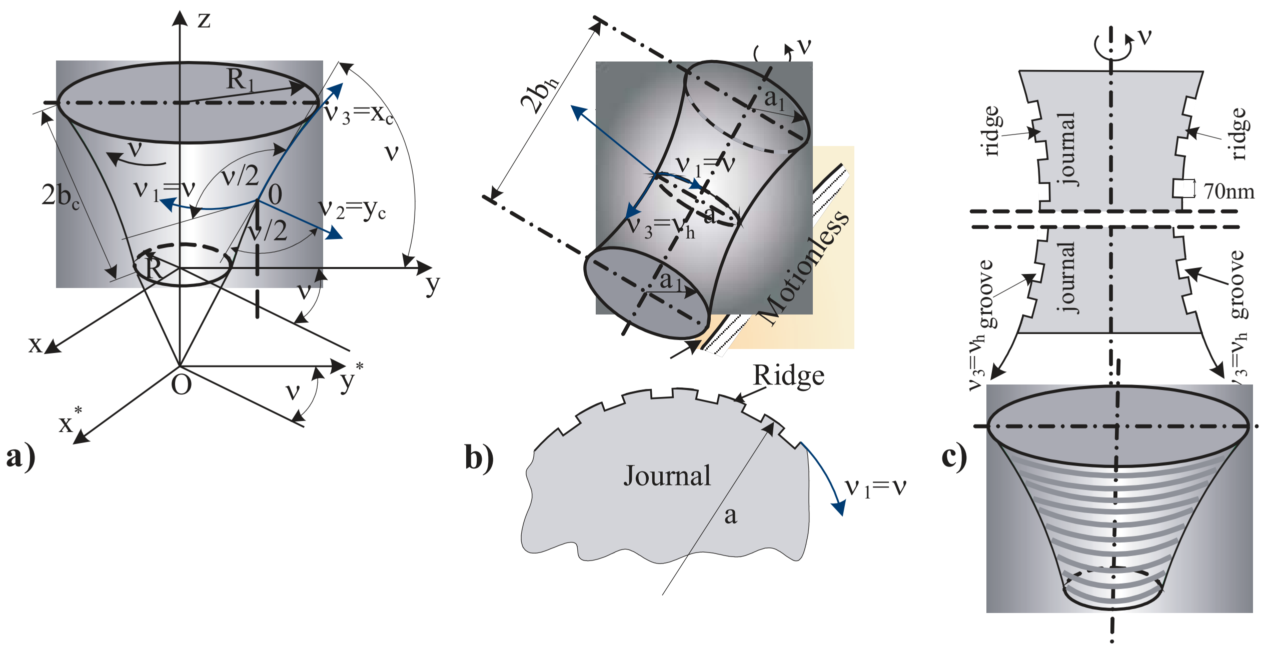

Fig. 2. A view of curvilinear orthogonal bio-bearing and micro-bearing surfaces: a) conical surface, b) hyperbolic surface with grooves in circumferential direction, c) hyperbolic surface with grooves in longitudinal direction

2. Pressure distributions in hyperbolic micro-bearings gaps

For the hyperbolic bearing we have $\alpha_1 = \varphi$, $\alpha_2 = y_h$, $\alpha_3 = \zeta_h$ and the non -monotonic generating line of the journal in length direction is taken into account. Hyperbolic micro-bearing are illustrated in Fig. 1c and Fig. 2b,c. We have: a_1 - the largest radius of the hyperbolic journal, a - the smallest radius of the hyperbolic journal, $2b_h$ - the bearing length. In this case the dimensional pressure function p in the hyperbolic coordinates (φ, y_h, ζ_h) satisfies the modified Reynolds equations in the following form:

$$\frac{\partial}{\partial\varphi}\left[\frac{\partial E(p)}{\partial\varphi}E\left(\int_0^{\varepsilon_T}A_\eta dy_h\right)\right]+$$

$$+\frac{1}{\sqrt{1+4(\Lambda_{h1}/L_{R1})^2\tan^2(\Lambda_{h1}\zeta_{h1})}}\frac{\partial}{\partial\zeta_{h1}}\left[\frac{1}{\sqrt{1+4(\Lambda_{h1}/L_{R1})^2\tan^2(\Lambda_{h1}\zeta_{h1})}}\frac{\partial E(p)}{\partial\zeta_{h1}}E\left(\int_0^{\varepsilon_T}A_\eta dy_h\right)\right]=$$

$$=\omega a^2\cos^{-4}(\Lambda_{h1}\zeta_{h1})\frac{\partial}{\partial\varphi}\left[E\left(\int_0^{\varepsilon_T}A_s dy_h\right)-E(\varepsilon_T)\right],$$

(1)

for $\eta=\eta(\varphi,y_h,\zeta_h)$, $A_s(\varphi,y_h,\zeta_h)$, $A_\eta(\varphi,y_h,\zeta_h)$, $0\le y_h\le\varepsilon_T$.

The equation (1) it tends to the form:

$$\frac{\partial}{\partial\varphi}\left[\frac{E(\varepsilon_T^3)}{\eta}\frac{\partial E(p)}{\partial\varphi}\right]+$$

$$+\frac{1}{\sqrt{1+4(\Lambda_{h1}/L_{R1})^2\tan^2(\Lambda_{h1}\zeta_{h1})}}\frac{\partial}{\partial\zeta_{h1}}\left[\frac{\cos(\Lambda_{h1}\zeta_{h1})}{\sqrt{1+4(\Lambda_{h1}/L_{R1})^2\tan^2(\Lambda_{h1}\zeta_{h1})}}\frac{E(\varepsilon_T^3)}{\eta}\frac{\partial E(p)}{\partial\zeta_{h1}}\right]=$$

$$=6\omega a^2\frac{\partial E(\varepsilon_T)}{\partial\varphi}\cos^{-4}(\Lambda_{h1}\zeta_{h1}),\quad |\zeta_{h1}|\le\frac{1}{\Lambda_{h1}}\arccos\sqrt{\frac{a}{a_1}},\tag{2}$$

$$\Lambda_{h1}\equiv\sqrt{\frac{a_1-a}{a}},\qquad L_{R1}\equiv\frac{b_h}{a},$$

for $\eta=\eta(\varphi,\zeta_h)$ where $0\le\varphi<2\pi\theta_1$, $0\le\theta_1<1$, $\zeta_{h1}=\zeta_h/b_h$, $-b_h\le\zeta_h\le b_h$.

The equation (1) describes the pressure function $p(\varphi,\zeta_h)$ in hyperbolic micro-bearing if oil viscosity changes in gap height direction are taken into account. The equation (2) describes the pressure function $p(\varphi,\zeta_h)$ in hyperbolic micro-bearing if oil viscosity changes in gap height direction are neglected.

3. Friction forces in hyperbolic micro-bearing gap

This section presents the friction forces calculation in micro-bearing gaps.

The components of friction forces in curvilinear α_1, α_3 directions occurring in micro-and bio-bearing gaps have the following forms:

$$F_{R1}=\iint_F\left(\eta\frac{\partial v_1}{\partial\alpha_2}\right)_{\alpha_2=\varepsilon_T}h_1h_3d\alpha_1d\alpha_3,\quad F_{R3}=\iint_F\left(\eta\frac{\partial v_3}{\partial\alpha_2}\right)_{\alpha_2=\varepsilon_T}h_1h_3d\alpha_1d\alpha_3,\tag{3}$$

where:

$0\le\alpha_1\le2\pi\theta_1$, $0\le\theta_1\le1$, $b_m\le\alpha_3\le b_s$, $0\le\alpha_2\le\varepsilon_T$, $\varepsilon_T=\varepsilon_T(\alpha_1,\alpha_3)$, $\eta(\alpha_1,\alpha_2,\alpha_3)$,

- lubrication surface,

$\varepsilon_T(\alpha_1, \alpha_3)$ - gap height,
$\eta(\alpha_1, \alpha_2, \alpha_3)$ - fluid dynamic viscosity,
v_1,v_3 - fluid velocity components in α_1, α_3 directions, respectively,
h_1,h_3 - Lame coefficients.

In this intersection the friction velocity components F_{R1}, F_{R3} in α_1, α_3 directions, respectively, will be determined. For the hyperbolic shapes of micro-bearing journals we have following coordinates: $\alpha_1 = \varphi$, $\alpha_2 = y_h$, $\alpha_3 = \zeta_h$, and Lame coefficients are as follows:

$$h_1=a\cos^{-2}\left(\frac{\zeta_h}{b_h}\sqrt{\frac{a_1-a}{a}}\right),\quad h_3=\sqrt{1+4a\frac{(a_1-a)}{b_h^2}\tan^2\left(\frac{\zeta_h}{b_h}\sqrt{\frac{a_1-a}{a}}\right)}\cos^{-2}\left(\frac{\zeta_h}{b_h}\sqrt{\frac{a_1-a}{a}}\right),\tag{4}$$

where:

a1 - denotes the largest radius of the hyperbolic shaft,
a - the smallest radius of the hyperbolic journal,
2bh - the hyperbolic bearing length (see Fig. 2b, c).

In this case the components of friction forces (3), in two directions have the following form:

$$F_{R\varphi}=\iint_F\frac{\partial p}{\partial\varphi}\left[\varepsilon_T(\varphi,\zeta_h)-\frac{\int_0^{\varepsilon_T(\varphi,\zeta_h)}\frac{y_h dy_h}{\eta(\varphi,y_h,\zeta_h)}}{\int_0^{\varepsilon_T(\varphi,\zeta_h)}\frac{dy_h}{\eta(\varphi,y_h,\zeta_h)}}\right]h_3(\zeta_h)d\varphi d\zeta_h+$$

$$-\omega a^2\iint_F\left[\frac{\sqrt{1+4a\frac{(a_1-a)}{b_h^2}\tan^2\left(\frac{\zeta_h}{b_h}\sqrt{\frac{(a_1-a)}{a}}\right)}\cos^{-6}\left(\frac{\zeta_h}{b_h}\sqrt{\frac{(a_1-a)}{a}}\right)}{\int_0^{\varepsilon_T(\varphi,\zeta_h)}\frac{dy_h}{\eta(\varphi,y_h,\zeta_h)}}\right]d\varphi d\zeta_h,\tag{5}$$

$$F_{R\zeta_h} = \iint_F \frac{\partial p}{\partial \zeta_h}\left[\varepsilon_T(\varphi,\zeta_h) - \frac{\int_0^{\varepsilon_T(\varphi,\zeta_h)} \frac{y_h dy_h}{\eta(\varphi,y_h,\zeta_h)}}{\int_0^{\varepsilon_T(\varphi,\zeta_h)} \frac{dy_h}{\eta(\varphi,y_h,\zeta_h)}}\right] h_1(\zeta_h) d\varphi d\zeta_h, \tag{6}$$

where:
$\eta=\eta(\varphi,y_h,\zeta_h)$, $0\le y_h\le\varepsilon_T$, $0\le\varphi<2\pi\theta_1$, $0\le\theta_1<1$, $\zeta_{h1}=\zeta_h/b_p$, $-b_h\le\zeta_h\le b_h$.

If the fluid dynamic viscosity changes not in gap height direction then the formulae (5), (6) tend to the following form:

$$F_{R\varphi} = \frac{1}{2}\iint_F \varepsilon_T(\varphi,\zeta_h)\frac{\partial p}{\partial \varphi}\sqrt{1+4a\frac{(a_1-a)}{b_h^2}\tan^2\left(\frac{\zeta_h}{b_h}\sqrt{\frac{a_1-a}{a}}\right)}\cos^{-2}\left(\frac{\zeta_h}{b_h}\sqrt{\frac{a_1-a}{a}}\right) d\varphi d\zeta_h -$$

$$-\omega a^2 \iint_F \frac{\eta(\varphi,\zeta_h)}{\varepsilon_T(\varphi,\zeta_h)}\sqrt{1+4a\frac{(a_1-a)}{b_h^2}\sin^2\left(\frac{\zeta_h}{b_h}\sqrt{\frac{a_1-a}{a}}\right)}\cos^{-6}\left(\frac{\zeta_h}{b_h}\sqrt{\frac{a_1-a}{a}}\right) d\varphi d\zeta_h, \tag{7}$$

$$F_{R\zeta_h} = \frac{a}{2}\iint_F \varepsilon_T(\varphi,\zeta_h)\frac{\partial p}{\partial \zeta_h}\cos^{-2}\left(\frac{\zeta_h}{b_h}\sqrt{\frac{a_1-a}{a}}\right) d\varphi d\zeta_h. \tag{8}$$

where: $\eta=\eta(\varphi,\zeta_h)$, $0\le\varphi<2\pi\theta_1$, $0\le\theta_1<1$, $\zeta_{h1}=\zeta_p/b_h$, $-b_h\le\zeta_h\le b_h$.

4. Conclusions

- After Author's investigations [17], [18] the magnetic induction field increases the pressure distribution and capacities in hyperbolic micro-bearing.
- We can simulate the increases of the memory capacity of fluid dynamic HDD micro-bearings not only by the bearing width changes, and by the herringbone or spiral grooves indicated in papers [9, 12], but also by the various hyperbolic shapes of journal bearings.
- The properties of the changes of memory capacity simulations in presented micro-bearings are compared with the similar capacity memory which had been attained in human bio-bearings with various hyperbolic shapes of bone heads formed during the thousand years of evolution.

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Nomenclature

a - smaller radius of hyperbolic journal, *m,*
p - hydrodynamic pressure, *Pa,*
y_h - hyperbolic coordinate in gap height direction, *m,*
ε_T - total gap height, *m*,
ω - angular velocity of hyperbolic journal, s^{-1},
η - hydrodynamic viscosity of the fluid, *Pas.*

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