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CAPACITY ENHANCEMENT IN HDD CONICAL MICRO-BEARINGS

ZWIĘKSZENIE NOŚNOŚCI W STOŻKOWYCH MIKROŁOŻYSKACH HDD

Key-words:

computer discs, micro-bearings, artificial intelligence

Słowa kluczowe:

dyski komputerowe, mikrołożyska, sztuczna inteligencja

Summary

This paper presents a method of pressure and carrying capacity calculation in slide conical micro-bearing occurring in HDD computer discs. The authors compare they're own results of pressure and capacity distributions with the results that are obtained G.H. Jang. Considered micro-bearings have intelligent memory features. G.H. Jang attain memory properties through the nano- grooves on the cylindrical micro-bearing surfaces which implies the whirling motion and whirling flows of the lubricant in the bearing gap. In the presented paper, the proper pressures and capacity distributions and memory effects the of course are obtained by the conical shapes of the journal and sleeve and additionally by the grooves

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with depth of about 25 nm. Such shapes increase and regulate the pressure and capacity distributions and the effect of whirling motion and therefore increase the bearing memory properties.

INTRODUCTION

The presented topic concerns determining the memory and capacity enhancement during the slide conical micro-bearing lubrication. Unsteady and random flow conditions 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 **[L. 6**, **7]**. The lubrication of conical micro-bearing surfaces is characterized by various geometries form and artificial intelligence. The aim of the presented paper is to generalize the recently calculation methods of the pressure distributions in a thin layer lubricant of slide micro-bearing gaps **[L. 1–5]**.

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 **[L. 3]**. 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 conical journal bearings at concentric operating conditions. **Fig. 1a, b** show the conical bearing system of a HDD and particularly a circumferential and longitudinal grooves.

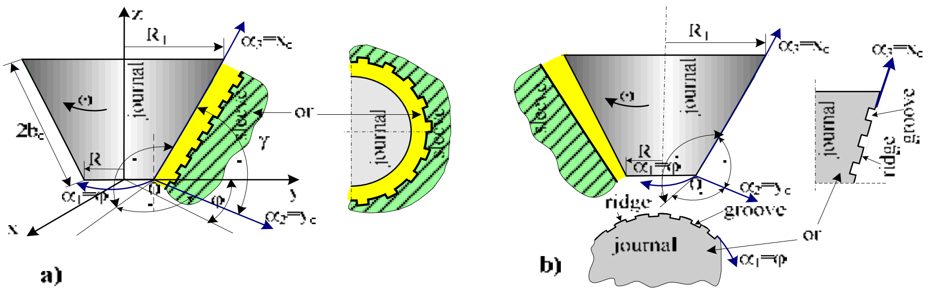

Fig. 1. Conical journal for hydrodynamic HDD micro-bearing (20 000 rpm after K. Wierzcholski): a) circumferential and longitudinal grooves on the conical sleeve, b) circumferential and longitudinal grooves on the conical journal

Rys. 1. Czopy stożkowe w hydrodynamicznych mikrołożyskach HDD (20 000 obr./min wg Wierzcholskiego): a) rowki obwodowe i wzdłużne na stożkowej panewce, b) rowki obwodowe i wzdłużne na stożkowym czopie

Cooperating surfaces in above devices are limited by the conical surfaces.

Random conditions are taking into account. Micro-bearing has application in medical drill bits and hard disc driver HDD spindle medical systems **[L. 5]**.

The HDD spindle samples have a shaft diameter 3.0 mm; rotational speed 20 000 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 equations of continuity, and motion **[L. 6]**. The lubricant flow in bearing gap is generated by rotation of a conical, or spherical journal. Bearing sleeve is motionless. The micro-bearing lubrication is characterized by the dynamic viscosity changes in thin gap- height direction.

CAPACITY DISTRIBUTIONS IN CONICAL MICRO-BEARINGS GAPS

- The dimensional pressure function $p(\varphi,x_c,t)$ in the conical coordinates (φ, y_c, x_c) satisfies the modified Reynolds equations (1) in the following form:

$$\frac{1}{R+x_c\cos\gamma}\frac{\partial}{\partial\varphi}\left[\frac{\partial E(p)}{\partial\varphi}E\left(\int_0^{\varepsilon_T}A_\eta dy_c\right)\right]+\frac{\partial}{\partial x_c}\left[(R+x_c\cos\gamma)\frac{\partial E(p)}{\partial x_c}E\left(\int_0^{\varepsilon_T}A_\eta dy_c\right)\right]=$$

$$=\omega(R+x_c\cos\gamma)\frac{\partial}{\partial\varphi}\left[E\left(\int_0^{\varepsilon_T}A_s dy_c\right)-E(\varepsilon_T)\right]+(R+x_c\cos\gamma)\frac{\partial E(\varepsilon_T)}{\partial t} \quad (1)$$

where

$$A_s(\varphi,y_c,x_c)\equiv\frac{\int_0^{y_c}\frac{1}{\eta}dy_c}{\int_0^{\varepsilon_T}\frac{1}{\eta}dy_c},\ A_\eta(\varphi,y_c,x_c)\equiv\int_0^{y_c}\frac{y_c}{\eta}dy_c-$$

$$-A_s(\varphi,y_c,x_c)\int_0^{\varepsilon_T}\frac{y_c}{\eta}dy_c \quad (2)$$

for $\eta=\eta(\varphi,y_c,x_c)$, $0\le y_c\le\varepsilon_T$, $0\le\varphi<2\pi\theta_1$, $0\le\theta_1<1$, $0\le x_c\le 2b_c$. We denote: γ – angle between conical surface and the cross section plane of the journal, b_c – length of the cone generating line, R – radius of the journal, t – time (see **Fig. 1**).

If dynamic viscosity is constant in the gap height direction, then the equation (1) tends to the form:

$$\frac{1}{X_c}\frac{\partial}{\partial\varphi}\left[\frac{E(\varepsilon_T^3)}{\eta}\frac{\partial E(p)}{\partial\varphi}\right]+\frac{\partial}{\partial x_c}\left[\frac{X_c E(\varepsilon_T^3)}{\eta}\frac{\partial E(p)}{\partial x_c}\right]=$$
$$=6\omega X_c\frac{\partial E(\varepsilon_T)}{\partial\varphi}-12X_c\frac{\partial E(\varepsilon_T)}{\partial t} \tag{3}$$

for $\eta = \eta(\varphi, x_c)$, $X_c = R + x_c\cos\gamma$, where $0 \le \varphi < 2\pi\theta_1$, $0 \le \theta_1 < 1$, $0 \le x_c \le 2b_c$

The equation (1) describes the pressure function $p(\varphi, x_c, t)$ in conical micro-bearing if oil viscosity changes in gap height direction are taken into account. The equation (3) describes the pressure function $p(\varphi, x_c, t)$ in conical micro-bearing if oil viscosity changes in gap height direction are neglected.

By using the optimal function f of probability density distribution of the stochastic gap changes caused by the roughness the mean value of total film thickness $E(\varepsilon_T)$ and the mean value of pressure function E(p) are represented by virtue of the expectancy operator in the following form **[L. 6, 7]**:

$$E(*)=\int_{-\infty}^{+\infty}(*)\times f(\delta_1)d\delta_1, \quad \sigma_s=\frac{c_1}{\sqrt{13}}=0{,}375$$
$$f(\delta_1)\equiv\begin{cases}\left(1-\dfrac{\delta_1^2}{c_1^2}\right)^5 & \text{for } -c_1\le\delta_1\le+c_1\\ 0 & \text{for } |\delta_1|>c_1\end{cases} \tag{4}$$

where the symbol $c_1 = 1.353515$ denotes the half total range of random variable of thin layer thickness for normal hip joint. The symbol δ_1 denotes dimensionless random part of the gap height. We have $\delta = \varepsilon_o\delta_1$ and $c = \varepsilon_o c_1$ where symbol ε_o denotes characteristic value of gap height. The dimensionless value of the standard deviation $\sigma_s = 0.37539$ was obtained on the basis of calculations for real roughness of micro-bearing surfaces.

- The carrying capacities in conical bearing are calculated from the following formula:

$$C_{tot}^{con}(t) = \left\{ \left[\int_0^{+2b_c} \left(\int_0^{\varphi_k} p(\varphi, x_c, t)(R \sin\varphi + x_c \sin\varphi\cos\gamma) d\varphi \right) dx_c \right]^2 + \right.$$

$$\left. + \left[\int_0^{2b_c} \left(\int_0^{\varphi_k} p(\varphi, x_c, t)(R \cos\varphi + x_c \cos\varphi\cos\gamma) d\varphi \right) dx_c \right]^2 \right\}^{0,5} \quad (5)$$

where symbol φ_k denotes the end coordinate of the film in circumferential direction and $0 \le \varphi < 2\pi\theta_1$, $0 \le \theta_1 < 1$, $0 \le x_c \le 2b_c$. Friction coefficients in conical coordinates are as follows **[L. 6]**:

$$\mu_{con}(t) = \frac{\left| \mathbf{e}_\varphi F_{R\varphi} + \mathbf{e}_x F_{Rx} \right|}{C_{tot}^{(con)}(t)} \quad (6)$$

where $F_{R\varphi}$, F_{Rx} denote friction forces in circumference φ and longitudinal x_c directions and moreover $\mathbf{e}_\varphi$, $\mathbf{e}_x$ are the unit vectors in conical φ and x coordinate directions.

NUMERICAL CALCULATIONS

The pressure distributions and capacity values in machine conical slide micro-bearings are determined in the lubrication region Ω_c, which is defined by the following inequalities: $0 \le \varphi \le \varphi_k$, $0 \le x_c \le 2b_c$ where $2b_c$ – micro-bearing length.

Numerical calculations are performed in Matlab 7.8 Professional Program by virtue of the equation (3) by means of the finite difference method (see **Fig. 2**).

The gap height of the conical micro-bearing and bio-bearing has the following form:

$$\varepsilon_T = \varepsilon(1+\lambda_c\cos\varphi)\sin^{-1}\gamma, \ \gamma \ne 0, \quad (7)$$

where λ_c – eccentricity ratio in conical micro-bearing, ε – radial clearance of conical micro-bearing or bio-bearing and γ is angle between generate line and horizontal axis y.

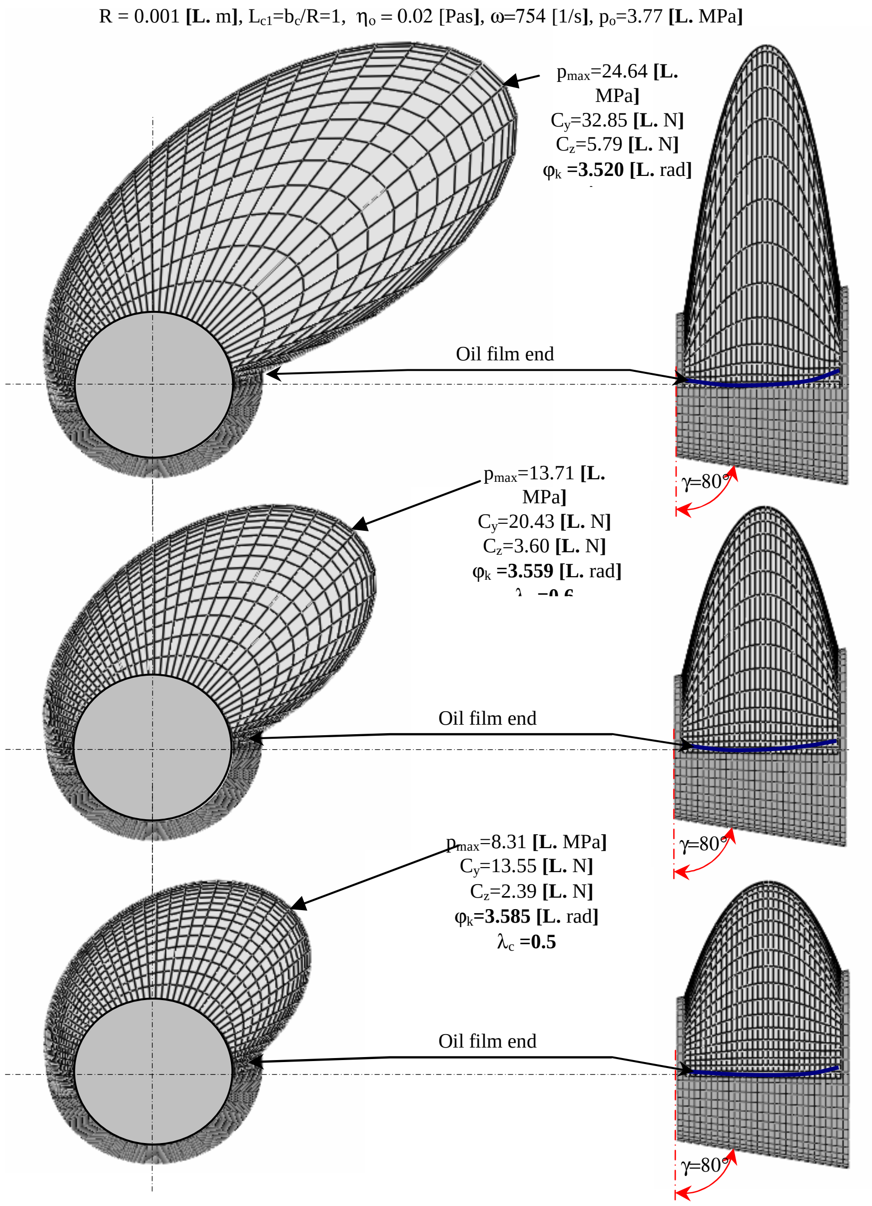

Fig. 2. The pressure distributions in conical micro-bearings caused by the rotation in circumferential direction where conical inclination angle $\gamma = 80^o$. Left side presents the view from the film origin, right side shows the view from film end

Rys. 2. Rozkłady ciśnienia w stożkowym mikrołożysku wywołane ruchem obrotowym w kierunku obwodowym przy kącie nachyleniu $\gamma = 80^o$ powierzchni bocznej z płaszczyzną prostopadłą do osi wałka. Rozkłady znajdujące się po lewej (prawej) stronie rysunku pokazują początek (koniec) rozkładu ciśnienia hydrodynamicznego

Fig. 2 shows the numerical pressure values in conical micro-bearing gap for the angle $\gamma = 80^o$ between conical surface and the cross section plane without magnetic field influences and stochastic changes for: least value of the conical journal R = 0.001 m, $L_{c1} = b_c/R = 1$, oil dynamic viscosity $\eta_o = 0.02$ Pas, angular velocity $\omega = 754\ s^{-1}$, $p_o = \omega\eta_o R^2/\varepsilon^2 p_o = 3.77$ MPa, eccentricity values $\lambda_c = 0.5$; $\lambda_c = 0.6$; $\lambda_c = 0.7$.

By virtue of the boundary Reynolds conditions the angular coordinate of the film end has the values: $\varphi_k = 3.585$ rad; $\varphi_k = 3.559$ rad; $\varphi_k = 3.520$ rad. If eccentricity ratio increases from $\lambda_c = 0.5$ to $\lambda_c = 0.7$, then the maximum value of hydrodynamic pressure increases from 8.31 MPa to 24.65 MPa and total capacity in y direction increases from 13.54 N to 32.85 N and z direction increases from 2.39 N to 5.79 N.

CONCLUSIONS

- If the angle γ between conical surface and the cross section plane increases in conical bio-bearing and micro-bearings, then the capacity in cross-wise direction increases and in longitudinal direction decreases.
- We can simulate the increases of the memory capacity of fluid dynamic HDD micro-bearings not only by the bearing width, and by the herringbone or spiral grooves indicated in papers **[L. 6, 7]** and also by the various shapes of journal bearings.
- The properties of the changes of memory capacity simulations are functioning for human bio-bearings with various shapes of bone heads which are formed during the thousand years of evolution.

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Recenzent:
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Streszczenie

W niniejszej pracy wyznacza się rozkłady wartości ciśnienia oraz siły nośne w mikrołożyskach stożkowych stosowanych w dyskach komputerowych. Prace z zakresu mikrołożysk ślizgowych publikowane w ostatnich trzech latach dowodzą, że mikro- i nanorowki na powierzchniach czopa i panewki mikrołożysk przyczyniają się do zwiększenia nośności i powodują, że łożyska mają właściwości inteligentne, manifestujące się zdolnością zapamiętywania określonych reakcji na konkretne obciążenia w trakcie eksploatacji. Autorzy niniejszej pracy wykazują, że cechy pamięci i symulacji nośności są powodowane nie tylko nano- i mikrorowkami na powierzchni czopa i panewki, ale również rozmaitymi kształtami czopów, a w niniejszej pracy czopem stożkowym. Opublikowana praca autora w Solid State Phenomena, Switzerland (2009) dotycząca mikrołożysk z czopami parabolicznymi oraz przedstawione w niniejszej pracy wyniki dotyczące łożysk o czopach stożkowych potwierdzają przedstawioną hipotezę.

W niniejszej pracy autorzy przedstawiają równanie typu Reynoldsa wyznaczające rozkład ciśnienia w szczelinie stożkowego mikrołożyska przy uwzględnieniu stochastycznie zmiennej wysokości szczeliny łożyskowej.

Ponadto wyznaczone zostały rozkłady wartości ciśnienia hydrodynamicznego oraz wartości siły nośnej.