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ORIGINAL ARTICLE

# The performance and stability of three-lobe journal bearing textured with micro protrusions

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**Abstract** The present research work deals with studying the steady state performance and dynamic stability of sliding element hydrodynamic bearings of the three-lobe type and provided with a bushing surface textured with uniform micro protrusions. A mathematical model has been put forward for the problem using the Reynolds equation governing the unstable fluid lubrication inside the bearing as well as the equations governing the dynamic movement of the journal. The equations have been put in their numerical forms suitable for computer solution using the finite difference method. Two types of three lobe bearings have been considered, one with its plain bushing and the other with bushing textured with uniform micro protrusions. This is in addition to other two plain journal bearings one with plain bushing and the other with textured bushing. This is for the purpose of carrying out a general comparison to include the steady performance of these bearings in terms of their load carrying capacity and the friction losses in their parts in addition to their dynamic stability. It was concluded in the present work that the inclusion of these textured micro protrusions in the bushing of bearings, whether they are plain or of the three-lobe geometry improves their performance in terms of reducing their friction losses and raising their load carrying capacity along. It was found that the three-lobe bearing with protruded bushing surface texture is superior to the other types of bearings considered in the present work as far as steady state performance is concerned. Regarding the margin of stability to small sinusoidal disturbances the protruded three-lobe bearing shows a relatively lower margin. Some useful recommendations for future research work in this field of study are given in this work and the most important one is to carry out extensive experimental studies on sliding bearings surfaces fitted with textured bushings of different micro protrusions designs.


## 1. Introduction

Many researches have been made on the performance and dynamic stability of different types of journal bearings. Han et al. [1] investigated the hydrodynamic stability of a rotating journal with a stationary bearing. A long (two-dimensional)

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**Nomenclature**

| | |
|---|---|
| c | radial clearance, m |
| e | eccentricity, m |
| $F_r, F_t$ | radial and transverse load components, N |
| $\bar{F}_r, \bar{F}_t$ | dimensionless load components in radial and transverse directions respectively made dimensionless with respect to $(\mu u_o L(\frac{R}{c})^2)$ |
| $F'_r, F'_t$ | perturbation load components in radial and transverse directions respectively made dimensionless with respect to $\left(\mu u_o L(\frac{R}{c})^2\right)$ |
| $F^*_r$, $F^*_t$ | steady load components in radial and transverse directions respectively made dimensionless with respect to $\left(\mu u_o L(\frac{R}{c})^2\right)$ |
| h | film thickness, m |
| $\bar{h}$ | dimensionless film thickness, $\bar{h} = h/c$ |
| $h^*_o, h'$ | film thickness for steady state and perturbation solutions made dimensionless with respect to c |
| $H_a$ | protrusion height, m |
| L | bearing length, m |
| N | journal speed, rps |
| m | geometry factor |
| $n_w$ | number of waves (three-lobe) |
| $n_x$ and $n_z$ | protrusion widths in both x-direction and z-direction |
| p | pressure, Pa |
| $\bar{P}$ | dimensionless pressure, $\bar{p} = p/(\frac{\mu u_o R}{c^2})$ |
| $p^*$ | dimensionless fluid pressure for steady state made dimensionless with respect to $(\mu\omega(R/c)^2)$ |
| $p'$ | dimensionless fluid pressure for perturbation solution made dimensionless with respect to $(\mu\omega(R/c)^2)$ |
| R | journal radius, m |
| $R_b$ | bearing radius, m |
| S | Sommerfeld no $\frac{\mu NLD}{W}\left(\frac{R}{C}\right)^2$ |
| t | time, s |
| $t_o$ | characteristic time $\left(t_o = \frac{1}{\omega}\right)$, s |
| $\bar{t}$ | dimensionless time, $\bar{t} = t/t_o = \omega t$ |
| u | flow velocity component in x-direction, m/s |
| $u_o$ | characteristic velocity, $(u_o = \omega R)$, m/s |
| W | load-carrying capacity, N |
| $\bar{W}$ | dimensionless load-carrying capacity, $\bar{W} = W/(\mu u_o L(\frac{R}{c})^2)$ |
| $W^*, W'$ | steady load and perturbation load respectively made dimensionless with respect to $(\mu\omega RL(R/c)^2)$ |
| (x, y, z) | Cartesian co-ordinate system |
| $(\theta, \bar{y}, \bar{z})$ | dimensionless Cartesian co-ordinate system, $\bar{x} = x/R, \bar{y} = y/c, \bar{z} = z/L$ |

*Greek symbols*

| | |
|---|---|
| $\beta$ | dimensionless frequency $\left(\beta = \frac{\Omega}{\omega}\right)$ |
| $\Delta(\theta, z)$ | variation of the film thickness, m |
| $\Delta^*(\theta, z)$ | dimensionless variation in the film thickness, $\Delta^* = \Delta(\theta, z)/c$ |
| $\varepsilon$ | eccentricity ratio, $\varepsilon = e/c$ |
| $\varepsilon_o, \varepsilon'$ | eccentricity ratios for equilibrium and perturbation solutions respectively |
| $\varepsilon_w$ | the wave amplitude |
| $\theta$ | bearing coordinate angle in circumferential direction, rad |
| $\Lambda$ | stability (mass) number, $\Lambda = \frac{\omega M}{\mu (R/c)^3 L}$ |
| $\rho$ | lubricant density, kg/m$^3$ |
| $\mu$ | lubricant viscosity, Pa s |
| $\Omega$ | frequency of oscillation, rad/s |
| $\omega$ | angular velocity, rad/s |
| $\varphi$ | attitude angle, rad |
| $\varphi_o, \varphi'$ | attitude angles for steady state and perturbation solutions, rad |

journal bearing separated by Newtonian non-cavitating lubricant was studied for shaft stability. Spectral element methods, perturbation methods, and linear stability analyses are used. They found that increasing eccentricity helps stabilize a whirling shaft. Non-circular shaft bearings, for example elliptical bearings, they observed to have better dynamic stability and by increasing their ellipticity they leaded to an improved anti-whirl capability. Rao and Sawicki [2] presented the two-dimensional linear stability analysis considering the fluid flow in both full film and cavitation regions for a plain cylindrical journal bearing. The unsteady pressure gradients in the full film region were evaluated taking into consideration the perturbed flow parameters in the cavitation region, i.e., at both rupture and reformation boundaries. Tile linearized stiffness and damping coefficients, whirl dimensionless frequency, and threshold speed for various values of eccentricity and L/D ratios were obtained for a plain cylindrical journal bearing with an axial groove along the load line. They showed good agreement between the theoretical and experimenta1 results. Bhushan et al. [3], analytically investigated a four-lobe bearing supporting rigid and flexible rotors to determine its performance when L/D ratio was varied in the range 0.75–1.5. The static and dynamic characteristics were studied at various L/D ratios. The results showed that the stability of a four-lobe pressure dam bearing increases with decrease in L/D ratios both for rigid as well as flexible rotors. Abdou et al. [4] analyzed the dynamic behavior of the plain cylindrical journal bearing having three-dimensional asperity shell (liner). A perturbed Reynolds equation is used to determine the unsteady components resulting from given small excitations of the bearing journal, the coupling of the journal external excitation with fluid forces is studied. Values of the stability number which give critically stable conditions of motion were determined. The effect of the liner asperities on the stability of fluid film bearing of finite width is investigated. Batra et al. [5], investigated analytically an inverted three-lobe pressure dam bearing supporting rigid and flexible rotors. A four-lobe pressure dam bearing which was produced by cutting two pressure dams on the upper two lobes and two relief-tracks on the lower two lobes of an ordinary four-lobe bearing was found to be more stable than a conventional four-lobe bearing. Boukhelef et al. [6] applied the Finite Element method to compute bearing characteristics, especially stiffness and dynamic coefficients. The different governing equations deduced from the

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