DINAME 2019 - Proceedings of the XVIII International Symposium on Dynamic Problems of Mechanics,
M.A. Savi, T.G. Ritto and W.M. Bessa (Editors), ABCM, Buzios, RJ, Brazil, March 10th to 15th, 2019

Influence of textured journal bearings on rotor's dynamic behavior

Leandro Ito Ramos[1], **Douglas Jhon Ramos**[1], **and Gregory Bregion Daniel**[1]

[1] School of Mechanical Engineering, University of Campinas, Mendeleyev Street, 200 - SP, Brazil

Abstract: The surface texturing of journal bearings is one of the methods currently applied to increase its performance mainly by increasing load capacity and/or reducing friction. The objective of this work is to determine the influence of textured journal bearings on the dynamic behavior of the rotor, verifying how the instability threshold is changed due to the presence of different texturing parameters for the journal bearings. Journal bearings fully textured with cuboid, cylindrical and spherical cap shapes were simulated considering a established range of maximum depths for the textures in order to determine the respective damping factor diagrams of the rotating system. Results show that the insertion of textures in the bearing surface decreases the instability threshold of the rotating system for the simulated textures' distribution and parameters.

Keywords: Journal bearings, Surface texturing, Instability threshold

INTRODUCTION

Development of rotating machines has increasingly demanded improvement of journal bearings that act as supporting structures for the system. The lubricating fluid film that separates the surfaces of bearing and shaft allows the support of large loads at high speeds as well as drastically reduces friction between the bearing-shaft pair. Texturing of journal bearings' surface is meant to improve its load capacity and/or friction characteristics and many investigations have been developed in this area as shown in Etsion (2013), Wang (2014) and Gropper et al. (2016). In addition to study the journal bearing's performance changes due to surface texturing it's also important to understand how the dynamic behavior of the rotating system supported by such textured bearings can be affected. Significant results were reported by Yamada et al. (2018) showing the delay of the instability threshold and Matele and Pandey (2018) showing that in some cases can occur anticipation of the instability threshold with textures insertion in journal bearing's surface.

In this context, the present investigation consists in the development of a computational model capable of predict the instability threshold of a rotating system supported by textured journal bearings aiming to verify whether or not the bearing with textured surface is capable to change the instability threshold of the rotating system as well as to determine which parameters of the textured surface are more significant on the observed behavior. The study of the instability threshold is important for the analysis of the rotating system once it represents a fault condition of the system which is characterized by the impact between shaft and journal bearings surfaces. The damping factor diagrams were analyzed in this study considering the stiffness and damping equivalent coefficients of the bearings, searching for the instability threshold.

METHODOLOGY

Bearing lubrication model

The pressure field developed in journal bearing's lubricant film can be mathematically described through Reynolds equation as follows

$$\frac{\partial}{\partial x}\left(h^3\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial z}\left(h^3\frac{\partial p}{\partial z}\right)=6\mu U\frac{\partial h}{\partial x}+12\mu\frac{\partial h}{\partial t} \tag{1}$$

where p is the hydrodynamic pressure, μ is lubricant's absolute viscosity, U is the linear velocity at shaft's surface and (x,z) are the coordinates established on bearing's surface. The lubricant film thickness h for a smooth bearing can be calculated as

$$h(\theta)=C_r+e_X sin\theta-e_Y cos\theta \tag{2}$$

where $\theta=\frac{x}{R}$ with R being shaft's radius, C_r is the bearing's radial clearance, e_X and e_Y are shaft's Cartesian coordinates relative to bearing's inertial coordinates system. However, surface texturing introduces a correction term to Eq. 2 as follows

$$h'(\theta,z)=h(\theta)+\Delta h(\theta,z) \tag{3}$$

Correction's term values in Eq. 3 depends on surface textures geometry such that for cuboid and cylindrical shapes it's written as

$$\Delta h\left(\theta,z\right) = r_y \tag{4}$$

where r_y is the texture's maximum depth which is constant for both cuboid and cylindrical shapes. In case of spherical cap textures correction's term can be written as proposed by Tala-Ighil and Fillon (2015):

$$\begin{aligned} &\Delta h\left(\theta,z\right) = \frac{r_y}{r}\sqrt{r^2-(x-x_c)^2-(z-z_c)^2}, when \sqrt{(x-x_c)^2+(z-z_c)^2} \leq r, \\ &\Delta h\left(\theta,z\right) = 0, otherwise. \end{aligned} \tag{5}$$

where (x_c, y_c, z_c) are the coordinates of the textures' centers with $y_c = 0$ and r is textures' surface radius which can be obtained from textures' density ρ.

Pressure distribution in the bearing can be obtained from Reynolds equation solution and from which is possible to calculate the hydrodynamic forces. In order to properly evaluate the influence of textures in bearing's pressure distribution an adequately refined FVM (Finite Volume Method) grid should be employed and the respective discrete problem obtained is solved through the Gauss-Seidel method. The equilibrium position of the shaft inside the bearing for a given operating condition is determined using Newton-Raphson search method.

Applying perturbations to bearing's equilibrium point in both position and velocity it's possible to calculate stiffness and damping coefficients for the component, as shown in Eq. 6.

$$K_{ij} = \frac{\partial F_i}{\partial x_j^{eq}} \quad C_{ij} = \frac{\partial F_i}{\partial \dot{x}_j^{eq}} \tag{6}$$

In Eq. 6, x^{eq} is the position around the equilibrium position and $\dot{x}^{eq}$ is the velocity.

Rotor model

Equation 7 describes the dynamic behavior of the rotating system with the global matrices obtained using the FEM (Finite Element Method). The matrices of the shaft and disk elements are calculated using the works of Nelson and McVaugh (1976) and Nelson (1980).

$$[M]\{\ddot{q}(t)\} + ([C]+\Omega[G])\{\dot{q}(t)\} + ([K]+[K_e])\{q(t)\} = \{F\} \tag{7}$$

where $[M]$, $[C]$, $[G]$ and $[K]$ are the global matrices of mass, damping, gyroscopic and stiffness, respectively, $\{F\}$ is an excitation vector, $\{q(t)\}$ is the degrees of freedom vector and Ω is the rotor's angular velocity. The additional stiffness $[K_e]$ considered in the model was introduced according to Friswell et al. (2010). The bearings are introduced in this model by means of its stiffness and damping coefficients which are obtained as previously discussed.

From the global matrices of the rotating system it is possible to determine the dynamic matrix as follows

$$[A] = \begin{bmatrix} [0] & [I] \\ -[M]^{-1}([K]+[K_e]) & -[M]^{-1}([C]+\Omega[G]) \end{bmatrix} \tag{8}$$

whose eigenvalues allow to determine the natural frequency (ω_n) and damping factor (ζ) of the system for each rotational speed Ω. The instability threshold is obtained searching the rotational speed in which the damping factor becomes negative.

RESULTS AND DISCUSSION

In order to verify the influence of bearing's surface texturing on dynamic behavior of the rotating system, simulations were carried out considering cuboid, cylindrical and spherical cap textures shapes also varying for each geometry textures' maximum depth (r_y). The rotor used in simulations is shown in Fig. 1 which is made of steel and is supported by two bearings whose properties are indicated in Tab. 1. The bearing used in this work is the one proposed by Kango et al. (2014).

Table 2 shows the cases simulated and the respective instability threshold values obtained, also showing the percentage deviation from the values obtained for the textured bearings relative to the one of the respective smooth bearing. In all cases a fully surface texturing is assumed for the bearing's surface, with textures' density $\rho = 0.6075$. A mesh with 584 volumes in circumferential direction and 184 volumes in axial direction was used. Figure 2 shows the damping

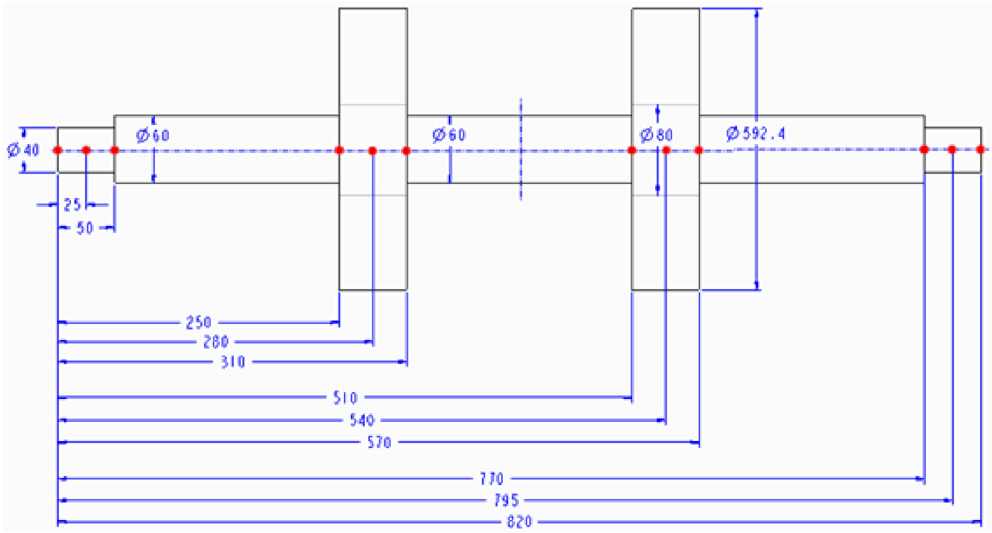
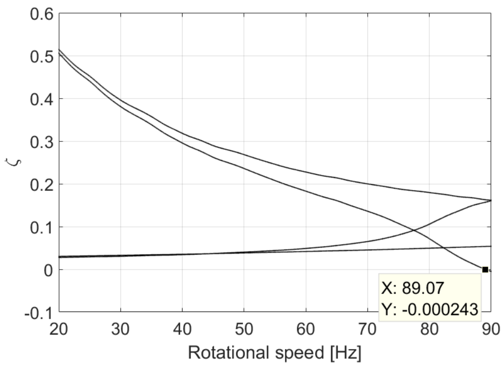


Figure 1: Schematic representation of the rotor (in mm).

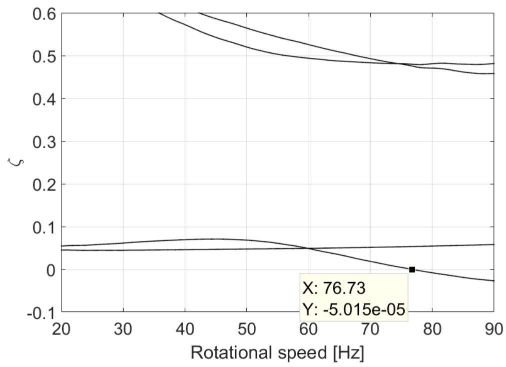
Table 1: Characteristics of the bearing proposed by Kango et al. (2014).

Parameter and Units	Symbol	Value
Diameter [mm]	d	40
Length [mm]	l	40
Radial clearance [μm]	C_r	50
Absolute viscosity [Pa.s]	μ	0.08

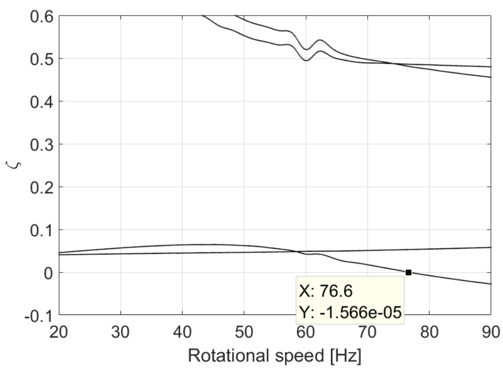
factor diagrams obtained for the respective smooth bearing (case 0) and for the textured bearings with textures geometric parameters given by cases 2, 4 and 6 from Tab. 2.



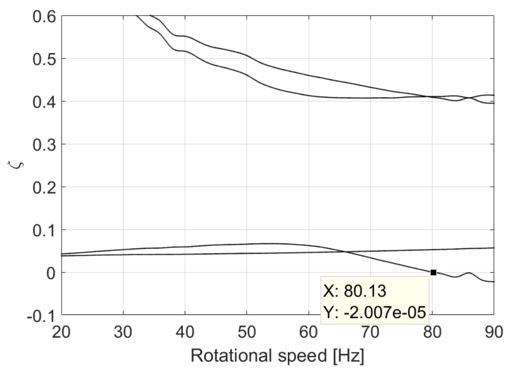
(a) Case 0: Without texture



(b) Case 2: Cuboid texture and $r_y = 40\mu m$



(c) Case 4: Cylindrical texture and $r_y = 40\mu m$



(d) Case 6: Spherical texture and $r_y = 40\mu m$

Figure 2: Damping factor diagrams for the different textures shapes.

Table 2: Simulated cases and respective results.

Case	Texture Geometry	r_y μm	Instability threshold [Hz]	Variation %
0	No Texture	-	89.07	-
1	Cuboid	20	86.53	-2.85
2		40	76.73	-13.85
3	Cylindrical	20	84.13	-5.54
4		40	76.60	-14.00
5	Spherical	20	88.27	-0.90
6		40	80.13	-10.04

Results in Tab. 2 show that the instability threshold values for the textured bearings were always smaller than the one obtained for the respective smooth bearing. The results in the literature show that there are texturing conditions that anticipate the instability threshold (Matele and Pandey, 2018), as well as texturing conditions that delays the instability threshold (Yamada et al., 2018; Matele and Pandey, 2018), showing that the surface texturing's influence depends on the specific texture's distribution and geometric parameters analyzed. Moreover, the results in Tab. 2 show that the increase in textures' maximum depth tends to decrease the instability threshold value since textures effects become more significant. Textures' shape also influence the investigated instability threshold but with less significance than the textures' maximum depth being that spherical cap shapes caused the smaller reductions in the instability threshold values, respectively.

CONCLUSION

The present investigation showed that the insertion of textures on the surface of the bearing is capable to change the dynamic behavior of the rotating system by changing its instability threshold. The results show that the simulated textured bearings anticipate the instability threshold when compared to the one for the system supported by the respective smooth bearing. Texture's maximum depth is significant in the mentioned behavior being that an increase in this geometric parameter decreases the threshold value accordingly.

ACKNOWLEDGMENTS

The authors would like to acknowledge the grants 2016/20975-4, 2015/20363-6 and 2015/20036-5, São Paulo Research Foundation (FAPESP). This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

REFERENCES

Etsion, I., 2013. “Modeling of surface texturing in hydrodynamic lubrication”. Friction, Vol. 1, pp. 195-209.

Wang, L., 2014. “Use of structured surfaces for friction and wear control on bearing surfaces”. Surf. Topogr.: Metrol. Prop., Vol. 2, pp. 043001.

Gropper, D., Wang, L., Harvey, T.J., 2016. “Hydrodynamic lubrication of textured surfaces: A review of modeling techniques and key findings”. Tribology International, v.94, pp.509-529.

Yamada, H., Taura, H., and Kaneko, S., 2018. ”Numerical and Experimental Analyses of the Dynamic Characteristics of Journal Bearings With Square Dimples”. Journal of Tribology, 140.1: 011703.

Matele, S., and Pandey, K. N., 2018. ”Effect of surface texturing on the dynamic characteristics of hydrodynamic journal bearing comprising concepts of green tribology.” Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology: 1350650117752611.

Tala-Ighil, N., Fillon, M., 2015. “A numerical investigation on both thermal and texturing surface effects on the journal bearings static characteristics”. Tribology International, v.90, pp. 228-239.

Nelson, H., and McVaugh, J., 1976. “The dynamics of rotor-bearing systems using finite elements”. Journal of Engineering for Industry, Vol. 98, No. 2, pp. 593–600.

Nelson, H., 1980. ”A finite rotating shaft element using Timoshenko beam theory”. Journal of mechanical design, 102(4), pp. 793-803.

Friswell, M., Penny, J., Garvey, S., and Lees, A., 2010. ”Dynamics of Rotating Machines (Cambridge Aerospace Series)”. Cambridge: Cambridge University Press.

Kango, S., Sharma, R.K., and Pandey, R.K., 2014. ”Thermal analysis of microtextured journal bearing using non-Newtonian rheology of lubricant and JFO boundary conditions.” Tribology International, 69: 19-29.

RESPONSIBILITY NOTICE