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Textured conical hybrid journal bearing with ER lubricant behavior

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ABSTRACT

This work examines the ER lubricant behavior on the performance of conical hybrid journal bearing. The influence of micro-texture with different shapes used on the bearing surface is studied. FEM is used to solve the modified Reynolds equation using GMRES method. A parametric study is carried out to optimize the dimple attributes on the basis of radial load. The numerical results show that a textured surface and ER lubricant enhances the values of load carrying capacity ($\overline{W}_R$ and $\overline{W}_A$) and fluid film stiffness coefficients ($\overline{S}_{ij}$) for conical journal bearing. Further, it has been observed that the use of ER lubricant enhances the value of minimum fluid film thickness ($\overline{h}_{min}$), thereby reducing the chances of metal to metal contact.

1. Introduction

Continuous technological developments and advancements necessitate the accurate and precise design of bearing elements for high speed and heavy load operation. Conical bearings have been widely used in different engineering applications like high-speed rotating machineries and precision machine tool application like lathes and grinding machine for their excellent capability of carrying both axial and radial loads at the same time. Moreover, the adjustment of clearance of the conical bearing during assembly and the self-guiding nature of the conical surfaces are its additional advantages [1,2]. In the past decades, the studies on conical bearings have been reported by many researchers [3–10]. In 1974, Stout and Rowe [3] showed that non-recessed bearings are best suited for power dissipation reduction and high-speed applications. Prabhu and Ganesan [4,5] studied the dynamic stiffness characteristics of annular recess conical hydrostatic thrust bearings compensated with capillary restrictors. They studied the effect of tilt, eccentricity and rotation on the performance behavior of bearing. Nowak and Wierzcholski [6] studied the conical journal bearing with finite width and computationally solved the non-Newtonian fluid problem. Khalil et al. [7] carried out a computational investigation to analyze the effect of turbulent flow conditions on the performance of externally pressurized conical thrust bearings and compared the results with that of laminar flow conditions. Yoshimoto et al. [8,9] carried out numerical as well as experimental investigation on water lubricated hydrostatic conical bearings with spiral grooves and reported that larger load carrying capacity may be seen by compliant surface than rigid one. He also reported that the stability of the shaft gets significantly improved by the aid of spiral grooves. Further, Guo et al. [10] studied experimental and theoretical work concerning pockets of different depth in hybrid conical bearing. They studied the dynamic performance and stability parameters for hydrodynamic and hydrostatic/hybrid conical journal bearing.

Nowadays, mechanical components such as mechanical seals [11] and piston ring [12] are designed to minimize friction coefficient and leakage by introducing micro-textures on the sliding surfaces. Unlike roughness, micro-texturing is well organized and can be provided over the bearing surface in the form of discrete features (micro-dimples) or continuous features (micro-grooves). Micro-texture acts as micro-bearings and generate localized pressure in addition to hydrodynamic pressure generated due to physical wedge. Thus, the developed hydrodynamic pressure aids in generating additional load carrying capacity which otherwise solely depends upon pressure generated due to hydrodynamic/hydrostatic action of the bearing. Micro-texture also act as lubricant reservoirs and entrap wear debris and abrasive particles thereby reducing friction between sliding pairs. Latest advancement in manufacturing processes such as chemical etching [13], vibro-mechanical machining [13], micro-machining, laser surface texturing [14], micro-sterlithop- graphy [15], etc. facilitates the development of textured bearing surface with high degree of accuracy at micron level. In last few decades, several researchers have investigated the influence of textured surface on the performance of bearing systems [16–18]. In most of the aforementioned studies, micro-texture over the bearing surface are provided in the form of dimples of various geometric shapes such as spherical, cylindrical, trapezoidal, etc. Sinanoğlu et al. [16] used neural network technique for examining journal bearing system by considering two types of texture profile. They reported that saw profile textured bearing provides reduced load carrying capacity than

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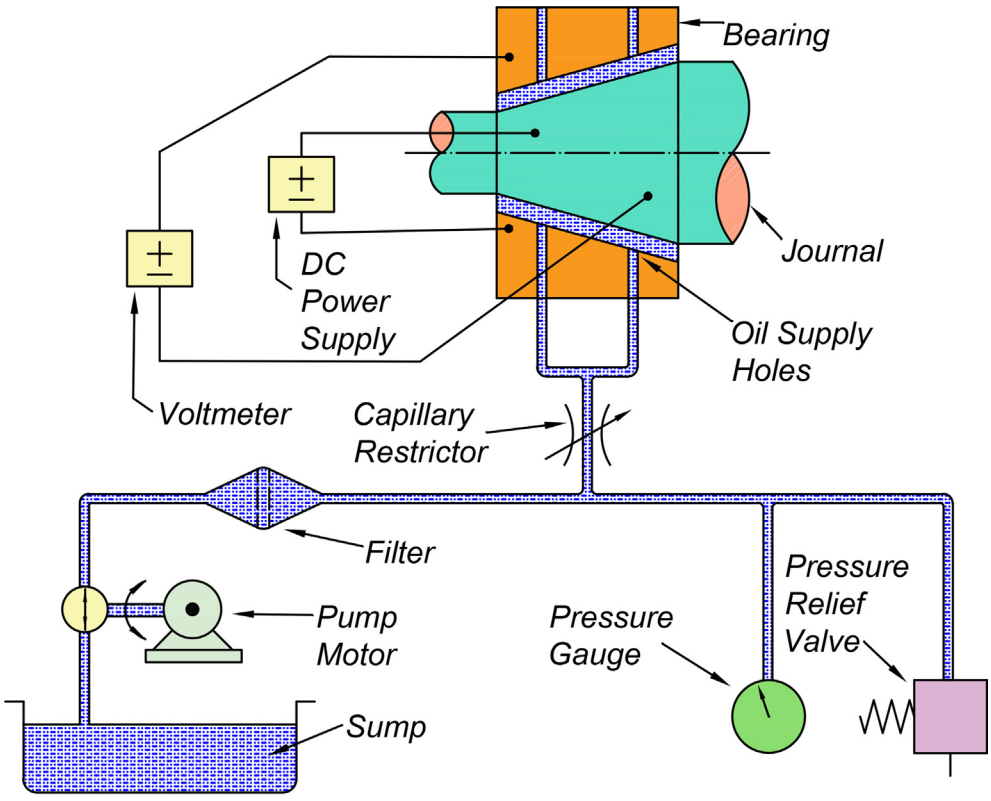
trapezoidal profile textured bearing. Under steady state conditions, the effect of texturing the surface of journal bearing was studied using FDM method by Tala-Ighil et al. [17]. They presented that textured surface at the declining part of the contact pressure field shows more pronounced effect. Using narrow groove theory, the journal bearing and partially textured slip slider was computationally examined by Rao et al. [18] and concluded that the proposed bearing provides less coefficient of friction and significantly increase the load carrying capacity.

The performance of a bearing greatly depends on the lubricating performance of lubricants. Commercially available non-Newtonian lubricants are often blended with traces of additive packages to improve the bearing performance operating in severe conditions. During the last few decades, the Electro-rheological (ER) lubricant has emerged as an effective way to enhance the performance of tribo-contacts. These fluids comprises of electrically active particles in an electrically insulating lubricant. The behavior of ER fluid is characterized by yield stress and viscosity similar to Bingham fluid model. Kollias and Dimarogonas [19] were the first one to propose the design of ER fluid, applying this concept to low speed partial journal bearing and evaluating the hydrodynamic pressure. Their results were found to be in good agreement with theoretical Bingham model of Wada et al. [20]. Further, Nikolakopoulos and Papadopoulos [21] experimentally investigated the performance of high speed journal bearing operating with ER fluids. It was noticed that an increase in the value of electric field causes an improvement in the rotor dynamic coefficients of journal bearing. Similar results were observed in the work of Jang and Tichy [22] in which they studied the behavior of rotor dynamic system with ER fluid lubricated journal bearing. Zhu and Peng [23] studied the effect of bearing eccentricity ratio on the hydrodynamic behavior of ER fluid in the journal bearing and reported that at low eccentricity ratio, the control of bearing with the help of electric field becomes difficult than at high eccentricity ratio. Peng and Zhu [24] studied the hydrodynamic characteristics of ER fluid in journal bearing using CFD technique and reported that ER fluid has prominent effect on the performance of fluid film journal bearing.

During the last couple of decades, the surface texturing has emerged as a technique to improve the performance of tribo-contacts [11,12,17]. A thorough scan of the literature reveals that most of the work reported in the area of texturing is mainly limited to hydrodynamic circular journal bearings. No study is yet available in the literature for the case of conical hybrid journal bearing system considering the textured surface in the analysis. Further, it has been observed that the use of smart lubricants (ER lubricant) has gained a great popularity in tribo-contacts. Also, for the case of conical journal bearing, no study have been reported in the available literature operating with ER lubricant. Therefore, the present study has been planned to study the influence of ER lubricant on the performance of textured conical hydrostatic/hybrid bearings. Another notable observation of the studies reported earlier is that they do not comprehensively studied the bearing performance characteristics. The bearing performance characteristics parameter such as load carrying capacity and rotor dynamic coefficients have been studied separately for radial direction (in the journal bearing) as well as for axial direction (in the thrust bearing). Therefore, the present study deals with the variation of bearing rotor dynamic coefficients ($\overline{S}_{ij}$, $\overline{C}_{ij}$) in radial as well as axial direction. The study is expected to be useful to the academic community.

2. Problem formulation

The general layout of textured conical hybrid journal bearing with application of external electric field (supplied using DC power supply) along with the arrangement of micro-texture in the form of dimples and its coordinate system is described in Fig. 1. The bearing, with consideration of micro-dimples, is modelled to examine the performance of



(a) Conical journal bearing system

Fig. 1. Non recessed conical hybrid journal bearing system.