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An investigation of tribological behaviors of dynamically loaded non-grooved and micro-grooved journal bearings

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ABSTRACT

Tribological performances of non-grooved and micro-grooved journal bearings were studied under dynamic loading. Numerous experiments were performed using purpose-built test rig and then simulated using various numerical methods. Friction force, friction coefficient, shaft center orbit, and film thickness were determined experimentally and numerically. The experimental and numerical results were in good agreement and the friction forces progressively increased on plain and circumferential, herringbone, and transversally micro-grooved bearing. The results show that it is necessary to complete detailed investigation about the tribological properties of the micro-grooved journal bearing by taking their shape, depth and operating condition into account.

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1. Introduction

It is extremely important for journal bearing designers to know tribological performances of journal bearings used in a number of machines such as internal combustion engines, jet engines, compressors, piston pumps, mechanical presses, and rolling mills during the design process. The journal bearing surfaces encountered in many studies were assumed to be smooth. However, the possibility of improving bearing performance by modifying bearing surface geometry has attracted attention of many researchers and they have performed several theoretical studies on hydrodynamic lubrication field for rough journal bearing surfaces in recent years [1]. Zhang and Qiu [2] conducted a theoretical investigation on effects of geometric structure of journal bearing surfaces under dynamic loading and hydrodynamic lubrication conditions. They investigated effects of surface roughness of dynamically loaded journal bearings on longitudinal, transversal and isotropic basis. In their analysis, they used a statistical method (Stochastic Model) that was based on estimation principles developed by Christensen et al. [3,4]. They found that the maximum oil film pressure on the transversally rough bearing was higher than those of the longitudinal and isotropic rough conditions. They also concluded that oil film thickness for an isotropic rough condition was less than those of the transversal and longitudinal rough bearings. Hata et al. [5] investigated effects of frictional characteristics on surface roughness under mixed and hydrodynamic lubrication conditions by using a test device that operates on pin-disc principles. The roughness on bearing surface was cut precisely in a triangular and trapezoidal shape. It was found that the friction on transversally grooved surface was higher than the friction on plain and longitudinally grooved bearing surfaces. Nakahara et al. [6] performed a study to measure effects of surface roughness on friction characteristics after cutting regular and irregular threads on rectangular specimens spinning on a small axis. They also used a test device that operates on pin-disc principles. They found that the results obtained from the experiments correlated with theoretical results. They also came to conclude that the effects of roughness on transverse rough surface were greater than those on the longitudinal rough surface. Nakahara [7] then remarked that it was extremely difficult to achieve accurate measurements for surface roughness on hydrodynamic lubrication characteristics. This was related to the difficulties in measuring film layer thicknesses among rough surfaces.

A new generation of bearings with micro-grooves has now been used particularly in automotive engines operating at extreme conditions since last two decades. The studies about performances of micro-grooved bearings have been, theoretically, shown that circumferential micro-grooves on journal bearings enhanced dynamic characteristics of bearings [8]. Moreover, it was also shown that circumferentially grooved bearings were stronger in terms of resistance against deformation and wear as compared

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Nomenclature

R	bearing radius [m]
P	oil film pressure [N/m^2]
h	oil film thickness [m]
D	bearing diameter [m]
L	bearing length [m]
B	bearing width [m]
C	radial clearance [m]
F	bearing load [N]
C	radial clearance [m]
M	mobility vector [N-m]
η	oil viscosity [Ns/m^2]
ω	bearing rotational speed [1/s]
V	circumferential velocity [m/s]
e	eccentricity
γ	bearing's width to diameter ratio, (B/D)
ε	eccentricity ratio, (e/C)
α	eccentricity ratio in x direction
β	eccentricity ratio in y direction
z	axial coordinate
θ	circumferential coordinate

to plain journal bearings. In a study conducted by Hargreaves and Armatys [9], the performances of different shapes of micro-grooved-journal bearings, transversal and longitudinal, under different static and dynamic loads were investigated. A sample of dynamic bearing load in a near sinusoidal form and on a single axis was applied on a bearing by using a cam mechanism. The variations of frictional moments within liquid friction zone under different static loads suspended on the bearing and at operating speeds of 400–2000 rpm were determined. They found that the journal bearings with circumferential grooves had lower frictional moments as compared to the other shapes at high operating speeds bearings. Watanabe et al. [10] developed the high performance micro-grooved engine bearings by cutting circumferential grooves on plain journal bearings. They also determined the performances of the micro-grooved bearings by applying hydrodynamic and elastohydrodynamic lubrication theory.

According to the recent studies, plain cylindrical journal bearings with grooves were used extensively in industry to distribute oil over the entire surface of the bearings and to obtain optimum performance as mentioned above [11,12]. It was shown that as the oil flow rate increased, the bearing temperature in the micro-grooved bearings became less than that of the bearings without micro-grooves and as the oil remained in the grooves, the possibility for the bearings to fade was low. Moreover, it was found that effects of micro-grooves had direct impacts on journal bearings performances under dynamic loading conditions. It was also stated in the literature that the minimum oil film thickness of micro-grooved bearings was thicker than that of the traditional plain bearings due to the oil being retained in the grooves. Finally, having micro-grooves on the surface of journal bearings was proven to be an effective method to enhance the tribological behavior of the journal bearings under starved lubrication conditions.

However, there has been little discussion on the shape of groove and the operating conditions, such as friction zones. It became a necessary problem to discuss the shape of the groove and operating conditions of the journal bearing. The objective of this study was, therefore, to experimentally and theoretically investigate and compare the tribological behavior of purpose-made micro-grooved and non-grooved (plain) journal bearings loaded dynamically. In order to achieve this objective, the plain journal bearings were first tested at full film lubrication zone by utilizing the journal bearing test rig under dynamic bearing load. The experiments were then repeated for the circumferential, transversally and herringbone (V-shaped) micro-grooved journal bearings for the same bearing parameters to present the effects of different shapes of micro-grooves on the performance of a typical engine crankshaft main bearing. Later on, a commercial software ORBIT, developed for analyzing dynamically loaded journal bearings using the mobility and the finite difference methods [13], was used to numerically simulate the experiments. Moreover, an additional computational program which operates on the Schaffrath method [14,15] was utilized to test the tribological behavior of journal bearing. Finally, the experimental results were compared with the numerical predictions.

2. Experimental background and test procedure

In this study, the purpose-built laboratory test rig was utilized to investigate tribological behavior of the dynamically loaded engine journal bearing. It uses a direct method where the friction torque of only the test bearing is measured without any interference of the shaft-supporting bearings. The test rig was designed to measure friction force under dynamic loading conditions by Bıyıklıoglu [16] and then modified to measure the orbit of the journal center under dynamic load by Bıyıklıoglu et al. [17–19]. Fig. 1 shows the cross-sectional view of the test rig along the shaft axis while the measurement system constructed specially to measure friction force is illustrated in Fig. 2. The detailed

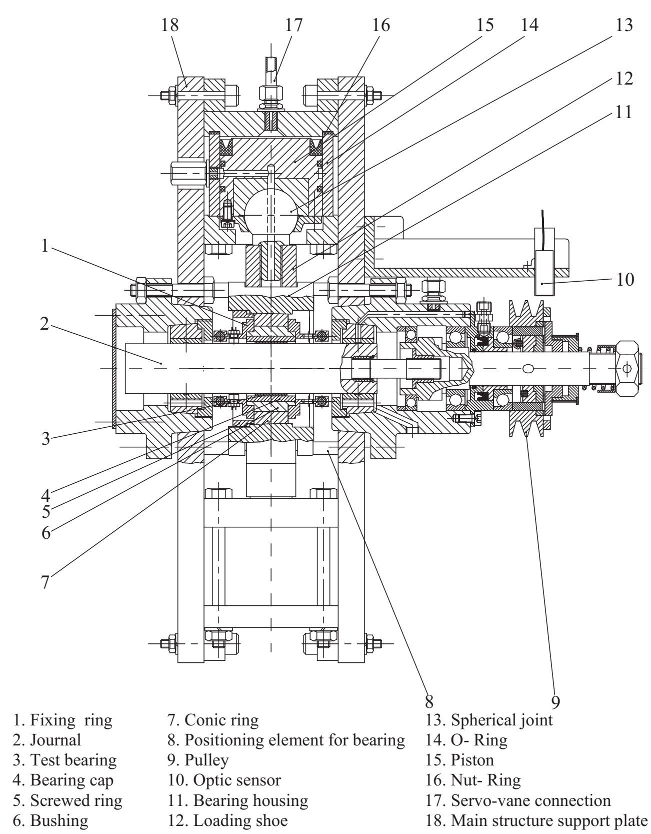

Fig. 1. Cross-sectional view of the test rig along journal axis [16–18, 20].

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