Lecture Notes in Mechanical Engineering

Himanshu C. Patel
Gunamani Deheri
Harshvadan S. Patel
Shreya M. Mehta *Editors*

Proceedings of International Conference on Advances in Tribology and Engineering Systems

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Foreword I

In the ancient world, mechanical engineering was developed to satisfy the needs of the military. Archimedes used differential gears in his machines and catapults were used widely by armies. So, mechanical engineering was known as military engineering. During the eighteenth century, the French were the first to begin university-level education in civil engineering. All those engineers who practiced engineering for non-military applications were Civil Engineers. With the development of the steam engine, when military engineers started to provide technology for non-military applications, the British initiated the first professional society for mechanical engineering. As engineers developed mathematical analysis and measurement methods, university education in mechanical engineering came about.

Every machine required movement of metal on metal and the issues of friction, wear, and corrosion became of interest to mechanical engineers. In 1966, when H. Peter Jost pointed out that losses due to friction may be reduced by a systematic study of materials and lubricants, several national centers for tribology were set up in the UK. In India, tribology is studied at a number of engineering institutes. IIT Delhi, for example, has a dedicated Center for Research in Industrial Tribology.

Gujarat Technological University (GTU) is a relatively new University and it is encouraging its affiliate colleges to develop research programs in different areas of engineering. Research in tribology today includes a study of the way in which energy is dissipated at the interface between moving solids, the atomic- and molecular-scale mechanisms of interfacial wear, and the effect of the environment on these processes. Tribology requires an understanding of the property of materials, a study of the effects of fluid film lubrication and simulations of the processes of deformation of bearings. The performance of a magnetic fluid-based journal bearing, the effects of velocity-slip and viscosity variation in spherical bearings, the power law fluid film lubrication of journal bearings with squeezing and with variation of temperature effects—including the performance under cryogenic conditions, are being studied by researchers. The use of ferro-fluids and transient analysis of plain circular bearing with micro-polar fluid are also active areas of research. These studies have led to better efficiencies in multi-cylinder I.C. engines and in development of high-density hard disk drives. Experimental investigation on life cycle analysis of the moly (Mo) coated piston ring in

C.I. engines, the work on tribological properties of CuO Nano-lubricants at elevated temperatures and the work on new composite materials are included in this publication. Research in tribology needs inter-disciplinary work in mathematics, physical sciences, chemical sciences, material sciences, mechanical engineering, and almost all of the engineering disciplines. The work of eminent researchers from all these fields is included in this volume.

An era of good governance in Gujarat is creating an environment, where our businesses and industries have started working closely with the researchers at GTU. By maintaining sustained and continuous interaction with the researchers at GTU, researchers from other national and international institutes can benefit from these close relationships formed by GTU. The close linkages, which have been established by GTU with the industries, can help make our research directly useful and relevant to the needs of the industries. The International Conference on Advances in Tribology and Engineering Systems (ICATES-2013) is being organized by Gujarat Technological University, which is the largest university in the state of Gujarat. GTU is pleased to welcome professors and researchers, working at premier institutes within India and abroad. Let us hope this conference serves to create active research links between the visiting researchers and professors and researchers at GTU.

Gujarat Dr. Akshai Aggarwal

Foreword II

Tribology is an essential aspect of engineering systems. Traditionally, tribology has held an important place in mechanical and aerospace engineering research. However, of late, nano-tribology has gained significance in almost all walks of engineering, thus making the topic of tribology truly multidisciplinary in nature. It is heartening to know that the Department of Mathematics at L. D. College of Engineering, Ahmedabad is organizing the International Conference on Advances in Tribology and Engineering Systems in October 2013, under the aegis of Gujarat Technological University. Researchers from both India and abroad are contributing wholeheartedly. It is my sincere hope that this conference serves to strengthen the partnerships between academic tribologists and industry practitioners. I would like to congratulate both of the organizing institutions, viz., Gujarat Technological University and L. D. College of Engineering. In particular, I felicitate Dr. M. N. Patel and Dr. H. C. Patel for organizing the event, and offer my best wishes for a resounding success of this conference.

Gujarat — Dr. Jayanti S. Ravi

Preface

Tribology is the science and technology of friction, lubrication, and wear. Primarily, mechanical engineers and mathematicians are concerned with this discipline. Bio-tribology is also a fast-emerging field. Tribology of orthopaedic biomaterials and artificial joints is the field of active interest to many. Nano-tribology which studies friction phenomenon at the nanometer scale is also a promising new development in tribology.

The organizers of the *International Conference on Advances in Tribology and Engineering Systems* (ICATES) wish to provide a platform for deliberations on theoretical calculations and experimental results in different areas of tribology. The papers are so selected that, as far as possible, equal emphasis is laid on both theoretical and experimental research. The response to the conference was overwhelming on both national and international fronts. The submitted papers were by renowned experts in the field.

Broadly, the contents of this set of proceedings can be classified into two aspects, namely: analytical methods and experimental validation. There are several papers incorporating the contribution of magnetic fluid (micro polar fluid and power law fluid) toward the reduction of adverse effects of roughness and slip. Nano-tribology in the context of rheology, also figures in some of the studies. A good number of investigations deal with the evaluation of friction and wear from the point of view of design.

There are studies to indicate that tribological properties can be enhanced by mainly using polymers and nanocomposites; and by considering fiber surface modifications. The discussions contained in these proceedings also underline the importance of CuO nano-lubricants at elevated temperatures.

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Part I
Fluid Film Lubrication

Experimental Thermal Analysis of Bronze Elliptical and Offset-Halves Journal Bearing Profiles

Rakesh Sehgal

Abstract The present research study is aimed at experimental and theoretical investigation of the thermal behavior of metallic (Phosphor Bronze) elliptical and offset-halves journal bearing configurations of same geometrical size under low to high operating conditions (loads ranging from 800 to 1,900 N and speeds ranging from 2,000 to 5,000 rpm) using three different commercially available grades of oils (Hydrol 68, 2T and Mak Multigrade oil). Experimentally, it is established that offset-halves journal bearing runs cooler than elliptical bearing for all the three grades of oils under all operating conditions thus making it suitable for all operating loads and speeds. The lowest operating temperatures are obtained for 2T oil (oil 2) thus making it most suitable for use under all operating conditions.

Keywords Elliptical journal bearing · Offset-halves journal bearing · Temperature profile · Load capacity

1 Introduction

In the past few decades industries world over have gone through tremendous changes. This is due to ever increasing demand for high speed machinery, be it manufacturing sector, power generation sector, transportation sector or cybernetics. Bearings, especially hydrodynamic journal bearings are extensively used in high speed rotating machines because of their low friction, high load capacity, and good damping characteristics. With the development of technology, hydrodynamic bearings are expected to work with higher load capacity having small sizes, more stability and less degradation of the lubricating oil due to rise in temperature while

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machinery is running. One problem associated with conventional (circular) journal bearings is that these become highly unstable under high operating speeds. Researchers are continuously striving to overcome this problem and have suggested many design modifications in the circular journal bearings to not only increase stability under high speed operation but also enhance the load capacity and minimize the thermal degradation of the lubricating oil used. One such design modification is to go for multilobe/non-circular configurations such as two lobe bearings (elliptical, offset-halves/orthogonally displaced, lemon bore), three lobe and four lobe bearings etc. These bearing profiles operate with more than one active oil film, the number of active oil films being a function of number of lobes. This feature reduces the cavitation zone and hence accounts for the superior stiffness, enhanced shaft stability, and reduced temperature in the oil film as compared to the circular journal bearings.

Though different researchers have attempted to investigate the performance of non-circular journal bearings, most of these studies have been theoretical and focused on stability analysis. A very few studies (especially experimental) have been reported on the thermal behavior of non-circular journal bearings which is important to establish optimum operating parameters for these bearings.

Pinkus and Lynn [1], Singh and Gupta [2], Tayal et al. [3], Booker and Govindachar [4], Singh et al. [5], Mehta and Singh [6], Read and Flack [7], Hussain et al. [8], Banwait and Chandrawat [9], Sehgal et al. [10–12], Mishra et al. [13], have investigated various non-circular journal bearing profiles. Literature reveals that thermal studies on metallic non-circular journal bearing profiles especially elliptical and offset-halves are very scarce. Chauhan et al. [14–16] have recently attempted few investigations on non-circular journal bearing profiles made from acrylic (Methyl Methacrylite). Further, these investigations are limited to very low range of loads up to 600 N and operating speeds up to 4,000 rpm. However, these bearings find wide applications in high speed machinery because of their better stability and cool running characteristics. Moreover, the design procedures for these non-circular bearing profiles have not been standardized and no design curves/monograms for these bearings are available in design hand books. Hence there is a compelling need to investigate these bearing profiles made from common bearing materials like bronze, aluminium etc. over a wide range of operating parameters such as load, speed using commonly available commercial lubricants. This will help to produce relevant design data to analyse and standardize the design procedures for these non-circular journal bearing profiles for the required operating conditions.

In the present work, experimental evaluation of circumferential bush-oil film interface temperatures at the central plane of elliptical and offset-halves journal bearings made from phosphor bronze under various load, speed, and constant flow rate conditions for three commercial grade oils namely Hydrol 68, Mak 2T and Mak Multigrade has been attempted with an aim to optimize the set of operating parameters as well as to explore the suitability of an oil for the operation of a particular bearing under these operating conditions. In the subsequent sections of this paper, Hydrol 68, Mak 2T and Mak Multigrade oils are referred to as oil 1, oil 2 and oil 3 respectively.

2 Methodology

The objectives of this research study have been achieved by conducting experiments for specifically designed elliptical (Figs. 1, 2) and offset-halves (Figs. 3, 4) journal bearing profiles on an existing journal bearing test rig modified (Fig. 5) suitably to accommodate loads up to 2,000 N and speeds up to 5,500 rpm. The elliptical test bearing is not truly elliptical but has the centres of its upper and

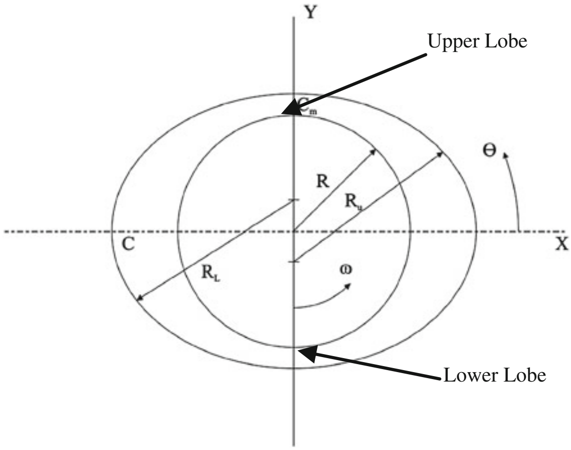

Fig. 1 Schematic diagram of elliptical journal bearing

Fig. 2 Actual elliptical journal test bearing

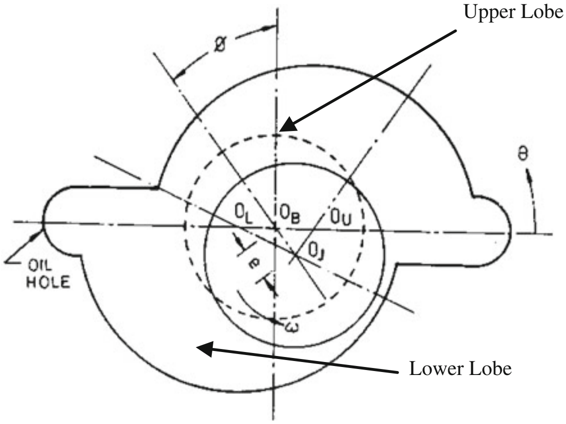

Fig. 3 Schematic diagram of offset-halves journal bearing

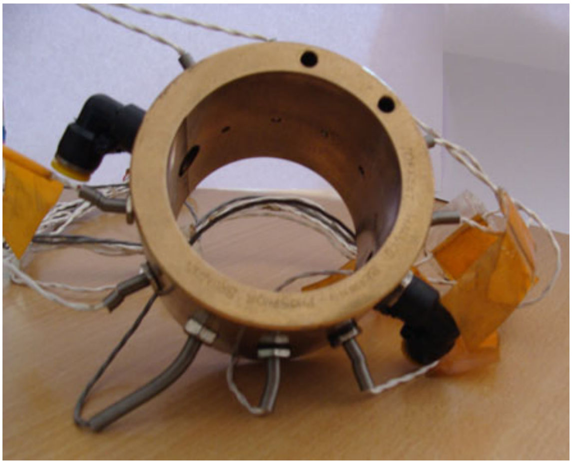

Fig. 4 Actual offset-halves journal test bearing

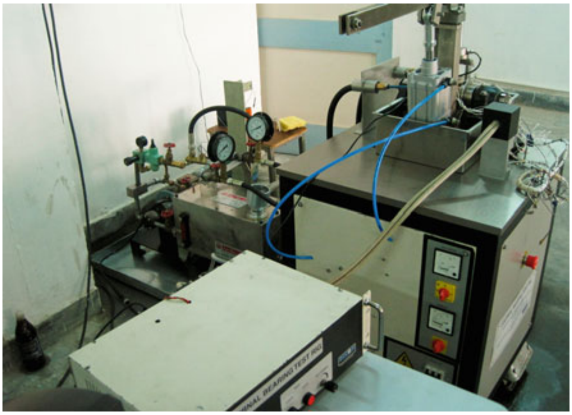

Fig. 5 Modified journal bearing test rig

lower lobes shifted on a vertical line passing through its geometric centre. The offset-halves journal bearing has been designed by orthogonally displacing the two halves (upper and lower) of a cylindrical bearing. The bearings are provided with temperature sensors at 12 circumferential locations (30° angular position).

The journal (Fig. 6) is made of C45 steel material and is mounted horizontally on two pedestal bearings. A chrome plated journal sleeve is tightened at middle portion of journal with lock nuts and bearing slides over it. Dimensions of the elliptical test bearing are given in Table 1. Table 2 gives test operating conditions.

Fig. 6 Actual C45 steel journal

Table 1 Dimensions of elliptical test journal bearing

Parameter	Dimension	Tolerance	Roughness (μm)
Outer dia. of brg, OD	85 mm	±0.2 mm	10
Max. inner dia. of brg., D_{Imax}	65.4 mm	±0.2 mm	10
Min. inner dia. of brg., D_{Imin}	65.2 mm	±0.2 mm	10
Length, L	65 mm	±0.2 mm	10
Radial clearance, C	300 μm	±50 μm	
Min. clearance, C_m	200 μm	±50 μm	
Oil hole	6.35 mm	±0.15 mm	
Rel. sensor position	30°	±1°	

Table 2 Test operating conditions

Oil inlet temperature, T_0	40 °C
Lubricants	Oil 1, oil 2 and oil 3
Rotational speeds, n	2,000, 3,000, 4,000 and 5,000 rpm
Loads, W	800, 1,000, 1,200, 1,500 and 1,900 N
Oil inlet pressure, P	0.1−0.2 MPa

Table 3 Properties of oils and bush material

	Oil 1 (Hydrol 68)	Oil 2 (Mak 2T)	Oil 3 (Mak Multigrade)
Viscosity, μ (at $T_o = 33$ °C)	0.075 Pas	0.065 Pas	0.200 Pas
Viscosity, μ (at $T_o = 100$ °C)	0.00771 Pas	0.004861 Pas	0.01239 Pas
Density, ρ	880 kg/m^3	868 kg/m^3	885 kg/m^3
Thermal conductivity, K_{oil}	0.126 W/m °C	0.126 W/m °C	0.126 W/m °C
Viscosity index	98	135	110
Flash point, °C	230	94	200
Pour point, °C	−9	−24	−21
Barus viscosity—pressure index, α	2.3 e^{-8} Pa^{-1}		
Temp. viscosity—coefficient, γ	0.03 K^{-1}		
Thermal cond. of bush, K_{bush}	54 W/m °C		
Coeff. of thermal expn. of bush, h_{bush}	17 e^{-6} K^{-1}		

Various properties of oils and bush material are given in Table 3. Elliptical and offset-halves journal bearings have been tested for load range (800–1,900 N), speed range (2,000–5,000 rpm) and constant flow rate of 6.8 l/min. The test data for these bearings has been presented and analysed for 800, 1,200 and 1,900 N loads and 2,000, 3,000, 4,000 and 5,000 rpm journal speeds.

3 Results and Discussion

Experimental results obtained for elliptical and offset-halves journal bearings are presented and discussed in the following sub-sections.

3.1 Elliptical Journal Bearing

The variation of circumferential temperatures at mid plane of elliptical journal bearing at 800, 1,200 and 1,900 N load, speed (2,000−5,000 rpm) and constant flow rate of 6.8 l/min for three grade oils are plotted in Figs. 7a−c, 8a−c and 9a−c respectively. It is observed that for all oils, the circumferential temperature at bush-oil interface increases with increase in journal speed. Maximum temperature was observed at lower lobe for all oils and speed conditions. For oil 1, maximum temperature rise (25.5 °C) was found for maximum load (1,900 N) and speed (5,000 rpm) conditions whereas the minimum temperature rise (9.3 °C) was found for minimum load (800 N) and speed (2,000 rpm). For oil 2, the maximum temperature rise (24.7 °C) was observed for maximum load (1,900 N) and speed (5,000 rpm) conditions whereas the minimum temperature rise (9.3 °C) was found for minimum load (800 N) and speed (2,000 rpm). For oil 3, the maximum temperature rise was found to be 27.9 °C for maximum load