Experimental Challenges and Solutions in Design and Operation of the Test Rig for Water Lubricated Journal Bearing

Ravindra Mallya, B. Satish Shenoy, B. Raghuvir Pai

***Abstract*—**The study deals with the challenges in developing a test rig to test the performance of water lubricated journal bearing. The test rig is designed to simulate the working conditions of the bearing in order to understand their performance before they are put in operation. The bearing that is studied is the commercially available water lubricated bearing which has a rubber liner bonded with a rigid metal shell. The lubricant enters the bearing axially through a pressurized inlet tank and exits to an outlet tank which is at sufficiently low pressure. The load on the bearing is applied through the dead weight system which acts both in upward and downward direction so that net load acts on the bearing. The issues in feeding the lubricant into the bearing from the inlet side and preventing the leakage of the lubricant is discussed. The application of the load on the test bearing while maintaining the bearing afloat is also discussed.

***Keywords*—**Axial groove, hydrodynamic pressure, journal bearing, test rig, water lubrication.

I. Introduction

THE design of journal bearings is important to the development of rotating machinery. Water lubricated bearings are often used on modern ships and in hydro power industry. Environmental concerns with oil and grease lubricated bearings have brought about an increase in the use of water-lubricated bearings [1]. The stringent requirements for environmental protection and economical calculations have resulted in ship designers, manufacturers searching for inexpensive, simple and reliable design solutions for building new ships and modernizing existing ones. The conventional materials that were used for water lubricated bearing were lignum vitae, a phenolic compound and rubber [2]. Water lubrication medium, is preferred particularly for marine craft, because of its natural abundance, non-compressibility, cooling properties, and low coefficient of friction when between the bearing and shaft.

These types of bearings also find application in water power plants, mining industry, water conditioning stations and pumps in which the pumped liquid, usually water, serves as a lubricating medium. A water lubricated bearing consists of a cylindrical shell and liner, made from hard plastics from a casting process and rubber as shown in Fig. 1 [3]. The flutes supply the bearing with lubricant, which enters at one end of the bearing and leaves at the other. The water enters the bearing through the longitudinal grooves and moves circumferentially between the propeller shaft and the bearing face in a thin film. Once this film, or wedge, has developed the shaft does not actually come into contact with the bearing. The hydrodynamic water wedge is formed between the shaft and bearing, even at very low shaft speed.

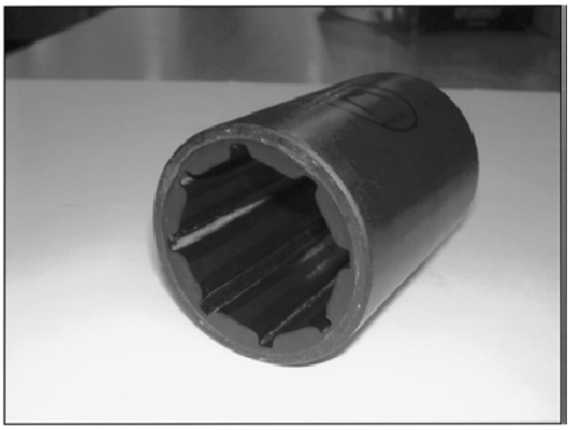

Fig. 1 Straight fluted water lubricated bearing [3]

Cabrera et al. [3] have developed a test rig to find the film pressure distribution in the water lubricated rubber journal bearing. The measurements of pressure indicated that the film pressure profiles are very different from those of the conventional rigid bearings. The behavior of the bearings was theoretically investigated using computational fluid dynamics and compared with the experimental values. Litwin [4] has developed two different test setups to test water lubricated bearings. The stainless steel shaft with a diameter of one hundred millimeters was used. The shaft was mounted in the stern tube with two sliding bearings like on a real ship. It was possible to measure the pressure in the water film in the middle length of the bearings, the resistance of movement, and the shaft center trajectories on both sides of the bearings. The radial load is the propeller and shaft weight. It was possible to make some tests with the static and the dynamic load. Through the experimental results it was indicated that, for rotation speed less than 5 rev/s the test bearing operated in mixed

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lubrication conditions. There was significant bearing bush deformation resulting from load and flexible material properties. The results showed full hydrodynamic lubrication in the center of the bearing, however, at the edges, there was mixed lubrication condition because of lower film thickness. Pai et al. [5] have compared the experimental results with the fluid flow modeled in CFD for a journal bearing with three equi-spaced axial grooves and supplied with water from one end of the bearing. A bearing test rig was developed to evaluate the non – metallic journal bearing performance when lubricated by water. It was observed that axial pressure variations along the groove agreed with experimental trends qualitatively, and did not quantitatively. Wang et al. [6] have also experimentally investigated the performance of water lubricated bearing with multiaxial grooves. The aim of the study was to obtain the actual continuous circumferential film pressure and to explore the properties of a water-lubricated rubber bearing. To avoid the disadvantages of the existing measurement techniques, the wireless measurement scheme was used. It was observed that the bearing groove greatly affected the film pressure distribution, and the rubber bush deformed when the bearing was in operation. For a bearing with concave staves, the continuous water film existed in the load carrying region. A depression was formed in the center of the concave stave, as two pressure peaks appeared in the plots. In the present study an experimental set up is developed to test the commercially available water lubricated bearings. The objective of the study was to simulate the practical conditions of the bearing and study the axial and hydrodynamic pressure behavior as the lubricant flows through the length of the bearing. The present experimental set up shown in Fig. 2 uses the commercially available water lubricated bearing with 8 grooves and 8 lands.

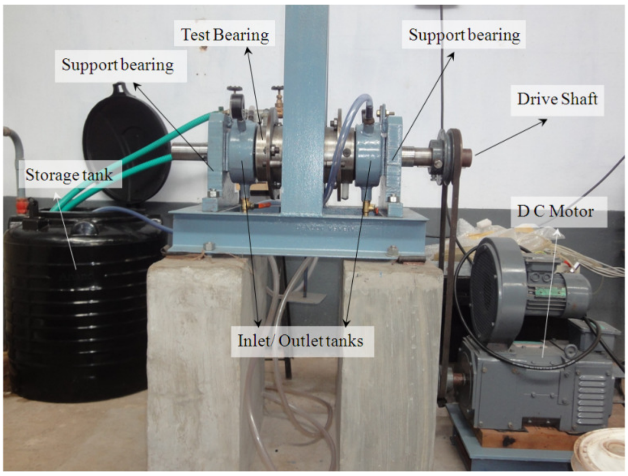

Fig. 2 Water lubricated bearing test setup

The bearing is made of hard rubber molded inside a gun metal liner. The bore diameter of the test bearing is 64 mm and length of the bearing is 250 mm. It is press fitted inside a bearing housing made of mild steel. A mild steel hollow shaft of 750 mm in length and 63 mm in outside diameter and 25 mm inside diameter is used as the drive shaft. The drive shaft is driven via a step-down pulley arrangement connected to a 3.7 kW DC Motor (1500 rpm). The operating speed range of the drive shaft is from 0 to 530 rpm. The shaft is ground finished and the diametral clearance between the test bearing and the shaft is 0.83 mm. The study emphasizes on the issues encountered during the development of the test rig. The following sections discuss the problems occurred in the different sections of the experimental setup and solutions found in overcoming them.

II. Drive Shaft

The drive shaft is one of the main components of the test set up and is made up of Mild Steel and is approximately 750 mm in length. The drive shaft supports the test bearing and the housing assembly. The shaft is supported by roller bearings on either side. The roller bearings are inserted into the housings which are fastened to the base of the test set up. The support bearing on one end is the ball bearing, the inner race of which is press fitted onto the shaft surface and outer race is press fitted into the housing. On the other side of the drive shaft, a needle type bearing supports it. The rollers of the needle type bearing run on the shaft surface, but are held in place with a cage which is press fitted into the housing. The purpose of using a needle type bearing is that, it helps in disassembling the journal bearing setup with ease. It also helps in saving time and effort during frequent assembly and disassembly of the test setup.

During the running of the test setup, there was an issue of the hardened steel rollers of needle bearing wearing away the shaft surface as the shaft is made out of mild steel. The shaft surface was ground further so that a sleeve made of steel was press fitted in the region where the rollers and the shaft surface came in contact.

The measured diametric clearance between the bearing and the shaft is 0.83 mm. A sufficiently large clearance must be provided for this type of journal bearing assembly as rubber being hydrophilic in nature. The seizing of the journal bearing assembly during the operation as stated in [1] is expected. The outside diameter of the hollow drive shaft is ground to 63.206 mm. A provision is made for mounting a flush type pressure transducer at the centre of the shaft, which will measure the steady state hydrodynamic pressure generated.

The issue of corrosion of the shaft after the experiment was also of concern. The test setup had to be frequently disassembled when not in use, as the water or traces of water present in the bearing, in the inlet and outlet chambers resulted in formation of rust on the surface of the shaft. After the experiments were conducted, the test setup was run using cutting oil as the lubricating medium. This displaced any traces of water inside the bearing and shaft clearance and delayed the process of corrosion.

III. Loading System

The journal bearing test setup is developed to test the bearing by simulating the conditions that are present during its operation. The bearing is required to be loaded and also to be floating when in operation. Two annular discs of 8 mm thickness, and with ID = 150 mm and OD = 235 mm are fastened to a tie rod of 15 mm diameter and approximately of 200 mm in length which forms a cage like structure. Three ball bearings are fastened to each annular disc at 120^o angle between them. The test bearing rests on the three ball bearings similar to the steady rest of a lathe machine. The ball bearings fastened to the annular disc, help the test bearing to rotate freely inside the cage during its operation. Grooves are cut on the tie rod for clasping the wire rope. The cage is fabricated in such a way so as to keep the two tie rods in the vertical plane on either side of the test bearing. The tie rods on the top and bottom of the bearing are attached through a hook and wire rope to a dead weight loading system. This arrangement helps in keeping the bearing afloat and also allows the loading on the bearing. An assembled view of the test bearing with the loading arrangement is shown in Fig. 3.

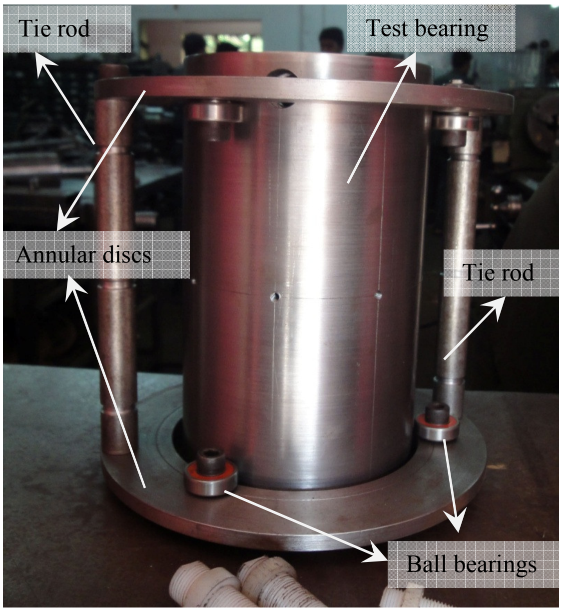

Fig. 3 Assembled view of cage and test bearing

IV. Lubrication System

The test bearing in the present study is axially fed through the grooves which run throughout the length of the bearing. The lubricant water is supplied to the test bearing through a pressurized inlet chamber. The issue of supplying the lubricant to the bearing without any loss of pressure and leakage of the lubricant is a challenging one. The lubricant chambers are to be positioned at the adjacent sides of the test bearing. The lubricant is pumped into the inlet chamber and it enters the clearance between the test bearing and the shaft and exits to the outlet chamber on the other end of the bearing. A centrifugal pump of capacity 0.37 kW and 30 m head is used to supply lubricant into the inlet chamber from a storage tank. The lubricant is fed into the inlet chamber through flexible tubes. The pressure in the chamber has to be maintained constant so that there is no scarcity of lubricant to the test bearing. The difficulty was in preventing the leakage of lubricant from the inlet chamber. The inlet chambers had to be pressurized placed adjacent to the bearing and permit the test bearing to float freely on the film of lubricant. The chamber was initially fabricated using a 152 mm diameter metal pipe welded with mild steel sheet on both sides. The issue with this system was though it did prevent the leakage of lubricant, the difficulty was in keeping the test bearing freely afloat. The weight of the metal chamber was also an issue during the alignment with the surface of the test bearing.

The inlet and outlet chambers were then redesigned. The chambers were then fabricated using PVC pipe sections. The chambers made out of plastic were lighter than the previous design. These plastic chambers were attached to Aluminium sheet, which was fastened to the test bearing making the inlet and outlet chambers, and the test bearing as a one component. This arrangement helped in preventing the leakage of the lubricant from the interface of bearing and the pressurized lubricant in the chambers kept the bearing afloat during its operation. A seating was also provided to attach a radial lip seal for preventing the leakage of the lubricant at the interface of the drive shaft and the chamber, as the drive shaft passes through the chamber.

V. Instrumentation

A flush type diaphragm pressure transducer is mounted on the shaft to measure the steady state hydrodynamic pressure developed in the bearing. The transducer had to be placed inside the shaft with its sensing surface exposed to the hydrodynamic pressure developed. The sensor should be well secured during rotation at high speed. The surface of the sensor had to be slightly below the shaft surface to prevent any damage to it. Also, the arrangement had to be such that, the sensor could be easily disassembled. Fig. 4 shows the schematic diagram of the working of pressure transducer.

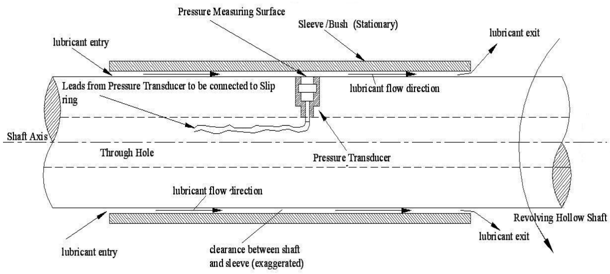

Fig. 4 Schematic diagram of pressure sensor mounted on the drive shaft

The shaft is drilled with a hole matching the sensor's diameter to seat the sensor and a cap nut fabricated from gun metal is fastened to the shaft which secures the sensor. The nut acts like a cover and prevents any relative motion between the shaft and the sensor. The sensor is seated on a thin Teflon washer to prevent leakage of water into the hollow shaft. Fig. 5 shows the sensor and the nut assembly to the shaft. The two holes on the surface of the nut help in gripping the nut for fastening it to the shaft.

(a) Without cap nut

(b) With cap nut

Fig. 5 Pressure sensor mounted on the drive shaft

VI. Conclusion

The study discusses the various issues encountered and resolved in developing the test rig for water lubricated journal bearing. Currently trial tests are being conducted on the test setup. The experience gained will enable us to design better rig for measuring the performance of water lubricated bearings.

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