Proceedings of the 2nd Marine Energy Technology Symposium
METS2014
April 15-18, 2014, Seattle, WA

EXPERIMENTAL STUDY OF TRIBOLOGICAL PERFORMANCE OF BEARING-SEAL ASSEMBLY OF HYDROKINETIC DEVICES IN SEDIMENTED WATER

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ABSTRACT

In this study, wear of polymer and ceramic coated bearings for use in hydrokinetic devices were investigated in sedimented water under the loading conditions similar to those expected in the field using a customized flume. This work is a continuation of the study performed in [1, 2] in which three polymer bearings, namely Vesconite, CIP, Feroform T814, and one ceramic coated bearing, namely Poly Crystalline Diamond Coated (PCD) along with two mechanical seals were tested in clean water for 60 hours. The results showed that PCD bearings experienced least amount of wear followed by Feroform T814, CIP, and Vesconite. The load side surfaces of polymer bearings exhibited a circular wear pattern whereas PCD bearings did not show any distinctively identifiable wear pattern. Following the same testing methodology, 60 hours long tests were conducted in fresh sedimented water on the same types of (new) bearings and seals. The data showed that bearings had similar (or less) total wear in sedimented water as compared to clean water, however, the drive shaft experienced a significant surface wear. In addition, the loading side of polymer bearing surfaces developed a circular wear pattern with significantly higher wear on the edge surfaces.

INTRODUCTION

Hydrokinetic devices have shown tremendous potential in harnessing energy from water currents of oceans, rivers, streams, and canals [2, 3]. However, there are some technological barriers that must be overcome before these devices become fully operational and commercialized. One of the critical issues with hydrokinetic devices is the longevity of their bearing-drive shaft assembly. Due to continuous relative motion of bearing and shaft surfaces on each other, unnecessary clearances are developed between them. The progressive increase in clearances induces undesirable drive shaft deflection and vibrations in the system. These vibrations and shaft deflection eventually exceed seal's operational tolerance limits causing (seal) leakage thus allowing water to enter into compartments causing damage to expensive components such as electric generator.

Bearing manufacturers have been trying to develop bearings for marine applications that could provide superior tribological characteristics, e.g., higher operational pressure-velocity values of bearings for their prolonged life. Recently, engineering polymers have emerged as an attractive option for bearing manufactures as engineering polymers: 1) are inexpensive in most cases, 2) have lower density, 3) exhibit higher resistance to wear and corrosion, and 4) have the ability to self-lubricate. Several studies have been conducted on understanding the effect of different parameters on wear of polymers such as filler properties, hardness, surface roughness, lubrication conditions, relative motion between two sliding components, and environmental factors [6-8]. The complex interactions among these parameters offer some challenges to precisely predict wear performance.

The prime motive of this study comes from the fact that the research of bearing material wear typically occurs under dry conditions and often follows standardized testing procedures such as a pin-on-flat wear machine, block-on-ring wear machine, or similar machines designed to evaluate simplified specimen geometries. There is a need for bearing performance data under conditions that are similar or close to field (conditions) for hydrokinetic devices.

In previous study [1, 2], wear performance of three polymer bearing types (Vesconite, CIP, Feroform T814) and one ceramic coated bearing type (PCD) were tested under clean water for 60 hours. The test data showed that PCD bearings experienced the least amount of wear in loading direction. The Vesconite bearings showed highest amount of wear. The Feroform T814 and CIP Marine bearings experienced relatively similar amount of total wear. In the present study, same types of bearings are studied in sedimented water for 60 hours. The wear data of bearings is compared with clean water data, and similarities and differences of test results are discussed.

EXPERIMENTAL SETUP

The test flume used in this study is shown in Figure 1. It consisted of two test stations, inlet and outlet diffusers, a water reservoir, a paddle flow meter, and a cross-flow heat exchanger. Figure 2 shows a close up of one of the stations with top cover removed and Figure 3 shows the complete station filled with clean water [5]. Each test station housed three bearings of the same type, which were mounted on a drive shaft through split supports in a single row in an arrangement similar to the layout of a bearing-shaft assembly of a typical hydrokinetic device in field.

A partial cross-sectional view of one of the stations is shown in Figure 4. The bearings were notated as drive, middle, and far side bearings based on their locations relative to the motor. The side bearings were mounted on fixed supports whereas the middle bearing was mounted on a support connected to a moveble link assembly and a hydraulic actuator. This arrangement allowed applying a vertical downward load of 2250 N on the middle bearing, which developed a reactive load of 1125 N on side bearings. The drive shaft was driven by a one horsepower Marathon Electric washdown motor at 300 rpm.

In order to prevent water from leaking from the station side walls, single and double cartridge seals were installed. One of the seals is shown in Figure 5. The sediment sizes, mineralogy, and concentration tested in the flume (as listed in Table 1) were chosen to be representative of the sediments typically seen in Alaska waters, which is one of the potential sites in the world where hydrokinetic devices might be deployed. The quantities of sediments introduced in the flume developed an approximate concentration of 1 g/L in the water.

TABLE 1. SEDIMENT SIZE AND QUANTITIES INTRODUCED IN THE FLUME

Sediment type	Grain size	Quantity
Yukon bed sample	d50 = 0.2 mm (range 0.18mm- 0.25mm)	90 g
Industrial sample 1	d = 0.010 mm	40 g
Industrial sample 2	d = 0.028 mm	50 g
Combined samples	d50= 0.07mm	180 g

In order to keep the sediment particles suspended, a flow rate of 1136 liters per minute was maintained at a temperature of 7.22 degrees Celsius in the flume. One station was used for performing tests on polymer bearings and the other (station) was used for ceramic coated bearings.

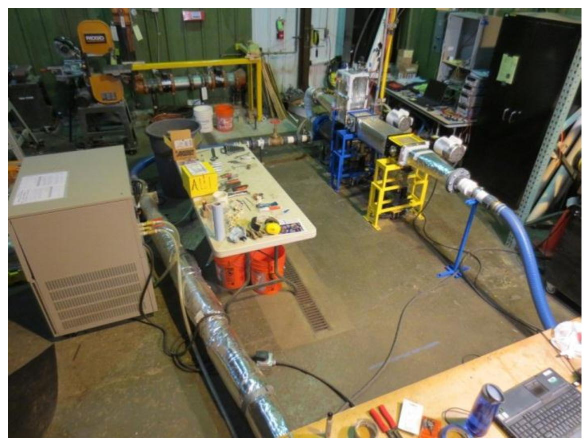

FIGURE 1. OVERHEAD VIEW OF THE ENTIRE FLUME SYSTEM

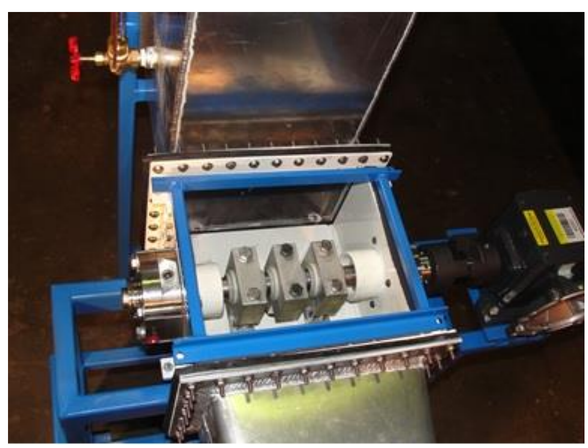

FIGURE 2. ALL THREE BEARINGS MOUNTED ON THE FIRST STATION

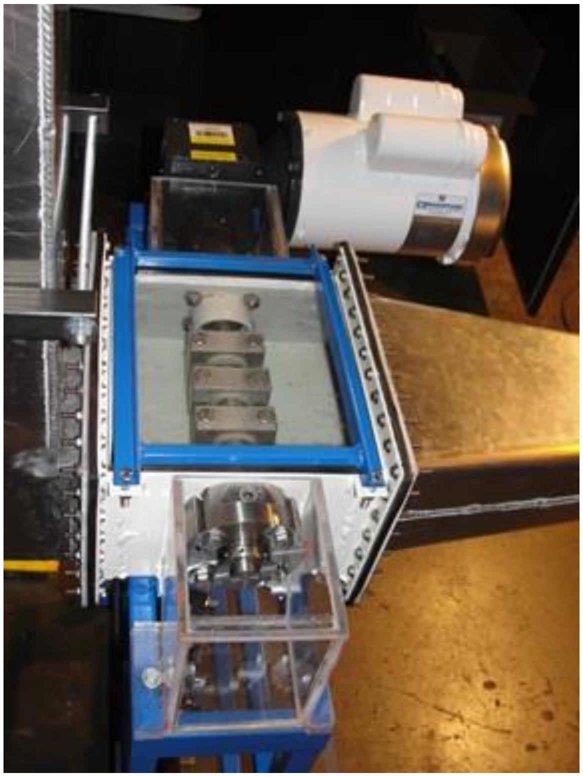

FIGURE 3. FIRST STATION IS FILLED WITH CLEAN WATER AND BEARINGS ARE READY TO TEST; NOTE THAT PRESENT STUDY WAS CONDUCTED USING SEDIMENTED WATER, HOWEVER, CLEAN WATER FIGURE IS USED TO SHOW THE INSIDE COMPONENTS.

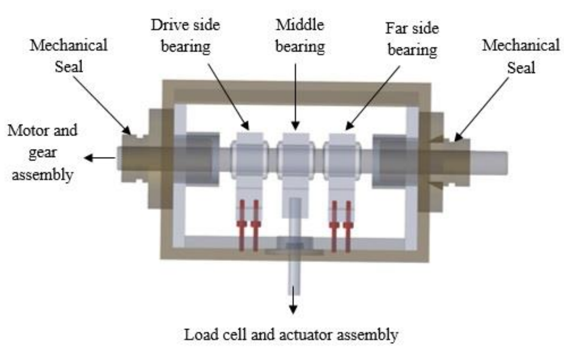

FIGURE 4. THE CROSS SECTION OF A STATION

FIGURE 5: A DOUBLE CARTRIDGE MECHANICAL SEAL

FIGURE 6: THE FOUR CANDIDATE BEARINGS TESTED IN THIS STUDY ARE SHOWN LEFT TO RIGHT – VESCONITE, CIP MARINE, FEROFORM T814, AND POLYCRYSTALLINE DIAMOND RADIAL BEARING [2, 4]

The bearings tested in this study (three polymer based bearings called Vesconite, CIP, and Feroform T814, and one ceramic coated bearing called Poly Crystalline Diamond) are shown in Figure 6. These bearings were selected based on recommendations from hydrokinetic device manufacturers, bearing manufacturers for marine applications, and experts in the field of bearing research.

Each test was run for 60 hours. This duration was long enough to cause measureable wear on bearings. Before each test, the bearings' inner diameters along load direction were measured at three different locations (using internal telescopic gauges and a micromere) and values were averaged. After the test, bearings were dismounted from their respective supports and their diameters were measured again following the (same) procedure explained above. The total wear was determined through the difference between the two measurements.

RESULTS

Figure 7 shows the total wear of bearings in load direction in sedimented water. As expected, the center bearing, which was exposed to the highest pressure-velocity (1.36 MPa-m/s) experienced the highest amount of wear as compared to the drive and the far side bearings (undergoing roughly half the pressure-velocity values of the center bearing) for all bearing types. The PCD bearings experienced the least amount of wear followed by Feroform T814, CIP, and Vesconite. Surprisingly, as compared to clean water test data [1] (as shown in Figure 8), all bearings showed relatively similar or lower total wear in sedimented water. However, a significant amount of scoring was observed on the (polymer bearings) shaft surface as shown in Figure 9 (which was absent in clean water test). The wear on the shaft was measured through a horizontal turning center and values are depicted in Figure 10. It is worth mentioning that no measurable wear was observed on the shaft during clean water test. The reason for lower wear on the bearings in sedimented water may be due to the contact between the shaft and the sediment particles impinged on the polymer bearing surface, which transferred portion of total wear on the shaft. For PCD bearings, the hardness of diamond inserts were most likely higher than the sediment particles' hardness, due to which total wear values remained unaffected (as compared to clean water test data).

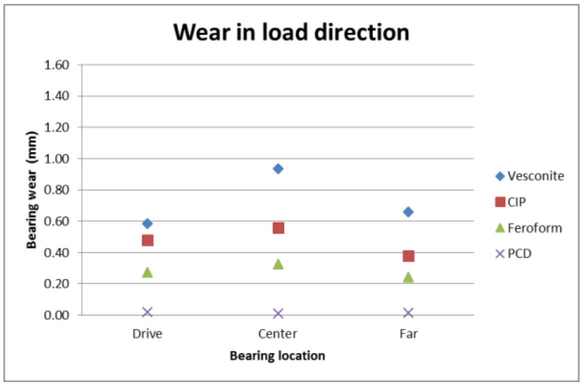

FIGURE 7. WEAR OF CANDIDATE BEARINGS IN LOAD DIRECTION IN SEDIMENTED WATER

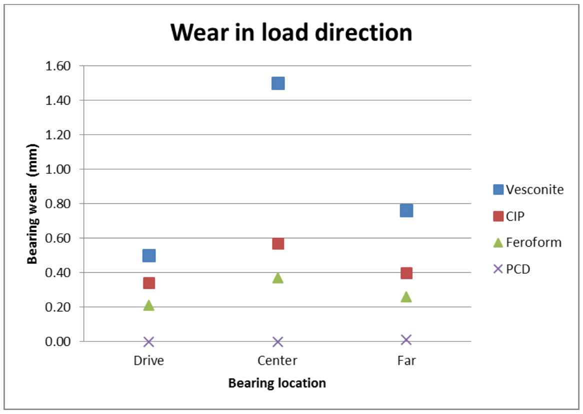

FIGURE 8. WEAR OF CANDIDATE BEARINGS IN LOAD DIRECTION IN CLEAN WATER

FIGURE 9. MAIN DRIVE SHAFT FOR POLYMER BASED BEARING AFTER 60 HOURS OF TESTING [4]

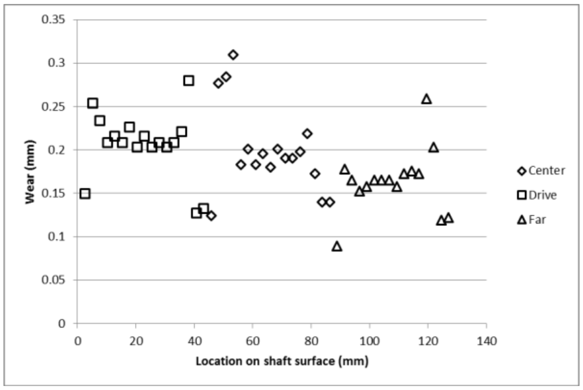

FIGURE 10. WEAR VALUES ON (POLYMER BEARING) DRIVE SHAFT WITH RESPECT TO AXIAL SHAFT LOCATION (EXCLUDING SPLIT PIN AREAS IN BETWEEN TWO BEARINGS)

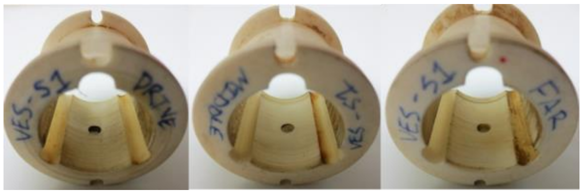

FIGURE 11. THE LOAD (WORN) SURFACES OF VESCONITE BEARINGS AFTER THE TEST. (A) DRIVE SIDE BEARING; (B) MIDDLE BEARING; (C) FAR SIDE BEARING.

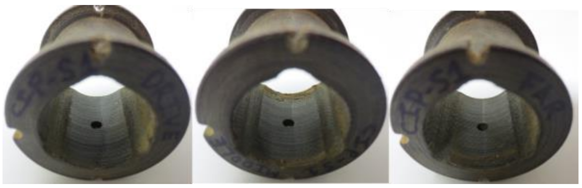

FIGURE 12. THE LOAD (WORN) SURFACES OF CIP MARINE BEARINGS AFTER THE TEST. (A) DRIVE SIDE BEARING; (B) MIDDLE BEARING; (C) FAR SIDE BEARING.

FIGURE 13. THE LOAD (WORN) SURFACES OF FEROFROM T814 BEARINGS AFTER THE TEST. (A) DRIVE SIDE BEARING; (B) MIDDLE BEARING; (C) FAR SIDE BEARING.

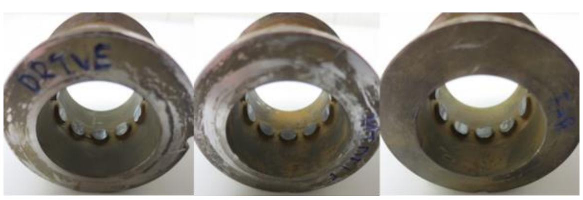

FIGURE 14. THE LOAD (WORN) SURFACES OF PCD BEARINGS AFTER THE TEST. (A) DRIVE SIDE BEARING; (B) MIDDLE BEARING; (C) FAR SIDE BEARING

Figures 11-14 show the load side surface of each bearing after the tests in sedimented water. The polymer bearings (Vesconite, CIP, and Feroform T814) developed a circular wear pattern (i.e. circular grooves travelling on the bearing surface along the circumferential direction normal to the axis of the shaft) on the load contact surface similar to ones commonly observed in full scale hydrokinetic bearings in field [5]. These patterns were also observed in clean water tests [1]. For PCD bearings, due to miniscule wear, the visual inspection didn't reveal any identifiable wear pattern. The surfaces near the edges of polymer bearings showed heavy wear. This was probably due to the proximity of sediments and edge contact pressure effects [9]. It may be noted that this heavy wear was excluded from the wear values shown in Figure 7. On a final note, the accumulation of worn particles along the main longitudinal grooves on polymer bearing surfaces as evidenced by dark regions in clean water tests didn't occur in present study.

CONCLUSIONS

In the present study, wear characteristics of three polymer bearing types, namely Vesconite, CIP, and Feroform T814 bearings, and one ceramic coated bearing type, namely Poly Crystalline Diamond were tested in sedimented water under loading and operating conditions similar to those expected in the field. The test data revealed that PCD bearings exhibited lowest wear among candidate bearings. As compared to clean water test data, a significant amount of wear occurred on the drive shaft for polymer bearings. In addition, loading side of bearing surfaces had a circular wear pattern with significant wear on the bearing edge surfaces. Furthermore, dark regions on polymer bearing surfaces along grooves showing accumulation of worn particles (as were in the case of clean water) didn't appear in sedimented water tests.

ACKNOWLEDGEMENTS

This work is supported by the Department of Energy fund (DE-EE0003631), ORPC match fund, and the Office of Research of the University of Alaska Anchorage match fund and Ohio University Research Travel Fund.

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