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ABRASION ANALYSIS OF CRITICAL SLIDING COMPONENTS OF HYDROKINETIC DEVICES: AN EMPIRICAL STUDY

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ABSTRACT

With Societies' increasing energy needs that are projected to increase exponentially combined with shrinking fossil fuel reserves, a growing sense of urgency on identifying renewable potential energy resources has emerged. Hydrokinetic devices albeit immature have shown potential to provide alternate energy from currents in rivers and ocean. One of the factors that can potentially affect the performance of hydrokinetic devices is clearances in assemblies, especially bearing-shaft assemblies, which must be maintained within acceptable limits to increase the longevity of the entire system. In this paper, an experimental approach is presented to quantify wear of bearings that are commonly used in hydrokinetic devices. To accomplish this, a flume was designed, which recreates the hydrodynamic, salinity, sedimentary, and mechanical conditions that hydrokinetic devices face in the field. The candidate bearings were tested for 60 hours in fresh clean water and their total wear were measured using internal contact telescoping gauges. The results showed that the Polycrystalline diamond bearing experienced the least amount of wear

INTRODUCTION

The bearing-shaft assembly is a critical part of typical hydrokinetic devices and has a direct impact on device performance. As contact pressure from the rotating shaft causes the bearings to wear over time, excessive clearances are created which could negatively impact the performance of other critical components, e.g. mechanical seals, the generator, and instrumentation. A clear understanding of the tribological behavior of bearing-shaft assemblies in marine environments and identification and selection of most wear resistant (bearing-shaft) system can potentially reduce the duration and frequency of expensive infield maintenance of hydrokinetic devices.

Engineering polymers are increasingly popular choices of materials for sliding components due to a number of desirable characteristics; polymers generally cost less to produce, weigh less, exhibit higher resistance to wear and corrosion relative to metals, and have the ability to self-lubricate. When designing hydrokinetic devices, it is essential to estimate expected wear behavior of the system. The effects of various parameters on bearing wear have been well studied, including filler properties in polymer composites, counterface hardness and roughness, lubrication conditions, the nature of relative motion between sliding components, excessive radial clearance, and environmental factors such as tribocorrosion and biofouling [4-10]. The complex interactions between these parameters can make it difficult to accurately predict wear performance.

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. Under this perspective, there is a need for bearing performance data which has relatively close relevance to marine applications. This paper focuses on the wear performance of a variety of different engineering polymer-based journal bearings currently deployed or being considered for use in hydrokinetic devices. The bearings were tested in temperature controlled clean fresh water. The results of this study would be valuable in identifying suitable bearing-shaft assembly for use in hydrokinetic devices or other similar marine applications.

TEST APPARATUS

A custom testing apparatus was designed and built for conducting this study. The testing apparatus consisted of a closed flume that included two test stations, inlet and outlet diffusers, water reservoir, paddle flow meter, and custom built cross-flow heat exchanger as shown in Figure 1.

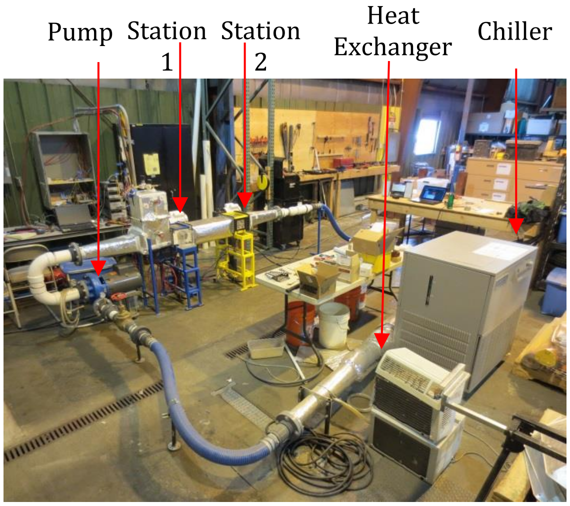


FIGURE 1: VIEW OF THE ENTIRE FLUME.

Each test station was comprised of three bearings and split support mounts, resistance temperature detectors (RTD's), a shaft, two seals, motor, load cell, and hydraulic actuator. Each test station housed three bearings, which were aligned in a single row and positioned in such a way as to imitate the arrangement of bearings deployed in the field. Figure 2 shows the portion of the cross-section of the station containing bearing, bearing mounts, and seals. In order to reduce any unnecessary wear due to deflection of the shaft, the two outer bearings were kept as close as possible to the center load-carrying bearing. The center bearing was mounted in such a way that horizontal motion was constrained with limited vertical motion. The two outside bearings were mounted in fixed positions and acted as supports when the center bearing was loaded. This arrangement constrained any deflection transferred to the seals. Each of the bearing mounts was equipped with an RTD to measure the temperature of the bearings during the flume operation. A force of 2250 N was applied on the middle bearing mount by using a linear hydraulic mechanical actuator. A one horsepower Marathon Electric washdown motor was used to turn the shaft at 300 rpm. The shaft speed and applied load developed a Pressure-Velocity (PV) value (in the contact area) comparable to that expected in the field. The PV value is a widely used industry standard for comparing bearing life expectancies and wear resistance [11].

Water was circulated through the flume at a rate of 1136 liters per minute and maintained at a temperature of 7.22 degrees Celsius using the heat exchanger. In order to prevent water from leaking from test stations, mechanical seals with single contact surfaces and double contact surfaces were installed (Figures 2 and 3). It may be noted that a double cartridge seal, as the name suggests, has two (inner and outer) sealing surfaces (as compared to a single cartridge), and it continues to perform its function should the outer ring fail. This allows replacement of seal before catastrophic failures in the downstream of the system occur from leaking water. Due to this fail-safe feature, the double cartridge seals have emerged as an attractive alternative over single cartridge seals, and therefore, were included in this study.

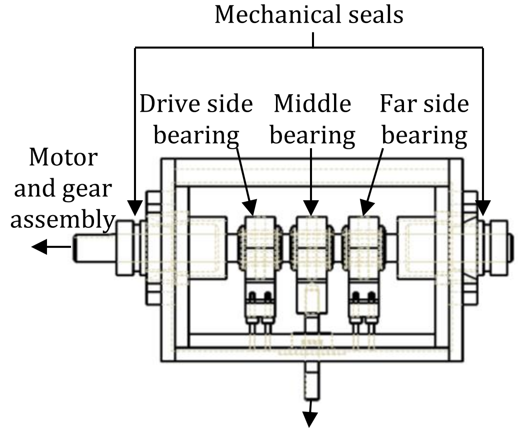


FIGURE 2: THE CROSS-SECTIONAL VIEW OF TEST STATION.

FIGURE 3: THE CHESTERTON 180 HEAVY DUTY CARTRIDGE SINGLE SEAL (LEFT) AND THE CHESTERTON 280 HEAVY DUTY CARTRIDGE DUAL SEAL (RIGHT) TESTED IN THIS STUDY [12].

Four types of bearings were tested; Polycrystalline diamond, CIP Marine, Feroform T814, and Vesconite Hilube. Each test lasted for a total of 60 hours in fresh clean water. This duration was long enough to allow measureable wear on bearings and was considered equivalent to a 60 hrs of in-field performance at peak loading conditions. Figure 4 shows the candidate bearings. Bearings were selected for testing based on recommendations from experts in marine hydrokinetic devices. Table 1 displays types of materials used for shaft and bearing support and co-efficient of friction (wet and/or dry) for each bearing type.

FIGURE 4: THE FOUR CANDIDATE BEARINGS TESTED IN THIS STUDY, FROM LEFT TO RIGHT – VESCONITE, CIP MARINE, FEROFORM T814, AND POLYCRYSTALLINE DIAMOND (PCD) RADIAL BEARING [12].

TABLE 1. TYPES OF MATERIALS USED FOR BEARING HOUSING AND SHAFT FOR EACH STATION

Bearing material	Support material	Shaft material	μ*
Vesconite, Station 1	Aluminum	Steel	Dry**, 0.09-0.1
CIP, Station 1	Aluminum	Steel	N.A
Feroform T814, Station 1	Aluminum	Steel	Dry, 0.04-0.08 Wet, 0.06-0.09
PCD, Station 2	Steel	Steel	Wet***, 0.05-0.08

* Co-efficient of friction,
** Vesconite on steel
*** PCD on PCD

TEST RESULTS

Figures 5 and 6 display the total wear on the inner diameter of each bearing tested in the load-bearing (vertical) and water flow (horizontal) directions, respectively, after 60 hours of testing in fresh clean water. The wear on the bearings was measured using internal telescopic gauges and micrometers. As expected, the center bearings which were exposed to the highest pressure-velocity (1.36 MPa-m/s) experienced the highest amount of wear as compared to drive and far side bearings with roughly half the pressure-velocity values of the center bearing. The PCD bearings experienced the least amount of wear among the candidate bearings followed by Feroform T814, CIP Marine, and Vesconite, respectively. The far side Vesconite bearing experienced slightly more wear in the load-bearing direction than the drive side and center bearings in the load direction. In the flow direction, far side Vesconite bearing showed less wear as compared to Feroform T814 and CIP Marine bearings. These deviations may be attributed to misalignment of the shaft during the Vesconite bearing test. It may be noted that the drive side PCD bearing showed a negative value of wear in the flow direction. The reason of this anomaly is probably due to the deposition of wear particles on PCD inserts or some metrological error or uncertainty in wear data.

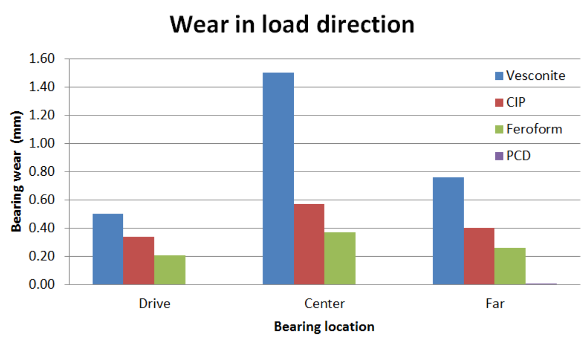


FIGURE 5: WEAR OF EACH BEARING IN THE LOAD-BEARING (VERTICAL) DIRECTION.

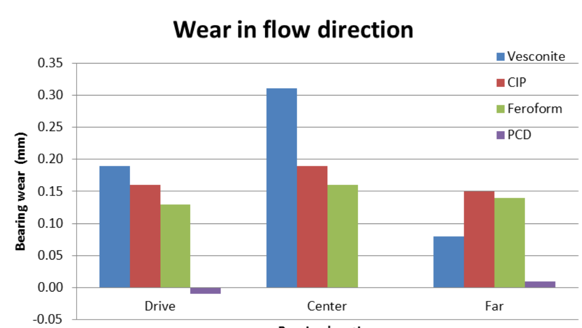
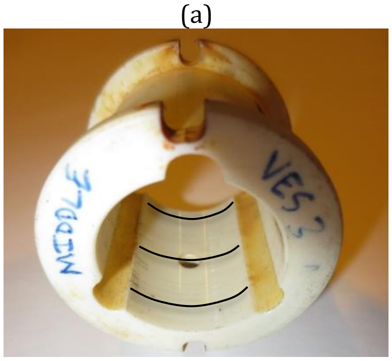


FIGURE 6: WEAR OF EACH BEARING IN THE FLOW (HORIZONTAL) DIRECTION.

Figures 7-10 show the worn side of each bearing after the test. The polymers bearings (Vesconite, Feroform T814, and CIP Marine) exhibited a circular wear pattern (i.e. circular grooves travelling on the bearing surface along the circumferential direction normal to the axis of the shaft as highlighted through curved lines) on the load contact surface similar to those commonly observed in full scale hydrokinetic bearings in field [13]. The circular marks, as expected, were more pronounced on the middle bearings. The bearing surfaces for each polymer bearing showed dark regions primarily along the main longitudinal grooves, which may be attributed to the accumulation of worn particles in those areas. In PCD bearings, due to miniscule wear, the visual inspection didn't reveal any distinctly identifiable wear pattern.

(a)



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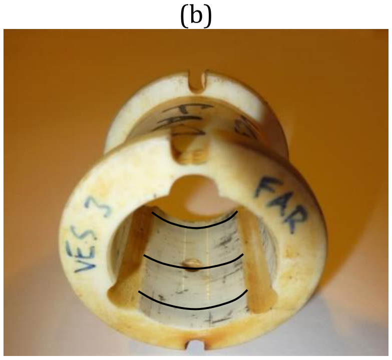
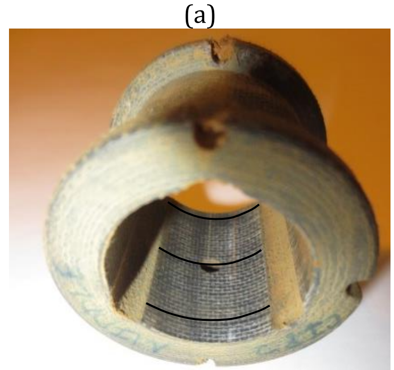


(c)

FIGURE 7: THE LOAD (WORN) SURFACES OF VESCONITE BEARINGS AFTER THE TEST. (A) DRIVE SIDE BEARING; (B) MIDDLE BEARING; (C) FAR SIDE BEARING. THE CIRCULAR WEAR PATTERN IS HIGHLIGHTED BY CURVED LINES.

(a)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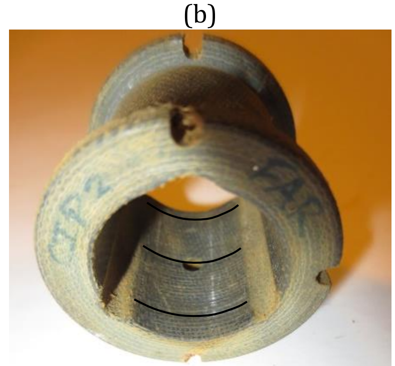

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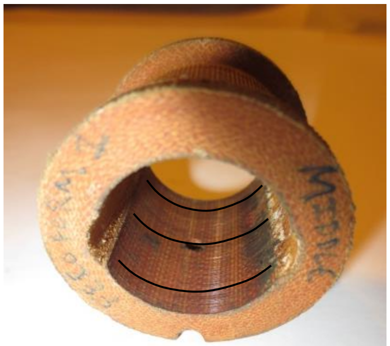
FIGURE 8: THE LOAD (WORN) SURFACES OF CIP MARINE BEARINGS AFTER THE TEST. (A) DRIVE SIDE BEARING; (B) MIDDLE BEARING; (C) FAR SIDE BEARING. THE CIRCULAR WEAR PATTERN IS HIGHLIGHTED BY CURVED LINES.

(a)



(b)

(c)

FIGURE 9: THE LOAD (WORN) SURFACES OF FEROFROM T814 BEARINGS AFTER THE TEST. (A) DRIVE SIDE BEARING; (B) MIDDLE BEARING; (C) FAR SIDE BEARING. THE CIRCULAR WEAR PATTERN IS HIGHLIGHTED BY CURVED LINES.

(a)

(b)

(c)

FIGURE 10: THE LOAD (WORN) SURFACES OF PCD BEARINGS AFTER THE TEST. (A) DRIVE SIDE BEARING; (B) MIDDLE BEARING; (C) FAR SIDE BEARING.

While the fresh clean water test conclusively recommends the PCD bearings as a favorable candidate for further study, heavily sedimented water will introduce an additional wear mechanism of three-body abrasion and results may vary as the candidate bearings could exhibit varying resistance to three-body abrasion. This aspect provides motivation to conduct similar testing in sedimented water. The results of those tests will be covered in a future paper.

COLCLUSIONS

The wear characteristics of bearings commonly used in hydrokinetics devices were studied using a customized flume under the loading and operating conditions similar to those expected in the field. The wear data collected during 60 hour tests in clean fresh water showed that PCD bearings experienced the least amount of wear both in loading and flow directions. The Vesconite bearings showed highest amount of wear with the exception of far side bearing in flow direction. The Feroform T814 and CIP Marine bearing experienced relatively similar amount of total wear with Feroform T814 bearing exhibiting slightly higher wear resistance. A circular wear pattern was observed on the loaded surface of Vesconite, Feroform T814, and CIP Marine bearings whereas PCD bearings didn't show any distinct wear pattern.

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