Fiber Resin Composite Bearings in Wave Energy Converter

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The Pelamis Wave Energy Converter harnesses ocean wave motion, converting it into electrical energy. The mechanical motion in the device that results from wave motion is translated through a series of composite bearings that support the mechanical joints and allow smooth, low friction oscillation. The composite bearing structure and properties are discussed along with the design considerations in choosing the bearing system.

1. WAVE ENERGY CONVERTER

The Pelamis Wave Energy Converter is an electric power generation system that uses a revolutionary power conversion unit to convert ocean wave energy to electricity. It harnesses the undulating motion of ocean waves by translating the wave force into oscillations at three power-generation joints along the Pelamis unit. The oscillating mechanical motion derived from the waves is converted into hydraulic fluid flow that drives electrical generators.

Figure 1: Pelamis Wave Energy Converter

The oscillating motion inherent in the operation of this device required a bearing design that supported that motion and provided long bearing wear life. Low friction at the shaft / bearing interface was also required to minimize power losses from relative sliding even under aggressive ocean conditions. The design also preferred self-lubrication, maintenance-free operation and a high degree of reliability. These factors were all required because of the remote location and limited accessibility of the power generating units in general, as well as the bearing locations in particular. The bearings were also not permitted to cause pollution of the environment, particularly through the release of hydrocarbons.

The optimum bearing type for this application was a composite that utilized a high strength fiber/resin construction combined with a self-lubricating bearing layer on the inside diameter. The self-lubricating layer consists of a combination of PTFE fibers and other high strength polymeric fibers encapsulated in a graphite-filled epoxy resin. High-Strength GarMax® was utilized in the design.

2. BEARING STRUCTURE

2.1 Composite Bearing Composition

The fiber / resin composite system chosen for the Pelamis system utilized a multi-layer structure consisting of a wear-resistant self-lubricating layer supported by a glass fiber / epoxy resin composite system.

The self-lubricating system includes lubricating fibers produced from polytetrafluoroethylene (PTFE) fibers encapsulated by polyester fibers, bound by an epoxy resin system. The self-lubricating nature of the system is further enhanced through the addition of graphite particulates to the epoxy matrix.

The filament wound composite bearing structure is shown in Figure 2, exhibiting a combination of fiber types with graphite particles providing additional solid lubrication. The image also shows the glass fiber support structure that provides the wall strength necessary for such an aggressive application as the Pelamis device.

2.2. Bearing Wear Performance

The impact of the additional solid lubrication in the low friction, wear-resistant layer is demonstrated in Figure 3, which compares the wear performance of two composite bearing types. One curve shows the wear rate of the bearing under discussion including a high fiber density developed during the filament winding manufacturing method and the added effect of solid lubrication.

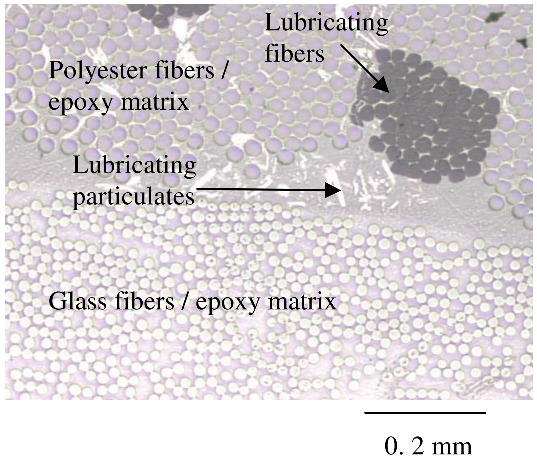

Figure 2: Cross-sectional image showing composite bearing structure

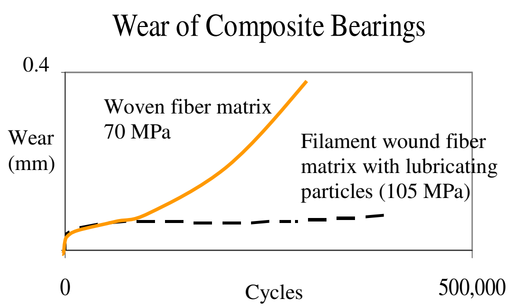

Figure 3: Wear of composite bearings showing the effect of solid lubrication and bearing construction. Test conditions: +/- 30^{o} oscillation; 15 cycles/min; steel shaft counterbody: 0.25 µm Ra.

2.3 Other Performance Criteria

In addition to wear performance, several other characteristics were essential to the selection of the bearing system.

Water absorption: The bearing operating conditions were to include a combination of both dry sliding and exposure to seawater.

GarMax® bearings have been demonstrated to have low water absorption in short term exposure (0.15% in 24h). They have also demonstrated the ability to serve below the waterline as a drive shaft support bearing in a marine motor.

Abrasive debris: Resistance to abrasion was considered a key characteristic, both from potential rust and a likely ingress of abrasive debris such as sand. The GarMax® composite bearing system has long provided favorable performance in aggressive applications such as agriculture, construction and off-road equipment. The positive performance in these applications has resulted in part from the high fiber density shown in Figure 2, inherent in the filament wound structure used to produce this composite bearing type.

Temperature range: The operating temperature range for GarMax® composite bearings is from approximately -200^{o}C to 170^{o}C, well beyond the operating range for the Pelamis system.

2.4 Environmental Impact of Composite Bearings

It was a requirement of the bearing system that the system not pollute. In fact, the use of hydrocarbon-based lubricants is an ever-increasing issue with the use of classic bearing systems. The self-lubricating fiber / resin composite that was chosen for use in the Pelamis equipment is not only capable of running without the use of externally-applied lubrication, but is designed to operate best when used without external lubricants. Figure 4 shows the lubrication state for different classes of bearings, showing that lubrication used under most conditions with classic bearing types such as rolling element bearings and bronze bushings. This aspect of the fiber / resin system had positive ramifications from the perspective of both environmental impact and long maintenance intervals required for the bearing system.

3 DESIGN CONSIDERATIONS

The Pelamis operates semi-submerged in a salt water environment. Temperatures expected at the bearing housing were consistent with the local sea temperature; hence a housing temperature range of 2ºC to 25ºC was expected.

Bearings are located at the interconnection points on the machine and are likely to be subject to a range of different environments. Some bearings may spend a significant amount of time out of the water running completely dry whilst other bearings are likely to spend virtually the entire time underwater running completely wet. Hence bearings must be equally capable of wet and dry running.

Clean Technology 2009, www.ct-si.org, ISBN 978-1-4398-1787-2

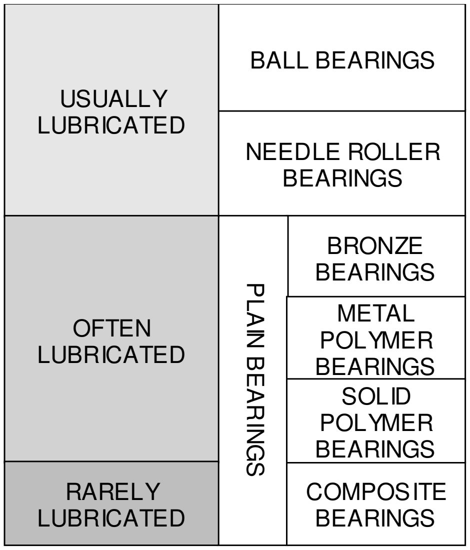

Figure 4: Bearing types and their typical lubrication schemes

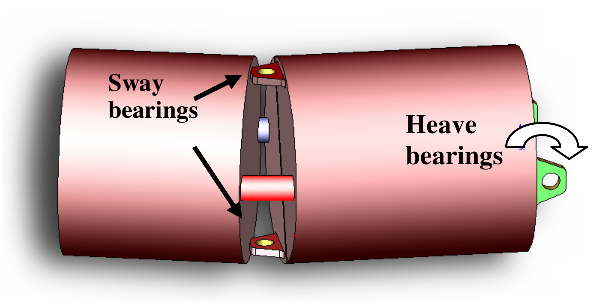

Figure 5: Schematic of the device showing bearing locations

Pelamis provided a proposed bearing design envelope, along with a complex series of calculated load and speed data. Method of life calculation utilized the standard GARMAX life calculation program, although that program is designed to assume a single set of conditions.

- Load: min to max at specific intervals
- Angular velocity: min to max at specific intervals
- % of operating life at each condition
- Bearing Length and ID: as specified
- Usable bearing liner: 635 µm minimum
- Target life: 15 years (5475 days)

3.2 Bearing Life Under Target Conditions

Figure 6 shows two calculations of bearing life at two of the load / speed conditions within the design envelope. These life calculations assumed that the target conditions would exist over 100% of the design life.

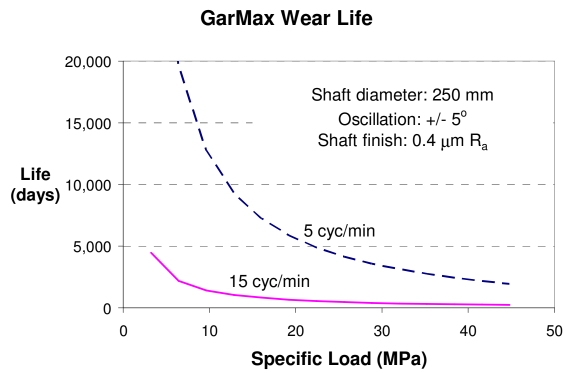

Figure 6: GarMax® wear life at two oscillation rates and a range of bearing loads.

The actual design parameters included a wide range of loads and speeds, with percentage of life predicted for all known conditions. The mean loads for both the Heave and Sway bearings were approximately 0.3MPa. The bearings had to be capable of withstanding peak loads which were an order of magnitude more than the mean load. The life prediction method utilized the calculation of life at each of the predicted conditions and evaluated the collective time at each unique condition over the proposed 15-year life of the device. Each fraction of total wear life consumed over 15 years is summed as: $\Sigma\Sigma L_f$ with Load (P), and oscillation rate (α) varied between design minimum and maximum values.

A specific example of one specific calculation was as follows

Load (P):	0 .16 MN
Oscillating speed (α):	58 cycles/min
Oscillation angle:	+/- 5°
Bearing diameter:	250 mm
Bearing length:	125 mm
Bearing life:	82 days

Fraction of life at this condition: $9.7\text{x}10^{-9}$

Time at condition (over 15 years): $5.3\text{x}10^{-5}$ days

Fraction of bearing life consumed at this condition (L_f) (time at condition / life at condition): $6.4\text{x}10^{-7}$

Results of the calculations provided that the heave and sway bearings would exhibit the following percentages of bearing life consumed in 15 years of operation:

Heave: 41% of bearing wear-life in 15 years
Sway: 82% of bearing wear-life in 15 years

4.0 Summary

The self-lubricating composite bearing chosen for the Pelamis Wave-Energy Conversion System includes lubricating fibers produced from polytetrafluoroethylene (PTFE) fibers encapsulated by polyester fibers, bound by an epoxy resin system. The self-lubricating nature of the bearing is further enhanced through the addition of graphite particulates to the epoxy matrix.

The Life Estimation calculations for both the Heave and Sway bearings demonstrate that the bearings will perform properly during the 15-year service life of the Pelamis Wave-Energy Conversion Unit.

Clean Technology 2009, www.ct-si.org, ISBN 978-1-4398-1787-2