BENEFITS OF SEAWATER LUBRICATED BEARINGS TO PREVENT ENVIRONMENTAL IMPACT FROM PROPELLER SHAFT SYSTEMS IN POLAR REGIONS

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SUMMARY

The IMO has recognized that the Polar Regions require special measures to provide adequate protection from the potential impact of vessels operating in those waters. Operational and accidental discharges of oil from a vessel's stern tube are all-too-common occurrences. This is of special concern in Polar waters as propellers are prone to impact with ice causing increased propeller shaft movements and seals struggle to maintain a complete barrier -- to keep lubricating oil in (and seawater out from) the sterntube. This often results in a discharge of lubricating oil to the environment.

This paper will outline a proven, viable option for ice-classed vessels operating in Polar waters to eliminate sterntube oil pollution by using seawater lubricated propeller shaft bearings. Non-metallic bearings are used in place of white metal bearings and seawater replaces oil as the operating medium. Seawater is taken from the sea, pumped through the bearing positions and exits back to the sea -- no sterntube oil is required. Use of seawater lubricated bearings means no storage, sampling or disposal of sterntube oil, it also eliminates the expense and maintenance of an aft seal. There is zero risk of sterntube oil pollution, as oil is not used.
This technology is currently in use in Polar waters on Canadian and US Coast Guards' ice breakers and by many ship operators worldwide – from oil tankers to bulk carriers and cruise ships. These systems already in operation have a history of low maintenance, reduced operating costs and zero pollution risk to the environment.

1. INTRODUCTION

Per the Canadian Standing Senate Committee on Fisheries and Oceans, *"The ice cover is becoming thinner and is covering progressively less of the circumpolar Arctic than before. It is no longer a matter of if, but when the Arctic Ocean will become open to regular shipping." [1]*
Commercial voyages through the Northern Sea Route (NSR) and Northwest Passage are already increasing.

Vessels operating in Arctic zones have generated environmental concerns of ship-sourced pollution threatening Arctic ecosystems. Zero tolerance for any kind of ship-sourced pollution is now becoming the standard and international regulations are becoming increasingly stringent. This is especially relevant to the Arctic, which presents a critical situation where detection, monitoring, and cleanup are grueling due the remoteness, climatic conditions and shifting interplay between land and sea-ice.

The mandatory IMO Polar Code, effective January 2017, prohibits *"any discharge into the sea of oil or oily mixtures…"*.[2]

Dominant among the many challenges facing ship operations in the Arctic is the danger of oil discharge from oil/sea interfaces. One major such interface, sterntube oil, can be eliminated.

2. PROPELLER SHAFT BEARING SYSTEMS - PAST

Over fifty years ago, propeller shafts were normally supported by bearings of *lignum vitae*, a dense hardwood from South America. As an '*open*' system, seawater lubricated and cooled the propeller shaft bearings. There was only one seal per shaft preventing seawater ingress to the vessel, at those times a stuffing box.

However, lignum vitae bearings did not have reliable wear life much beyond five years which meant frequent shaft withdrawals to replacing the bearings -- an expensive maintenance cycle. Bearings were somewhat unreliable –they operated in an uncontrolled environment and no one could predict when they would wear out, sometimes even lasting for only one Atlantic Ocean crossing. Additionally, the packing in the stuffing boxes tended to score the bronze shaft liner which meant frequent skimming or replacement of the packing liner -- more additional costs for the shipowner.

3. PROPELLER SHAFT BEARING SYSTEMS - PRESENT

The invention of the Simplex seal by Blohm & Voss in 1948 permitted the move to a 'closed' sterntube system using white metal bearings operating in a sealed oil system. The controlled environment offered reliability and controlled wear life. The majority of commercial ships use this system today -- the propeller shaft

supported by oil lubricated metal bearings within a stern tube sealed by forward and aft shaft seals.
However, the 'closed' system was and still is problematic, the two shaft seals require frequent maintenance or oil would leak into the sea or seawater would ingress and contaminate the lubricating oil. A typical commercial ship will operate 6000 – 8000 hours per year on a 5year dry-docking schedule, however scheduled seal maintenance frequency is often as short as a 2.5year cycle.

4. OIL DISCHARGES - OPERATIONAL

Some seal leakage is considered "*normal operational consumption*" and acceptable practice, however legislation against such discharge continues to intensify.
It is difficult to make an accurate estimate of such oil discharges to sea since the leak rate is dependent on multiple parameters -- operational profile, shaft size, shaft speed, wear, age and type of arrangement etc.

A 2010 independent study by *Environmental Research Consulting* in New York concluded that *"Total annual inputs of lubricating oil worldwide from propeller shaft leakage into port waters is estimated to be between 37 million to nearly 61 million litres. If the same rates of discharge occur at sea as they do in port, the estimated worldwide annual inputs of lubricants to marine waters both in ports and harbours and at sea might be estimated to be about four times the port estimate. Thus, total worldwide use of propeller shaft lubricants from operational leaks and discharges would then be about 130 million to 244 million litres annually."*[3]
For comparison purposes, this is about 5 times the 41.6 million litres of oil that spilled from the Exxon Valdez incident.

Figure 1: Oil sheen

Operational discharge of sterntube oil is a common occurrence for vessels in ice as propellers are prone to impact with the ice causing extra shaft movements and the seals struggle to maintain a complete barrier to keep lubricating oil in (or seawater out of) the stern tube. The DNV report, "*Regular Operational Emissions and Discharges from Shipping in Polar Areas - Particular Environmental Aspects"* prepared for the Norwegian Maritime Directorate expressed concern, paying particular attention to oil discharges from sterntubes in Polar waters. "*Vessels operating in areas with ice are expected to have a higher leak rate than ships with similar size operating in a less harsh environment (i.e. ice entering propeller flow, causing particular loads*).[4]

It is conceded that seal manufacturers have redesigned their seals, adding complexity against leakage and some even providing for recovery of smaller leakage amounts back into the vessel but all aft seals remain vulnerable to damage.

5. OIL DISCHARGES - ACCIDENTAL

Oil in larger quantities also quickly leaks to sea if the seal is damaged - commonly from interaction with a rope or fishing equipment.

Figure 2: Ropes and fishing line damage aft seals

Lloyd's Register reported the extent of seal defects of all defects in a ship: *"Defect statistics over the last 20 years indicate that the aft stern bush represents 10% of shaft line failures, with the forward stern bush representing 4% of total failures. Interestingly, the aft stern gland (seal) and forward stern gland (seal) represent 43% and 24% of failures respectively."*[5]

6. ENVIRONMENTALLY ACCEPTABLE LUBRICANTS

In December 2013, the U.S. EPA Vessel General Permit (VGP) became law stating, "*All vessels must use an*

"Environmentally acceptable lubricant" (EAL) in all oil-to-sea interfaces, unless technically infeasible".[6]
Many oil producers have introduced biodegradable lubricants that meet the EAL definition and these are promoted as "green" lubricants suitable for use in sterntube systems, however many concerns have been raised with using biodegradable lubricants in vessels operating in Polar regions (e.g. in ice) such as:

- Higher leakage rates of the lubricant due to ice impacts with propeller affecting sealing.
- Little research on the impact of biodegradable lubricants on the environment in Polar regions.
- There is some evidence that lower temperatures affect the biodegradability of these lubricants; Whereas solar radiation generally speeds the break-down of contaminants, the reduced level of sunlight in the Arctic lengthens the degradation process and increases the likelihood that toxic substances in the lubricating oil will find their way into the food chain. Hence, such "biodegradable" lubricants may indeed not be as biodegradable in Polar environments.
- While biodegradable lubricants may be deemed non-toxic by OECD testing, their presence on the water surface is a threat to seabirds.
  –bird plumage readily absorbs the oil, decreasing the bird's insulation, waterproofing, and buoyancy, often leading to death from hypothermia and/or starvation

Additionally, EAL's or biodegradable lubricants are typically 5 to 10times more expensive than mineral oils and reports are surfacing that their compatibility with existing seal materials is perhaps questionable.

The U.S. EPA recommends that all new build vessel operators… "*use seawater-based systems for their sterntube lubrication to eliminate the discharge of oil…to the aquatic environment*."[6]

The IMO Polar Code effective in 2017, decrees that Polar waters will be "zero discharge" areas under MARPOL Annexes 1 and 2 (oil and noxious liquids). The Code states: "Any discharge into the sea of oil or oily mixtures from any ship shall be prohibited." [2]

- This should be a concern for any ship owner operating in Polar waters.

7. CAN OIL-BASED DISCHARGES BE TOTALLY ELIMINATED FROM STERNTUBES?

Improvements in seal designs have reduced operational discharges, some designs even with provision to recover standard operational oil leakages back into the vessel, however the possibility of mis-operation of the seal controls or accidental damage to seal components mean that even the most complex seals cannot guarantee zero discharge.
However, an open, seawater lubricated propeller shaft bearing system uses no oil so zero oil discharge can indeed be guaranteed -- seawater lubricates and cools the propeller shaft bearings and flows back to the sea.
A proven, viable option to truly eliminate oil discharges from sterntubes already exists.

8. CAN SEAWATER LUBRICATED PROPELLER SHAFT BEARING SYSTEM COMPETE WITH OIL-BASED SYSTEMS?

Many of the world's Navies and Coast Guards did not change to oil systems and continued to use seawater lubricated propeller shaft bearings for battle damage safety reasons and non-catastrophic failure mode.
Modern polymer bearing materials and developments in bearing design have advanced performance and bearing life beyond 15years is achievable.
Seawater lubricated propeller shaft bearings are used successfully in Polar regions – they are fitted in many ice-breakers of the Canadian, US and Russian fleets.
Commercial ship owners are now seeing the proven performance with seawater lubricated propeller shaft bearings. Recent changes to Classification Rules can now allow extended shaft withdrawal intervals similar to with oil systems.

9. SEAWATER LUBRICATED PROPELLER SHAFT BEARING SYSTEM – BASIC COMPONENTS

A self-lubricating elastomeric polymer is used for the bearing. The material does not have a shelf life and will not work harden in use.

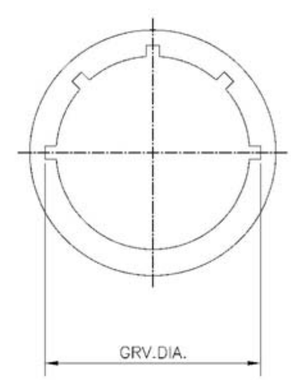

Figure 3: Cross section drawing of a self-lubricating elastomer polymer bearing

The bearing is designed to operate under true hydrodynamic principles and is machined without grooves in its bottom section.

The polymer and bearing design are approved by all major Classification Societies and for the bearing adjacent to the propeller can be as short as 2times shaft diameter making it much shorter than traditional stave-type or rubber bearings.

9.1 OPTIMUM POLYMER BEARING DESIGN

With no grooves on the bottom half of the bearing, the loaded section of the bearing is smooth to promote development of a hydrodynamic film at slower shaft speed than with a full-grooved or stave-type bearing where the grooves allow the film to escape.

With a grooved bearing, the hydrodynamic film must reform at the beginning of each bearing segment. The continuous film is thicker and consequently more stable at comparable shaft speeds.

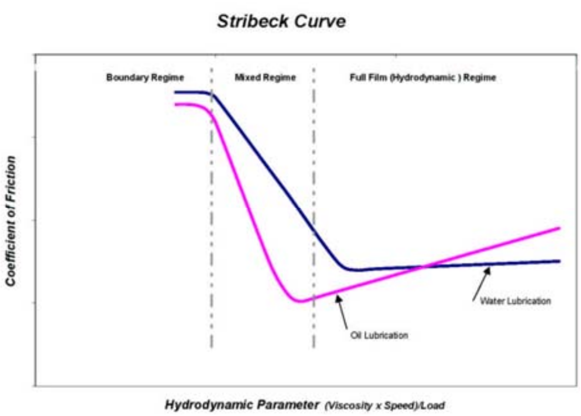

Figure 4: Hydrodynamic Film Development

The bearings are designed such that minimum operational shaft speed – Dead Slow or CPP idle is comfortably in the stabilized hydrodynamic region.

A further advantage of the polymer bearing is its self-lubricating properties. When starting and stopping, the shaft speed is less than the hydrodynamic threshold as it transits to/from zero and sliding contact with the bearing does occur. The low coefficient of friction of the polymer bearing minimizes start up torque and friction levels during these transient periods.

The polymer bearing is typically designed with an interference to its housing or carrier and is easily fitted by first chilling in dry-ice or liquid nitrogen. Mechanical anti-rotation, usually a key is fitted as insurance against rotation of the bearing.

9.2 BEARING REMOVAL WITH SHAFT IN PLACE

Traditional water lubricated designs use bearing shells fitted into split bronze carriers – the split bronze carrier is removed to access the bearing.
The polymer bearing is available with a tapered keyset design to facilitate bearing removal for inspection or replacement without removing the bronze carrier or shaft.

The bearing is split axially into shells. On one side the shells butt against each other and on the other side is fitted the tapered keyset. The keyset is comprised of two parts mating on a taper so when assembled the bearing shells are compressed and interferenced in the housing.

To remove the bearing, the retaining rings are removed and the top removable section of the keyset is extracted, relaxing the interference hoop stress in the bearing.

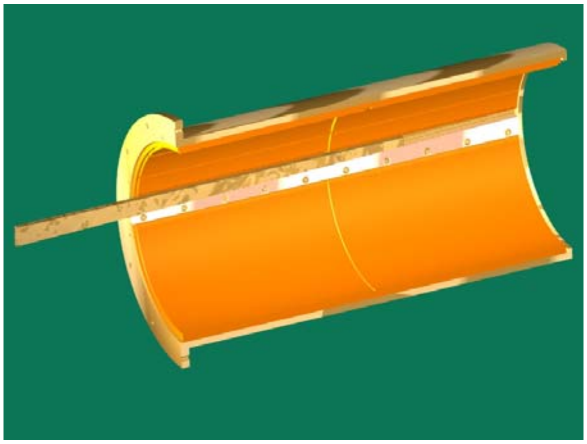

Figure 5: Extraction of single tapered keyset of water lubricated bearing in bronze carrier

With the interference relaxed, the bearing is free in the housing. The top bearing shell is removed, the shaft then lifted off the lower section of the bearing and the bottom shell then removed.

Removal of the forward seal or propeller typically provides the axial space required for bearing removal, however a strut bearing can be designed for removal forwards so even the propeller can stay in place.

For re-installation the bearing removal process is reversed.

Figure 6: Single tapered keyset allows for easy removal, inspection and re-install in a matter of hours without shaft withdrawal

Since only the polymer shells are removed, the heavy lifting equipment needed for removal of split bronze carriers is not required. This simplicity of bearing removal allows significant savings in time, manpower and equipment.
From experience the expected time to remove, inspect and re-install a polymer bearing for a 615mm (24") shaft is 6 man hours.

9.3 COOLING

The polymer bearings require water flow for cooling and the standard requirement is a minimum of 0.15 litres per minute per mm (1 U.S. gal. per minute per inch) of shaft diameter. It is recommended to use a dedicated independent pump for constant water supply at all shaft speeds and a flow sensor should activate an alarm in event of low flow. Water above 40°C (104°F) should be avoided and it is recommended that water supplied to the bearing(s) should come direct from the sea, not preheated from cooling other equipment.
For open strut bearings, water flow is induced by the motion of the vessel relative to the water and there needs to be sufficient openings at the forward and aft ends of the strut to not only allow, but to encourage sufficient water flow through the bearing.

9.4 WATER QUALITY PACKAGE

An important consideration in the wear life performance of any bearing system is the quality of the lubrication in which the bearing operates – in this case, the supplied seawater. Removal of abrasive particles significantly extends the wear life of the bearing and polymer bearing experience indicates that filtration to less than 200μm, or preferably 100μm, can extend bearing life to beyond 15 or even 20 years.

Figure 7: Water Quality Package

A Water Quality Package includes a pump, cyclonic separator, automation and a flow sensor/alarm as a "plug-n-play" unit. The separators are rated to remove particles greater than 80μm with specific density greater than 1.2. The collected debris is automatically purged overboard on a timed basis.
The package can be supplied in double configuration to meet UMS requirements.

9.5 SHAFT LINERS AND SHAFT CORROSION PROTECTION

Polymer shaft bearings operate successfully with all traditional shaft liner materials – Gunmetal being most common although stainless steel has been used, while performance of Inconel625 has been exemplary which somewhat offsets its cost premium.

Traditionally, shafts have been wrapped with fiberglass tape and epoxy against corrosion however such is vulnerable to mechanical damage and even prone to develop cracks during service.

Figure 8: Epoxy shaft coating

A toughened, modified epoxy coating was developed and offered to the market in 2006. It is applied to the exposed steel areas of the shaft between the liners to protect against corrosion. Seawater cannot wick under the coating along the shaft and localised areas of mechanical damage can be spot-repaired.

9.6 FORWARD SEAL

There are numerous water lubricated seals commercially available. Only one is needed – at the machinery space/sterntube interface.

10. OPERATIONAL AND PERFORMANCE BENEFITS

Using modern polymer bearing materials, new shaft coatings and a water quality package, bearing reliability and life expectancy is today in line with a sealed oil system. Historical wear measurements taken from large ships installed with seawater lubricated propeller shaft bearings in the late 1990's show that projected bearing life is approaching 20 years.

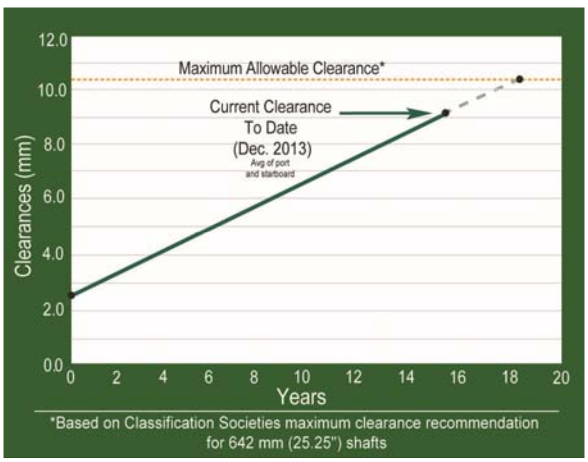

Figure 9: Seawater lubricated bearing wear life chart for *Grand Princess* cruise ship – 12 vessels in Class

After 15 years of operation on these ships, no bearings have been replaced due to wear, no shafts have been withdrawn and zero sterntube oil has been lost to the oceans and seas.

Little maintenance is required for seawater lubricated bearing systems, costs associated with the purchase, storage, sampling and disposal of oil are eliminated.

Studies show that the life cycle costs with water based systems are lower since any increased expense at installation is recovered through the minimal costs of operation – not even considering any fines or fees associated with discharge clean-up.

Bearing failure mode is non-catastrophic compared to babbit bearings. Even with bearings overheated or in distress, the vessel can typically return to port without consequential shaft damage.
Emergency repairs to aft seals vulnerable to encounters with fishing media are eradicated as there is no aft seal.

Recently, both Lloyds Register (LR) and Bureau Veritas (BV) have modified their Rules such that Extended Shaft Withdrawal intervals now also apply to seawater lubricated propeller shaft systems. Shaft withdrawal frequency is now on par with oil systems and removes a major economic obstacle that ship owners had with water-based propeller shaft bearing systems.

11. CONCLUSION

Modern materials, bearing design and control of operating conditions now mean performance, reliability and longevity of water systems similar to oil.

Savings are considerable on operating costs – no charges associated with sterntube oil nor aft seal repairs.

The elastomer bearings are lubricated with seawater – a free and truly non-polluting EAL

Seawater lubricated elastomer bearing systems are installed in over 600 commercial vessels with zero risk of oil pollution from their sterntube systems – these shipowners have prevented millions of litres of sterntube oil being lost annually to our oceans.

These bearing systems are proven successful in some of the world's largest ice breakers;

- *50 Let Pobedy*, a Russian nuclear-powered icebreaker regularly travels the Northern Sea Route in the Russian Arctic.
- US Coast Guard vessels *Polar Sea* and *Polar Star*, have been using seawater lubricated propeller shaft bearings since 1993.
- Canadian Coast Guard vessels *Terry Fox, Des Groseilliers* and *Amundsen*, regularly operate in the Canadian Arctic.

Use of water lubricated bearing systems ensures any vessel sterntube system full compliance with the upcoming IMO Polar Code.

Water lubricated sterntube systems truly mean "***zero discharge into the sea of oil or oily mixtures".***

Figure 10: Statements from U.S. and Canadian Coast Guard sources.

12. REFERENCES

[1] Canadian Standing Senate Committee on Fisheries and Oceans, 2009.
[2] IMO Polar Code, effective January 2017.
[3] Environmental Research Consulting, New York, USA, 2010.
[4] Det Norske Veritas, Norway, 2010.
[5] Marine Engineers Review, April 2009.
[6] Environmental Protection Agency, USA, 2013.

13. AUTHORS BIOGRAPHY

Ken Ogle holds the position of Director of Engineering at Thordon Bearings Inc. He started sea-going career as Engineer Cadet in 1977 and attained Chief Engineers License at age 26. After 17 years with the P&O group, returned ashore to study for a B.Eng in Mechanical Engineering (1st Class Hons) at Southbank University, London UK. Senior Surveyor within the Technical Investigation Department of Lloyds Register, then Engineering Manager with Railko before joining Thordon Bearings in 2001.

Craig D. Carter holds the position of Director of Marketing and Customer Service at Thordon Bearings Inc., a manufacturer of a complete range of environmentally friendly propeller shaft, rudder and shaftline products for the global marine market. He has been involved in the promotion of non-polluting bearings for the marine, clean power generation and offshore industries since 1996. He has been actively working with ship owners, government and special interest groups to provide cost effective solutions to reduce operational discharges from ships.

Prior to Thordon Bearings, he was involved with international marketing at Acadian Seaplants Ltd., a manufacturer of seaweed plant biostimulants, natural fertilizers and edible seaweeds based in Dartmouth, Nova Scotia. Born and raised in Newfoundland, Canada, Mr. Carter holds a Bachelor of Commerce from Saint Mary's University and an MBA from Dalhousie University, Halifax.