

Our **FUTURE** *Our* **OCEAN**

**Environmental & Commercial Benefits of
SEAWATER LUBRICATED PROPELLER SHAFTS**

A White Paper Published by Thordon Bearings Inc.

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INTRODUCTION

Oil lubricated propeller shafts – is there a problem?

- ◆ Oil lubricated systems increase maintenance costs for ship owners
- ◆ 60 million litres of operational oil is discharged annually from oil lubricated propeller shafts
- ◆ Operational oil leakage is currently considered normal operational practice
- ◆ Lubricating oil is an expensive pollutant that damages the environment
- ◆ Operational oil leakage is strongly regulated in US waters
- ◆ Oil based EALs have unproven performance and may not biodegrade in Polar environments

Despite the introduction of legislation to reduce shipping's impact on the oceans, together with shipowners' ever-present need to reduce operational costs; it is quite staggering that over 95% of all new commercial ships continue to be built with oil lubricated propeller shafts – a system that is not only operationally expensive but environmentally questionable.

While the low capital expenditure of this technology is an obvious attraction to shipyards and shipowners, this financial advantage is lost on operation. Firstly, the aft seal of an oil lubricated propeller shaft system is inherently prone to failure, resulting in a number of ships having to pay for drydock or in situ emergency repairs and seal replacements. And although it is difficult to put a definitive figure on the total number of vessels affected, regular reports in the international maritime press of commercial vessels undergoing propeller shaft seal repair is indicative of the scale of the problem.¹ Keeping an oil lubricated system in good order means high operating costs spent on aft seal maintenance and replenishing the lubricant.

Indeed, according to a Lloyd's Register Classification Society report: "Defect statistics over the last 20 years indicate that the aft stern bush represents 10% of all 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."²

While the repeated failure of this component is an obvious boon for ship repair yards and underwater hull maintenance companies, for the shipowner such unscheduled and unbudgeted drydocking fees and maintenance, along with any financial loss from vessel downtime and potential fines including financial impact on reputation, can render any savings gained from the initial expenditure of an oil lubricated propeller shaft as immaterial. An additional operating expense that shipowners need to budget for when selecting an oil lubricated propeller shaft bearing system is the amount of oil required to carry onboard to replenish the system as oil discharges occur.

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“Water-lubricated stern tube bearings improves environmental credentials and eliminates the costs associated with an oil system and associated equipment.”

– John McMillan, Beltship Management Ltd. (Monaco)

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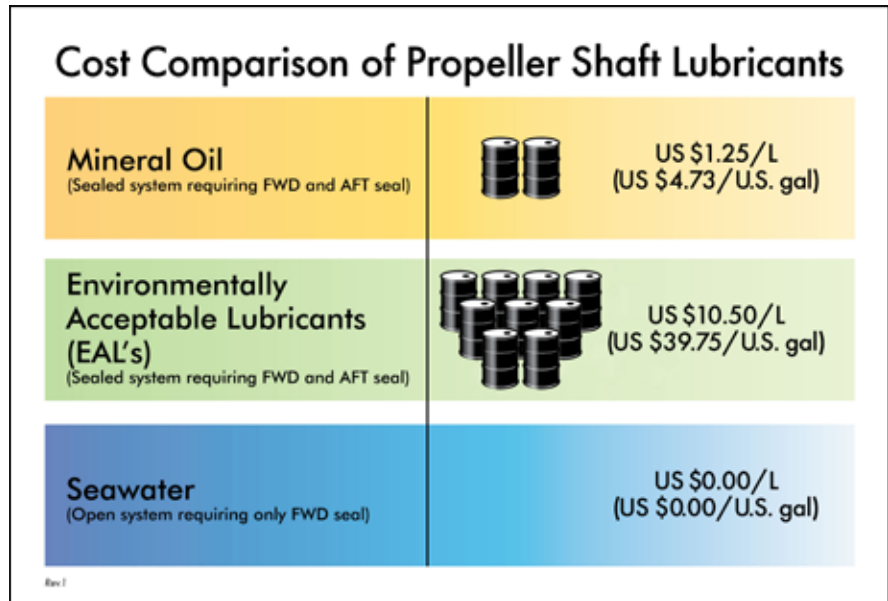
INTRODUCTION

A typical ‘sealed’ oil system, where the bearings supporting the shaft are mounted inside a hollow tube sealed with a lip type seal at each end, is filled with about 1500 litres (396 U.S. gallons) of mineral or synthetic oil. But rather than being considered a closed system, as it is designed to be, lubricating oil is commonly viewed as a consumable, with some shipowners accepting propeller shaft seal oil leakage as “normal operational consumption” and acceptable practice.

In the past, some Classification Societies provided Type Approvals that listed oil discharge rates of between 6 to 12 litre (1.6 to 3.2 U.S. gallons) per day³, which adds up to a colossal 244 million litres (64.5 U.S. gallons) of operational oil being discharged by commercial ships annually. That is equivalent to about five Exxon Valdez events every year. In 1989, the tanker spilled 41.6 million litres (11 million U.S. gallons) of oil into the Alaskan environment.

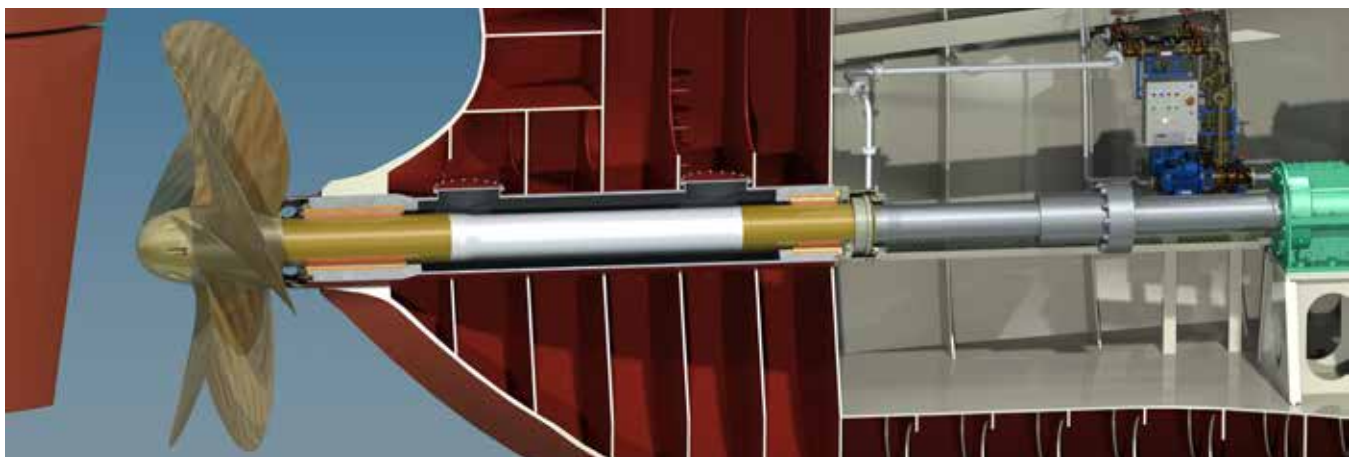
Aside from the environmental impact of this currently “legal and acceptable practice”, which will be covered further in this paper, the cost of constantly topping up an oil lubricated system combined with the regularity of aft seal failure is estimated to cost the shipping industry

in excess of US\$6.5 billion over a twenty-five-year period. Such needless expenses can be completely negated or re-invested in the purchase and installation of, say, a couple of ballast water treatment systems or, indeed, a new asset for the ship owner.



The intention of this White Paper is not only to raise awareness of the commercial disadvantages and environmental damage created from the continued use of oil lubricated propeller shaft bearing systems, but also to offer a more cost-effective and more environmentally acceptable solution:

**AN OPEN SEAWATER LUBRICATED
PROPELLER SHAFT BEARING ARRANGEMENT.**



THE ENVIRONMENTALLY ACCEPTABLE LUBRICANT (EAL)

- ◆ Oil-based EALs are relatively new and as yet, long-term performance is unproven
- ◆ EALs and sealing materials need to be compatible in order to control leakage
- ◆ A seal upgrade or replacement may be necessary when converting to or switching EALs
- ◆ EALs do not stop operational oil leakage so still impact the environment and marine life
- ◆ All oil and EAL discharges need to be reported to the US Coast Guard under U.S. VGP regulations
- ◆ All operational oil leakage is easily preventable

With more than 90% of world trade carried by about 50,000 ocean-going ships of 1000dwt or more, the threat of oil pollution is a real and growing international concern. However, in the past ten years, there has been a seismic shift in attitudes towards our environment and in some parts of the world, stricter legislation is intended to reduce the impact of shipping on the marine environment.

Legislation is now in force to reduce ship-to-air and ship-to-sea emissions, yet while the discharge of, say, oily bilge waters has been heavily regulated, operational oil leakage remains 'legal', despite some 244 million litres (64.5 million U.S. gallons) of oil being discharged annually from ships operating oil lubricated propeller shaft systems.⁴ It is widely believed that this type of pollution will also fall under the regulatory gavel. A prime mover in reducing the impact of operational oil on the marine environment was the U.S Environmental Protection Agency, which in 2013 mandated that all vessels trading in U.S waters use an environmentally acceptable lubricant (EAL) in all oil-to-sea interfaces. However, as many seal manufacturers attest, it is not a case of simply replacing mineral oil with an oil-based EAL.

While compliant with revised Vessel General Permit (VGP) rules, a major concern is that not all oil-based EALs are compatible with traditional propeller shaft seals. Some EALs can be used based upon the seal supplier's recommendation, but it is often the case that shipowners need to upgrade the sealing rings or the seal itself. And if an alternative seal is required, then third party certification is recommended to determine oil-tight integrity which, of course, further adds to the cost of an oil lubricated propeller shaft system.

Seawater is a free EAL!

U.S. VGP 2013, Section 2.2.9

EPA recommends that all new build vessel operators endeavor to use seawater-based systems for their stern tube lubrication to eliminate the discharge of oil from these interfaces to the aquatic environment.

THE ENVIRONMENTALLY ACCEPTABLE LUBRICANT

Another concern is that oil-based EALs absorb a major amount of water, which can place the longevity of the EAL into question. It could also affect the performance of system components, resulting in greater wear and tear due to corrosion. A question raised by one shipowner was “if an equipment [seal] manufacturer indicates that the working life of a conventional seal is reduced when used with EALs, is it possible to use a non-EAL lubricant based on technical infeasibility?” The EPA says no.⁵

“Some EALs can react negatively with stern tube seal lips which could lead to costly dry-docking, affecting the profitability of the vessel.”

- Marin Matana, Vice-President, Atlantska Plovidba (Croatia)

From an environmental perspective, the effect of these new EALs on marine life and birds must be considered the same as mineral oil-based lubricants in that their chemical composition can be toxic, with a viscosity that coats the feathers and fur of marine life causing hypothermia and death.⁶

What’s more, the use of an EAL in a conventional oil lubricated propeller shaft system is not a cure-all to meeting corporate social responsibility goals, since the system’s aft seal – the only barrier between the oil and the sea – can be damaged allowing lubricant discharges, if rope or fishing line wraps around the rotating shaft or if the propeller itself is affected by ice impact or grounding.

Not only can major seal damage cause the entire shaft lubricating oil (whether mineral or vegetable) to leak and pollute, but seawater ingress can corrode the shaft and bearings. Seawater dilutes the lubricant, reduces the viscosity and may cause damage to the bearing and possibly the shaft. It could also result in civil or criminal lawsuits being issued for unlawful pollution and an increase in insurance premiums.

It was reported in Britannia P&I Club’s RiskWatch⁷ magazine that Brazil’s Federal Prosecution Office is now treating even the slightest oil spill as seriously as larger pollution incidents, with the Club warning that “small spills do not necessarily correspond to small [insurance] claims”.

In the article, Brazilian law firm Siano & Martins Advogados Associados advised shipowners to treat even a small spill with care, since ‘contamination of habitats or organisms’ can result in civil lawsuits and significant punitive damages. Britannia also reported that there could be no time limit on civil public actions due to the long-term effects of oil pollution on the environment.

THE SEAWATER LUBRICATED PROPELLER SHAFT

- ◆ Use of seawater lubrication dates back to 1843
- ◆ The original bearing was *Lignum Vitae* - a very dense oily wood noted for its strength
- ◆ Seawater lubricated systems are less complicated and time consuming
- ◆ Zero pollution equals no criminal penalties or fines from illegal oil leaks
- ◆ Potential fuel savings can be achieved

To prevent oil pollution, reduce ship operational costs, and to simplify installation and maintenance procedures, shipowners can now adopt an alternative oil/EAL-free shaft bearing lubricating system that uses seawater as the lubricating medium. The technology, common place in ships prior to the introduction of oil lubricated systems in the 1950s, uses seawater pumped through non-metallic polymer bearings before discharge back into the sea.

Today's modern seawater lubricated propeller shaft bearing system consists of:

- ◆ Non-metallic polymer alloy bearings
- ◆ Shaft corrosion protection system
- ◆ Water quality package
- ◆ Forward shaft seal (there is no aft seal)
- ◆ Bearing condition monitoring system (optional)

NON-METALLIC BEARINGS

Non-metallic bearings are at the heart of the award-winning⁸ seawater lubricated propeller shaft bearing system. The polymer alloy bearing is homogeneous (there are no layers of differing materials) with properties that are consistent throughout the wall thickness. The polymer alloy bearing is also highly abrasion resistant and designed with no grooves in the bottom half of the bearing to reduce running friction and improve low speed hydrodynamic film development. And although start-up friction is initially higher than an oil system, at rated shaft speeds, viscous friction acting on the rotating shaft is lower with seawater than with oil. This has been shown to lead to fuel savings⁹ and thus reduced emissions. A key benefit of the seawater system is that it negates the need for a damage-prone aft seal, while new developments in forward seals provides a level of system redundancy up to this time unknown with seawater lubricated bearing systems.



“We chose the propeller shaft bearings for this vessel because these bearings are environmentally friendly, water lubricated and come with no risk of pollution.”

- Captain Simon Merritt,
Technical Manager, Carisbrooke Shipping Ltd. (U.K.)

THE SEAWATER LUBRICATED PROPELLER SHAFT

SHAFT CORROSION PROTECTION



A key difference between the oil and seawater lubricated system is that the latter technology requires a means to protect the propeller shaft against seawater corrosion. Fortunately, shaft coating technologies have significantly improved since the early days of water lubricated bearings. And today, two-part polymer coatings have been developed to keep the propeller shaft corrosion free. Typically, bronze liners, Inconel™ or welded cladding are used in way of the bearings.

New developments of shaft coatings for seawater lubricated propeller shafts prevent completely the cracking of shaft coatings and subsequent saltwater corrosion. A homogenous shaft coating offers a much higher level of corrosion protection and is three to nine times more flexible than traditional wrapped propeller shaft coatings. The effectiveness of the coating system was confirmed in extensive tests subjected to a harsh 180 degree bend. It failed to crack. The development in new shaft coatings was a major factor in the decision by Classification Societies to extend shaft withdrawal periods of seawater lubricated propeller shafts making them technically equivalent to oil lubricated propeller shafts.

Corrosion protection may mean higher up-front costs than an oil lubricated system but the elimination of the aft seal and associated maintenance, together with the obsolescence of oil/EAL and the requisite storage, sampling and disposal, these costs are recouped with a three to five year return on investment.

WATER QUALITY PACKAGE

The quality of the seawater supplied to the shaft bearings is critical in ensuring long predictable bearing wear life. With this in mind, a self-contained supply, conditioning and monitoring package is available to ensure that clean water is consistently delivered to both the forward seal and the bearings.

Designed for full integration into the ship's control and monitoring systems, the Water Quality Package uses centrifugal forces to remove particulate from the water stream. Suspended solids with a specific gravity of 1.2 or higher and greater than 100µm are removed.

The system also incorporates a flow alarm to alert the operator of low water flow. The Water Quality Package supplies seawater to the propeller shaft bearings for lubrication and cooling at a minimum flow rate of 0.15 litres/minute/mm (1 USGPM/inch) of shaft diameter. This conditioning and monitoring package controls the bearing environment similar to an oil lubricated system.



THE SEAWATER LUBRICATED PROPELLER SHAFT



FORWARD SEAL

In a seawater lubricated system, there is only one seal, to prevent seawater from entering the engine room. New forward seals are designed for a maintenance free life meaning that they are able to provide no visible or minimum leakage, long life and high operational reliability. Seal faces of silicon carbide are intended to last the life of the vessel. If there is a face failure, a Safe Return to Port Emergency Seal can be engaged. The seal is not meant to be completely water tight, but unlike other “maintenance seals”, the shaft can be rotated and the vessel can proceed to a repair facility on its own power, at 50% of shaft rpm.



BEARING CONDITION MONITORING SYSTEM (OPTIONAL)

In an open seawater lubricated system, Class rules may require a bearing monitoring system that enables real time observation of propeller shaft bearing behaviour by measuring the displacement of the shaft position in time due to bearing wear, and comparing it with the initial value at installation. The measured data is then displayed on the Control Panel located remotely in the vessel’s engine room or bridge.



“It is a challenge to identify opportunities that assist ship owners in meeting environmental standards cost-effectively and that don’t end up creating new environmental problems. The seawater lubricated propeller shaft bearing system meets this challenge and it is for that reason – and the system’s simplicity – that we were able to present Thordon Bearings with the Tanker Shipping & Trade Environmental Award.”

– Dr Karen Purnell
(Managing Director of the International Tanker Owners Pollution Federation (ITOPF))



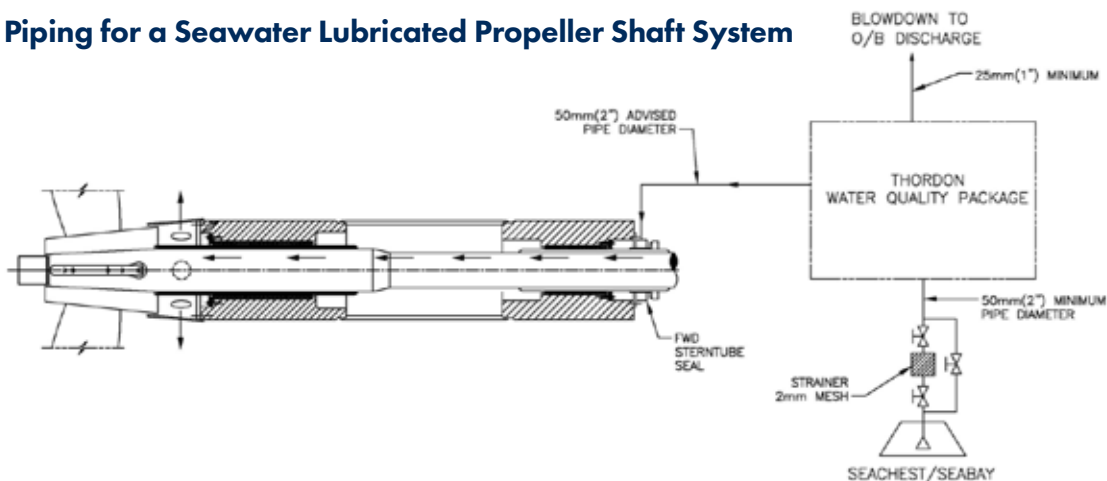
SEAWATER LUBRICATED PROPELLER SHAFT INSTALLATION SIMPLICITY

- ◆ Fewer components - only one shaft seal (there is no aft seal)
- ◆ No header tank
- ◆ Typically 8-10 less pipe runs
- ◆ No controlled air equipment required on certain ships with water lubrications
- ◆ Less wiring compared to installing an air seal with an oil lubricated system
- ◆ Heat sink surrounding the sterntube is not required on certain ships

There has been substantial growth in the newbuild and retrofit market for seawater lubricated propeller shaft bearings, with references on more than 2000 vessels, ranging from cruiseships, tankers and containerships to naval vessels and workboats. Yet still the vast majority of the global commercial fleet continues to operate with older technology that is costly to maintain and operate and detrimental to the environment and corporate reputations.

One of the primary reasons for the industry's slow adoption lies, unfortunately, with the shipbuilder. While shipowners drive any equipment decision, shipbuilders' unfamiliarity with the technology is placing a premium on the newbuild or retrofit cost of a seawater lubricated alternative. In fact, when shipowners have inquired about it, many have been discouraged by the shipbuilders unfamiliarity of a new open seawater lubricated propeller shaft system that ultimately is less complex and time-consuming to install than the oil-based system. The industry will need to provide further education to the shipyards that building a ship with seawater lubricated propeller shafts actually takes less time to build and has fewer components than a ship with an oil lubricated system.

Typical Piping for a Seawater Lubricated Propeller Shaft System



“Nature is pleased with simplicity. And nature is no dummy”

– Isaac Newton



ENVIRONMENTAL & COMMERCIAL BENEFITS

- ◆ No oil expenditures (acquisition, storage & disposal costs)
- ◆ Eliminates aft seal repair and emergency drydocking costs
- ◆ Zero pollution - stops environmental fines and penalties
- ◆ Installation costs recouped
- ◆ Bearing wear-life guarantee for newbuilds

While seawater lubricated propeller shaft bearings have a long history in the shipping industry, the problems associated with traditional seawater lubricated bearings had created a barrier to the wider adoption of seawater lubricated systems, despite the development of new bearing materials, shaft coatings and water conditioning technologies.

Today, a seawater lubricated propeller shaft bearing system offers considerable advantages to shipowners and shipbuilders, not only in bearing wear life predictability and reliability, but they are also much cheaper to maintain and operate.

The equipment cost to build a new ship with an open seawater lubricated bearing system is typically 15-20% higher than an oil lubricated system. The higher cost is related to the corrosion protection of the shaft and stern tube. Shaft liners are typically an expensive part of a shipowner’s decision to use a

seawater lubricated system at the newbuild stage. Bronze liners are used in way of the bearings although welded cladding and Inconel™ have also been used.

To operate a seawater lubricated bearing system, there is no oil/EAL replenishment required; no AFT seal lip replacement; no AFT liner adjustments, machining or replacement; no oil sampling, processing or record keeping; and no oil or oily water disposal. The concerns of oil discharges and any pollution risk are eliminated. The water lubricated shaft line is a simple solution and not complicated by the oil system’s compressed air multi-lip seal system with different storage tanks for offshore disposal of oil.

The higher up-front costs are recouped, as the maintenance costs to operate a seawater lubricated bearing system are much lower than an oil system along with being compliant with all pollution regulations such as the U.S. Vessel General Permit (VGP).

Typical Ship Life Cycle Cost Comparison

Bulk Carrier (650mm shaft diameter)	Seawater Lubricated Propeller Shaft Bearing System	Oil Lubricated White Metal Propeller Shaft Bearing System
Cost of Acquisition (Bearings & Related Shaft Line Equipment) & Installation	\$240,000	\$205,875
Cost of Ownership (25 years)	\$130,000	\$400,050
Total	\$370,000 + Zero Pollution to our Seas	\$605,925

ENVIRONMENTAL & COMMERCIAL BENEFITS



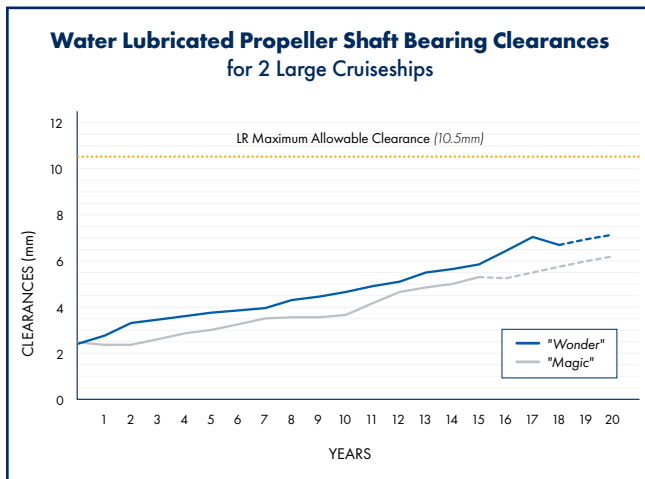
No Oil Leakage - Zero Pollution Risk

A seawater lubricated propeller shaft bearing system eliminates oil, as the lubricant is seawater. There is no aft seal, no storage of oil, no sampling of oil, no disposal of oil or costly EALs and no worry of seawater ingress contaminating the oil.



No Expensive Seal Repairs

A seawater lubricated shaft bearing system eliminates expensive aft seal repairs resulting from a damaged aft seal. Emergency seal repairs can cost anywhere from US\$150,000 to US\$300,000 or may even require a drydocking.



Controlled Bearing Environment

Advances in seawater lubricated shaft bearing technology have resulted in an adequate supply of clean water consistently delivered to both the forward seal and the propeller shaft bearings. A controlled supply of clean water allows long predictable bearing wear life that is guaranteed for 15 years.



Future Compliance

A seawater lubricated propeller shaft bearing system meets current and anticipated environmental requirements. It is more economical to adopt the technology at the newbuild stage rather than having to convert your vessel mid-life when more stringent regulations enter into force.

ENVIRONMENTAL & COMMERCIAL BENEFITS

Shaft Withdrawal Periods

Most Class Societies consider a seawater lubricated propeller shaft bearing system to be technically equivalent to an oil lubricated system. Based on monitoring criteria, shaft withdrawal periods for seawater lubricated systems can now be extended similar to oil lubricated systems.

Survivability

If a serious bearing failure occurs with a white metal or reinforced plastic bearing, significant heat is often produced and there can be damage to the shaft as well as the bearing. A seawater lubricated polymer bearing softens at a lower temperature than metallic or other non-metallic bearing materials, excessive amounts of heat are not produced in failure mode and shaft damage is avoided.

Proven Operational Performance

Current ship owners using seawater lubricated propeller shaft bearing systems include:

- Princess Cruises (USA)
- BP Shipping (UK)
- Groupe Desgagnés (Canada)
- Carisbrooke Shipping (UK)
- Seacor Marine (USA)
- ConocoPhillips (USA)
- CSL Group (Canada)
- COSCO (China)
- NY Staten Island Ferries (USA)
- Tropical Shipping (USA)
- BC Ferries (Canada)
- Lomar Shipping (UK)
- Grimaldi Group (Italy)
- Viking Cruise Lines (UK)
- Alaskan Ferries (USA)
- Polsteam (Poland)
- Erik Thun Group (Sweden)
- Algoma Corp. (Canada)
- Blue Star Ferries (Greece)
- + Over 40 Navies worldwide

Globally Supported

In-house design and engineering support is available for seawater lubricated propeller shafts systems with a global after-sales service capable of providing on-site installation and technical support wherever it is required.

Classification Society Approvals

- ABS (American Bureau of Shipping)
- BKI (Bureau Klasifikasi Indonesia)
- BV (Bureau Veritas)
- CCS (China Classification Society)
- CRS (Croatian Register of Shipping)
- DNV GL
- IRS (Indian Register of Shipping)
- KRS (Korean Register of Shipping)
- LR (Lloyd's Register)
- ClassNK
- RINA (Registro Italiano Navale)
- RRS (Russian Register of Shipping)



CONCLUSION

The shipping industry is returning to seawater lubricated systems for a number of commercial, technical and sustainable reasons. The performance of open seawater lubricated propeller shaft bearing systems to date has been comparable to a closed oil lubricated white metal bearing system. Ships trading in the world's oceans and seas can now eliminate propeller shaft operational and accidental lubricating oil pollution while reducing ship owner maintenance costs and saving money over the service life of the ship. With current and future regulations citing that the vessel must not discharge oil from any oil-to-sea interface that may be harmful to aquatic life, vessel operators can be totally compliant by using a seawater lubricated propeller shaft system. Today, an open seawater lubricated propeller shaft system offers considerable advantages to ship owners, not only in bearing wear life predictability and reliability, but they are also cheaper to maintain, easier to install and are future compliant. And this sustainable shipping solution eliminates another source of pollution from the world's oceans and seas.

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