The Challenge of Stern Tube Bearings and Seals
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In recent times, there has been a change of emphasis from lowest first cost to sustainable solutions, with environmental impact being high on the agenda. Risk reduction is now also one of the main drivers and is linked closely to Environmental legislation. Trends are changing in marine propulsion equipment specification. This paper discusses the drivers, the solutions, current status and future predictions of these trends within the stern tube bearing and seal business.

INTRODUCTION

As a starting point the basic function of stern tube equipment is presented along with the current possible environmental impact and sustainable options. The main influences on change are discussed, as are the benefits of using a sustainable offering. Lastly, the current status and a future prediction of the direction in which sustainable equipment offerings will take are expressed.

The Function of the Stern Tube Equipment

The relative mechanical stresses in the propeller shaft are typically 95% Torsional, 5% Bending and minimal compressive (Filcek 2014). The function of the propeller shaft is to Transfer torque from the prime mover (usually an engine but could be an electric motor or turbine) to the propeller. This torque when transmitted to the ship’s propeller produces a thrust which is transferred through the propeller shaft to the ship’s structure, via a thrust bearing, in order to propel the ship through the water. Due to the scales of the equipment, on larger ships particularly, another important function of the propeller shaft is to support the mass of the propeller which can be considerable.

Bearings

A stern tube bearing supports the weight of the propeller and shaft, which can be considerable for a large vessel; it also reacts upon the loads caused by the eccentricity in the centre of thrust of the propeller. Bearings are designed to operate hydrodynamically to maximise wear life and minimise friction. The propeller shaft or shaft journal rotate within the bearing with a typical “rule of thumb” clearance of between 0.001 to 0.0015 mm per mm of shaft diameter for an oil lubricated white metal bearing. Similar operational clearances are applied for water lubricated bearings, however an additional clearance is applied at installation to account for swell (DPM-01 2015). For satisfactory operation and life it is essential that the bearings are correctly aligned to the shaft. As a general rule a bearing is required to be aligned to the shaft to within 0.3 milli radians (0.3mm / 1000mm) (Lloyds Rules 2012), a value of 0.6 milli radians can result in edge loading and failure of a highly loaded bearing. The load bearing capacity of a bearing is usually defined as a pressure. The rated maximum load can be found by dividing the pressure by the projected area of the bearing. Oil lubricated plain bearings (white metal) have a typical load carrying capacity of 8 Bar whilst water lubricated plain bearings have a typical load carrying capacity of 6 Bar.

Stern Tube Seals

A stern tube seal is an essential component of a stern tube bearing arrangement. It is designed to prevent the leakage of lubricating oil or water from the propulsion system into the water in which the vessel is operating. Stern tube seals are typically made from a combination of materials such as rubber and metal to provide a good seal while also being able to handle the pressures and temperatures encountered in marine applications. They are designed to be resistant to wear and corrosion, and to maintain their sealing ability over the life of the vessel.

An example of a propeller shaft

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The relative mechanical stresses in the propeller shaft are typically 95% Torsional, 5% Bending and minimal compressive (Filcek 2014).
The sealing arrangement between the stern tube and the propeller shaft has an important role to play and has to function efficiently and reliably under arduous and sometimes changing conditions. The Forward seal prevents stern tube lubricant entering vessel and, most importantly, the Aft seal prevents stern tube lubricant entering the Sea water but also prevents Sea water entering stern tube.

**Oil Lubricated Stern Tubes**

![Typical Oil Lubricated Stern Tube Arrangement](image)

Most vessels sailing today employ an oil lubricated stern shaft bearing arrangement. The oil pressure in the stern tube is applied by a static gravity or header tank. Sometimes the oil is circulated, cooled and cleaned to further aid the lubrication efficiency and bearing life. In the majority of these installations the system is such that the oil pressure is greater than the sea water draft pressure, the header tank being positioned above the water line. The aim of such a system being to protect the bearings at the expense of oil loss to the environment.

**Environmental Impact**

In a simple oil lubricated stern tube system like the one described above, oil will inevitably be lost to the sea, as, to an extent, “all shaft seals leak”. This is the case because, in order to function satisfactorily and give a long operational life a seal must operate with a fluid film between the static and dynamic sealing surfaces. Some of this lubricating fluid will be pushed out into the sea.

**Annual Oil Losses into the Marine Environment (Based on NRC 2003)**

The chart above shows the annual oil loss distribution into the marine environment. Although the lubrication loss is not the greatest source it is significant and is easily detected from an operational vessel.

When considering large commercial ships greater than 1000 DWT, 90% are oil lubricated, which equates to approximately 80,000 ships worldwide. As stated above to an extent “all seals leak” and the amount of operational leakage is dependent on many factors such as the age of the seals, the bearing condition, vibration and shaft movement and many more but leakage of up to 3 litres/day may not be unusual. It would be a huge supposition to conclude that every one of these vessels leaks oil into the sea by this magnitude but if this was so then if operating for 330 days per year each, then the total oil volume entering the environment would be

\[ 80,000 \times 3 \times 330 = \text{Up to 80 million litres/year} \]

By comparison the Exxon Valdez oil spill which occurred in the Prince William Sound, Alaska, on March 24, 1989, was 41.6 million litres (IMO 2008). Clearly equipment specification which knowingly contributes to putting the equivalent of nearly two Exxon Valdez oil spills per year into our Oceans is not sustainable.

**Sustainable Equipment Options**

There are three strategies to eliminate harmful stern tube leakage to the sea, these are:

1. To remove the oil from the system - NO oil - NO oil leak!
2. To reduce the impact of leaking oil into the environment
3. To stop operational oil loss to the environment whilst maintaining the use of mineral oil lubrication

These strategies lead to these three equipment option respectively:

1. Employ a Water lubricated system
2. Use of an EAL (Environmentally acceptable lubricant) in place of the mineral oil
3. Fit an anti-pollution seal system with any oil type

A water lubricated stern tube bearing system is by far the most attractive of the above options should the main consideration be ultimate environmental protection. With no oil in the system there is zero chance of oil escaping into the sea. Typically the installation would include composite bearings, corrosion and wear resistant shaft liners (journals) and a shaft protection...
coating - unless a fully stainless steel shaft is utilised (only feasible for small vessels), stern tube corrosion protection and a water lubricated inboard seal. No outboard seal is required. In addition to this an operator may choose to fit a water quality system to the flushing water supply in order to ensure optimum wear life for the bearings.

Water Lubricated Composite Bearing and Housing

Water Lubricated Inboard Seal  Water Quality System

EAL Filled Stern Tube

By using an EAL (environmentally acceptable lubricant) to lubricate the stern tube bearings in place of a traditional mineral oil, the environmental risk is reduced considerably. On the face of it, this is a simple solution to adopt. However, careful selection of a lubricant which is compatible with both the stern tube bearings and seals is essential for long and trouble free life. Particular attention needs to be given to that of seal elastomer compatibility as the EALs can be aggressive to many of the elastomers traditionally used in stern tube seals. Invariably, to get a reasonably long life, the seal elastomers and in some cases the seal need to be changed for items specifically developed for use with these lubricants. A typical seal is shown below.

A Shaft Seal Fitted with a Bio Seal Ring

It is always advisable to check with the seal provider to ensure that a specific EAL is approved for use with the chosen or fitted seal.

Anti-Pollution Seal Systems

There are two basic types of anti-pollution seal system, the Air Seal and the Void Space Seal. Both these sealing solutions may operate on mineral oil lubricated stern tubes whilst maintaining an oil free environment under normal operating conditions.

With the Air Seal the system creates a pressurised air barrier between the oil and water, any oil leakage is collected inboard in the drain collection unit, hence avoiding pollution to the sea. The single biggest factor in lip seal life is load i.e. pressure differential. The system controls the pressure in all cavities thus creating the optimum running conditions for the lip seals; this ensures a long seal life.

The void space seal incorporates a simple drained and vented space between the oil and water seals, this is connected inboard to a collection tank which means that no oil pollution to the sea is possible. The robust outboard seal design with hard faces gives long life between overhauls even in “dirty” water conditions, whilst the rubber lip seals keeping the oil in the stern tube can operate in an optimum condition – sealing only low pressure oil.

Classification of Environmentally Sustainable Solutions

The table below shows how various environmental solutions may be categorised.
As a basis for the positioning on this scale, the risk to the environment of each type of solution is considered. The use of an EAL in a conventional bearing sealing system does satisfy the requirement of preventing mineral oil escaping into the sea but these lubricants are only considered to be “acceptable” and because of this I have put this solution at the bottom of the scale.

Providing the mineral oil is separated from the sea (no direct oil to water interface) then it can be continued to be used but again some risk of leakage may still exist under fault conditions outside of normal operation. For this reason it is essential that proper and regular maintenance is undertaken and that only the best quality, preferably OEM, spare parts and labour are used when overhaul is necessary. The combined use of an anti-pollution outboard seal with an EAL is a more risk averse solution as in the unfortunate event of a serious fault which results in lubricant leakage, the environmental impact is only that of a conventional seal with an oil to water interface running on the same EAL.

An option not discussed in detail here but never the less used in some special applications is to replace the Mineral oil with fresh water, a sort of “super EAL” solution. This would require water lubricated bearings, shaft journals, shaft and stern tube corrosion protection, as well as outboard and inboard seals suitable for the water lubrication. Treatment of the water may be necessary to maintain its condition but it should be noted that any additives will have a direct interface with the sea and should be selected with this in mind.

As stated previously the sea water lubricated stern tube is by far the most attractive solution for environmental protection and as such is at the top of this hierarchical table.

<table>
<thead>
<tr>
<th>Enviro Solution Level</th>
<th>Aft Seal Configuration</th>
<th>Lubrication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enviro 1</td>
<td>No Aft Seal</td>
<td>Sea Water</td>
</tr>
<tr>
<td>Enviro 2</td>
<td>Conventional Seal</td>
<td>Fresh Water</td>
</tr>
<tr>
<td>Enviro 3</td>
<td>Anti-Pollution Seal - No Oil Water interface seal</td>
<td>EAL</td>
</tr>
<tr>
<td>Enviro 4</td>
<td>Anti-Pollution Seal - No Oil Water interface seal</td>
<td>Mineral Oil</td>
</tr>
<tr>
<td>Enviro 5</td>
<td>Conventional Seal - Oil Water interface seal</td>
<td>EAL</td>
</tr>
</tbody>
</table>

What Drives Change?

In terms of stern tube lubrication and seals and bearings there are many factors which influence change and the rate of change towards more sustainable solutions. Here are three aspects which I consider to be most influential and so I will discuss them here:

1. People who want to do the right thing
2. Economics
3. Legislation

People Who Want To Do The Right Thing

Firstly, the “good guys”, those who believe it is their duty to do the right thing and protect the environment. Well, that may not be such a silly concept when tied in with corporate image and loss of face if an environmental issue is caused. Certainly, a cruise ship company operating in the Norwegian Fjords would not benefit from the adverse publicity that a major oil leak would generate. In this case ships with “Green” solutions could indeed be a selling point to the customers travelling on such vessels.

Economics

Economics are high on the list of considerations when selecting a stern tube arrangement. As can be seen on the diagram below, with the extra equipment that is needed for the installation of a sea water lubricated system as opposed to an oil lubricated one. It certainly is unlikely that a saving will occur on initial installation of a water lubricated system. Indeed, it is likely that despite the lack of requirement for an outboard seal the cost for the sea water lubricated system is likely to be far in excess of that of the oil lubricated alternative. Some through life savings may be gleaned as no oil is required to be bought, transported, stored and ultimately disposed of. The cost of lubricants, oil or especially an EAL, can be considerable throughout the life of a vessel. It is true that in many cases there is a requirement from Classification Societies to have the shaft withdrawn and inspected at more regular intervals on the sea water lubricated vessels, but with increased use and data gathering including the application of CM (Condition Monitoring) and advanced inspection techniques it is hoped that the constraint of such extra intervention may be alleviated.

Water Lube:
- Inboard Seal
- Bearing housings
- Bearings
- Journals
- Shaft Coating
- Water Conditioning System

Oil Lube:
- Inboard Seal
- Outboard Seal
- Bearings
- Oil System

Balance of Costs Oil Lubrication Vs Water Lubrication
The cost when things go wrong should also be considered seriously as an influence on future equipment selection. Broadly labelled as “Risk Reduction” the costs can be enormous and vastly outweigh the original extra costs for equipment and installation of a “less risk prone” solution.

<table>
<thead>
<tr>
<th>Cause of system failure</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward Bearing</td>
<td>4%</td>
</tr>
<tr>
<td>Aft Bearing</td>
<td>10%</td>
</tr>
<tr>
<td>Forward Seal</td>
<td>24%</td>
</tr>
<tr>
<td>Aft Seal</td>
<td>43%</td>
</tr>
</tbody>
</table>

Lloyds Statistics for Seal and Bearing Failure Distribution

It can be seen from the above table that the vulnerable aft seal is most at risk in a conventional stern tube system. A damaged aft seal will let water enter the stern tube, as the water content in the oil increases the load carrying capacity of the oil is reduced until the point at which the bearing no longer operates hydrodynamically and bearing failure results. In a recent example, a cruise vessel had a rope entangled in the aft seal causing it to leak water into the stern tube, an underwater repair was offered, however not ordered, 6 weeks later the aft bearing failed costing an estimated £30 Million. With a sea water lubricated stern tube arrangement there is no aft seal and so much less risk from rope damage.

Examples of Rope Entanglement, Damage and Consequential Oil Leakage

With any stern tube system with an outboard seal fitted it is important to exercise economic sustainability and underwater repair the aft seal “in Water” with the vessel afloat. Putting the appropriate action in place in a timely manner is a way of mitigating extra costs. This becomes economic when the cost of docking a vessel is greater (Cruise ships, charter vessels) and companies such as Wartsila provide a turnkey repair including divers and a Hyperbaric habitat required to allow bonding of elastomers where needed. This can usually be accomplished in 2 to 4 days at a fraction of the cost of dry docking a large ship.

### Legislation

The latest United States Environmental Protection Agency (EPA) legislation was revised in 2013. This rule, the Vessel General Permit (VGP), calls for the use of “Environmentally Acceptable Lubricants” (EALs) for various marine applications, including any propulsion systems that use oil lubricated seals and bearings where there is a direct oil to sea water interface. Although the VGP, in this respect, is only applicable for larger vessels operating in US waters, Worldwide Environmental legislation with regard to oil pollution is growing stronger and the EU maritime policy specifies the elimination of all vessel discharges into the marine environment by 2020.

As stated earlier here-in, leakages from stern tubes may not be the largest contributor to marine pollution but it is easily monitored and can therefore be punished by Harbour Authorities, vessels can be impounded for polluting, non-compliant vessels can be restricted in where they can operate and may be in breach of charter and at worst there are criminal charges against the operators.

In this way it can clearly be shown that there is a strong link between legislation and cost when risk turns into reality. An example is shown below:
The lowest cost option, ignoring legislation, still remains a mineral oil filled stern tube and these are currently fitted to 90% of ships. However, legislation is here that is changing behaviour but the seemingly simplest option for VGP compliance, i.e. switching over to EALs has not been without problems. As discussed above there are other options available including anti-pollution seals which at this time offer an environmentally sustainable solution but the optimum, and most future proof, is sea water lubrication.

Wärtsilä’s current view of the market, as a supplier of all these solutions, is for sea water lubrication. We have sold many new builds systems in 2014 and it is common place that Enquiries for new build now ask for dual quote (oil and water). There has also been a significant increase in quotes for conversion from oil to water lubrication. When it comes to the easiest compliant solution of switching to an EAL then Wartsila has seen a huge demand for its EAL compatible BIO seals. There has also been an increased interest in the Air and void space seals.

**Future Prediction**

It has been demonstrated here that, directly and indirectly, cost is a significant factor in driving behaviour as regards influencing the choice of sustainable stern tube equipment solutions and that legislation is closely linked to cost and therefore will also continue to drive change.

EALs will replace mineral oils in conventional stern tubes as International legislation aligns with that of the US EPA. Sea water lubrication may become a requirement for vessel operation in particular areas of the world as acceptance of EALs is questioned in particularly sensitive regions. Enabling Technologies will be progressed in order to further reduce the life cycle cost of Water lubrication, these will likely include: Improved condition monitoring for water lubricated systems which working with Classification Societies will allow a reduction in the frequency of dry docking requirements. The development of water lubricated Hydrostatic bearing solutions for higher load bearing capacity and longer life in order to compete on a par with oil lubrication. Improved shaft coatings to further enable the reduced frequency of shaft removal cycles.

**References:**

Lloyds 2012 “Lloyds Regulations for the classification of ships” Part 5 Ch.8 Section 5

Filcek 2014 - Technical Lecture: ‘Main Propulsion Shafting Failures’ by Peter Filcek Lloyds TIB (Retired)

DPM-01 2015 - Wartsila design manual DPM-01

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<table>
<thead>
<tr>
<th>Entry</th>
<th>No AI Seal</th>
<th>Water (Sea)</th>
<th>Compliant</th>
<th>Zero</th>
<th>Zero</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry 2</td>
<td>Anti Pollution</td>
<td>EAL</td>
<td>Compliant</td>
<td>Zero</td>
<td>High</td>
</tr>
<tr>
<td>Entry 3</td>
<td>Anti Pollution</td>
<td>Mineral Oil (MEO)</td>
<td>Compliant</td>
<td>Zero</td>
<td>High</td>
</tr>
<tr>
<td>Entry 5</td>
<td>Conventional</td>
<td>EAL</td>
<td>Compliant</td>
<td>Loss</td>
<td>High</td>
</tr>
</tbody>
</table>

**Table Showing the Various Stern Tube Equipment Solutions and VGP Compliance**

The development and validation of Lower cost bearing journals (possibly hard coated steel) and low cost bearing housings (possibly structural composite) will enable reduced first cost for water lubrication.