IS A WATER-LUBRICATED PROPELLER SHAFT ARRANGEMENT MORE EFFICIENT THAN PODDED PROPULSION?

A Thordon Bearings White Paper

August 2016

THORDON

CONTENTS

INTRODUCTION

In the twenty-five years since the first podded propulsion system was introduced to optimise the ice-breaking performance and manoeuvrability of ice-breakers operating in the far North, the pod has now more than 400 installations on various ship types, including super-yachts, high-speed ferries, oil tankers and offshore vessels and rigs.

It is the cruiseship, however, that provides the pod manufacturers with their greatest market share with over 60% of today's newbuild cruiseships specified with podded propulsion. High manoeuvring capability, low noise and vibration and space-saving characteristics of a podded propulsion system are key benefits claimed by the pod manufacturers.

Yet while there is a significant number of cruise vessels specifying the pod, there are as many cruiseships opting for more traditional seawater-lubricated propeller shaft lines. To date, there are over 30 cruiseships operating with seawater-lubricated propeller shafts. Current seawater-lubricated propeller shaft line orders from Princess, P&O, MSC, Regent Seven Seas, Viking, Seabourn and Oceania show that many operators continue to favour this traditional approach to propulsion, largely because the conventional shafted system is still widely seen as the more cost-effective option with proven reliability, performance and environmental efficiencies.

The aim of this White Paper is to consider both propulsion arrangements in order to stimulate interest for further comparative studies into their performance, cost efficiency, operational and safety characteristics, and to provide shipowners with a better understanding of the two very different arrangements in order to make more informed procurement decisions.

The prop or the pod?

POD EVOLUTION

It was in the late 1990s that the cruise sector adopted the technology, following the successful installation of ABB's first generation Azipod system to *Elation* (pictured), the first cruiseship to be fitted with the technology.

The development resulted in a number of other manufacturers introducing their own pod units to meet a potentially new market, such as Rolls-Royce with its Mermaid system and Wärtsilä's Dolphin. However, it is pod pioneer ABB that continues to dominate the market.

Yet although the technology has evolved over the past twenty-five years, compared to a water-lubricated shaft arrangement in which the propeller is driven directly by an engine or motor, the pod has been prone to failure and since 2002 there has been more than 20 operational problems reported from cruise lines operating podded propulsion systems.

However, before we look at the evolution of the pod, we first have to consider the electric propulsion arrangement, without which the podded drive would not be possible.

Compared to a diesel-mechanical propulsion arrangement and the higher installation costs of up to 15% to 20%, due largely to the additional components, generator sets, motors and automation required, the diesel-electric configuration offers significant advantages over its mechanical cousin and is increasingly specified for specialist vessels, ice-breakers, medium-size product tankers, ferries, cruiseships and offshore vessels having a wide range of operation and/or a high power requirements.

Developments in electric propulsion prompted Finland's ABB to look at alternative methods of propulsion. And while these second generation diesel-electric arrangements featured a propeller shaft connected to a motor (rather than directly to the diesel engine via reduction gears) to drive a controllable pitch propeller, ABB began looking at ways in which the electric motor could be housed in a submerged, rotating pod to drive a fixed pitch propeller.

The original idea was to optimise ice-breaker operations by way of a propulsion motor that could rotate 360 degrees in order to direct thrust in any direction, allowing an ice-breaker to break out of

POD EVOLUTION

existing ice channels. The first vessel to be fitted out with podded propulsion was in 1989, when Kvaerner Masa-yards converted the waterways service vessel *Seili*.

The success of the conversion resulted in the Finnish shipbuilder and ABB agreeing to jointly develop and market the Azipod. The next ships to be converted were the product tankers *Uikku* and *Lunni*, in 1993 and 1994, respectively, but the real breakthrough came in 1998, when Carnival Cruise Lines selected the Azipod for *Elation*, one of eight Fantasy-class vessels.

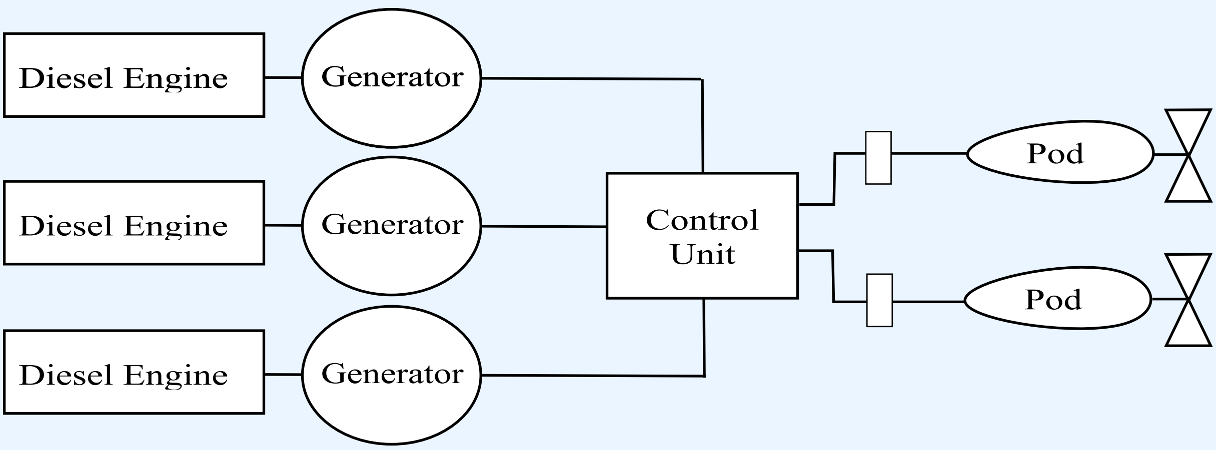
Not to be confused with the azimuthing thruster, which would have its motor inside the ship's hull, the development of an external pod that would house a motor directly coupled to a propeller shaft, was initially focused on ice-breaking vessels. But since *Elation*, cruiseships have been the primary market for podded propulsion, a potentially lucrative market that led to other manufacturers to develop competing products, such as the Rolls-Royce Mermaid.

However, earlier designs were problematic, susceptible to electrical failures, thrust and support bearing failures, shaft seal failures and lubricating oil leakage and consequent seawater contamination. As a consequence, new models were introduced.

Rolls Royce, having addressed the recurrent reliability problems that resulted in lengthy legal battles, introduced the Mermaid ICE and Mermaid HICE, ice-strengthened pods designed for vessels operating in the Arctic.

ABB, meanwhile, instigated a complete redesign programme between 2005 and 2008, resulting in the arrival of a new generation of Azipod propulsion units, including the Azipod XO in 2008. Propeller hub and motor modules were reduced, and reliability and efficiency improved to reduce lifecycle costs by avoiding the need for frequent drydockings.

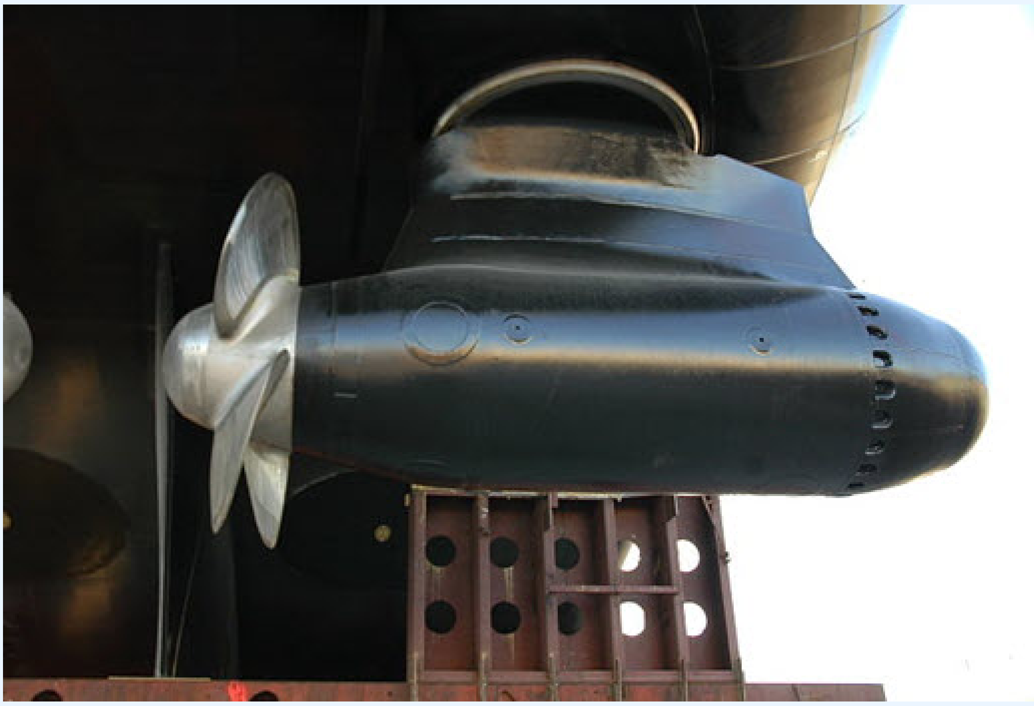
Podded Propulsion in a diesel-electric arrangement



POD EVOLUTION

Then in 2010, the company unveiled the smaller Azipod D, boasting a new air and water cooling system to reduce weight and direct more power toward propulsion. However, reducing lifecycle, maintenance and up-front costs was, again, the primary focus.

With new units designed to counter the problems of the past we can now consider the advantages of the podded propulsion system.



A podded propulsion system

POD ADVANTAGES

Despite the additional costs that a diesel-electric podded arrangement can entail, it is easy to understand why the concept has gained favour within some shipping sectors, particularly the cruise segment.

Compared to shafted vessels in a diesel-electric configuration, those with podded propulsion are cited as having better hydrodynamic performance in regard to propulsion efficiency, manoeuvring, vibration, propeller cavitation, and comfort onboard. This is largely due to the geometry of the hull as rudders, shaft lines, brackets, and other appendages are negated, reducing resistance and flow turbulence.

MANOEUVRABILITY

Manoeuvrability and comfort seem to be the main advantages attracting the offshore vessel and cruiseship sectors to the pod. In addition to the smaller turning circle afforded by a pod arrangement, it is claimed the system offers better reversing capability and steering during astern navigation because the pod(s) can be rotated 360 degrees, negating the requirement for side and bow thrusters.

NOISE

Low noise and vibration are other characteristics of the pod. Since the motor is housed externally, beneath the ship's hull, propeller excitation is cited as very low compared to traditional propeller shafts.

SPACE

Space within the hull otherwise taken by propulsion motors and shaft lines is saved and can reduce shipbuilding and installation time.

EFFICIENCY

ABB says that the hydrodynamic improvements made to the Azipod XO have increased efficiency by 9% compared to the *Elation* installation.

NB: While it is often reported that a podded ship can be 15% more energy efficient than traditional propulsion arrangements, these benefits may relate directly to a diesel-electric configuration, which can also be achieved with a direct-drive shaft arrangement.

POD DISADVANTAGES

While pod manufacturers have developed new systems designed to improve reliability and availability, a number of podded propulsion concerns remain. The higher up front cost is of course a major deterrent, but so too is a current 30MW power limitation. Pods depend on electric propulsion and sufficient speed may not be achieved, while bearing and seal system failures have often resulted in off-hire as emergency drydocking is required.

HULL FORM

Vessels opting for podded propulsion require a modified stern section before the pod can be installed.

POWER LIMITATIONS

Pods currently have a 30MW power limitation and depend on an electric propulsion arrangement. Requisite speed may not be achieved and power losses have occurred due to demand on electric propulsion.

STABILITY

According to research carried out in 2013 by the Foundation for Safety of Navigation and Environment Protection, Lech Kobyliński noted that when the pod units are “turned rapidly to a large angle at high speed, very high transverse forces would be created that may cause large heel angle of the ship endangering its stability and very high loads on pod construction that may cause serious damage to the pod, its bearings, transmission and shaft”.

CRASH STOP

Conventional crash stop with reverse thrust at high speeds is not recommended. Power has to be reduced and pods turned before crash stop can be implemented.

ADDITIONAL TRAINING

Research has indicated “some difficulties” in pod operation that merit “special training for masters and pilots” operating these vessels. The operation of pod-driven ships is not easy and ship masters and sea pilots taken onboard must be fully aware of the limitations otherwise they may cause damage to the propulsion units or to the ship itself.

OIL POLLUTION

The Kobyliński study noted the experience of cruise lines operating high power pod units which revealed some structural problems, particularly with thrust and support bearings and seals, resulting

POD DISADVANTAGES

in leakage, insufficient lubrication and contamination. It is also not possible to guarantee that oil leakage to the ocean will never occur from the seal interface - fishing nets and ropes further add to the risk as they can become caught around the propeller shaft and cause damage to the seals. In addition, external disturbances such as rough seas and vibration are considerable. Despite the introduction of legislation to clean up the seas forcing pod manufacturers to use biodegradable lubricants, operational oil leakage will continue.

RELIABILITY

The pod has been prone to failure and since 2002 there has been more than 20 operational problems reported from cruise lines operating podded propulsion systems, of which the most high-profile relates to the pod problems that affected Cunard's transatlantic liner *Queen Mary 2* (pictured below).

EVOLUTION OF THE WATER-LUBRICATED SHAFT

Prior to 1950, all ships operated with a seawater lubricated propeller shaft bearing system; seawater was used as the lubricant and *lignum vitae* wood was used as the bearing material to support the shaft, while stuffing boxes acted as the seal to prevent seawater from entering the engine room.

Seawater lubricated wooden bearings did not have reliable wear life limits much beyond five years, which meant withdrawing the shaft and replacing the bearings; an expensive task for the shipowner. In addition, most shaft seals of the day were packed stuffing boxes, and these tended to score the bronze shaft liner in way of the packing. That meant skimming or replacement of the packing liner at the same time, which was another additional cost.

In the 1950s, suitable shaft seals were developed to enable oil lubrication with white metal bearings supporting the propeller shaft. The seal technology was widely welcomed; it offered a controlled environment for the bearings, extending shaft withdrawal periods and increasing bearing life spans. The weakness of the system however has always been the effectiveness of the seals, which must leak oil in operation for cooling; seawater leakage into the stern tube causes oil emulsion and often catastrophic bearing failure, while leakage into the sea results in oil pollution. The seal's purpose is twofold: 1) keep oil inside the ship; and 2) prevent seawater from entering the stern tube and contaminating the oil.

Although propeller shaft bearing maintenance was reduced, the two shaft seals required frequent maintenance or oil would leak into the sea or into the ship. Some stern tube seal oil leakage was considered "normal operational consumption" and an acceptable practice. Some Class Societies provided Type Approvals that listed oil discharge rates of between 6 to 12 litres/day.

Shaft seals for oil lubricated propeller shafts have always been a problem for ship owners, noted Andrew Smith, Lloyd's Register Global Technology Leader – Engineering Systems, in a technical paper: "Defect statistics over the last 20 years indicate that the aft stern gland (seal) and forward stern gland (seal) represent 43% and 24% of failures respectively," he claimed.

Nevertheless, oil lubricated propeller shafts soon became the norm, with white metal bearings becoming the standard for shipyards building all types of commercial ships.

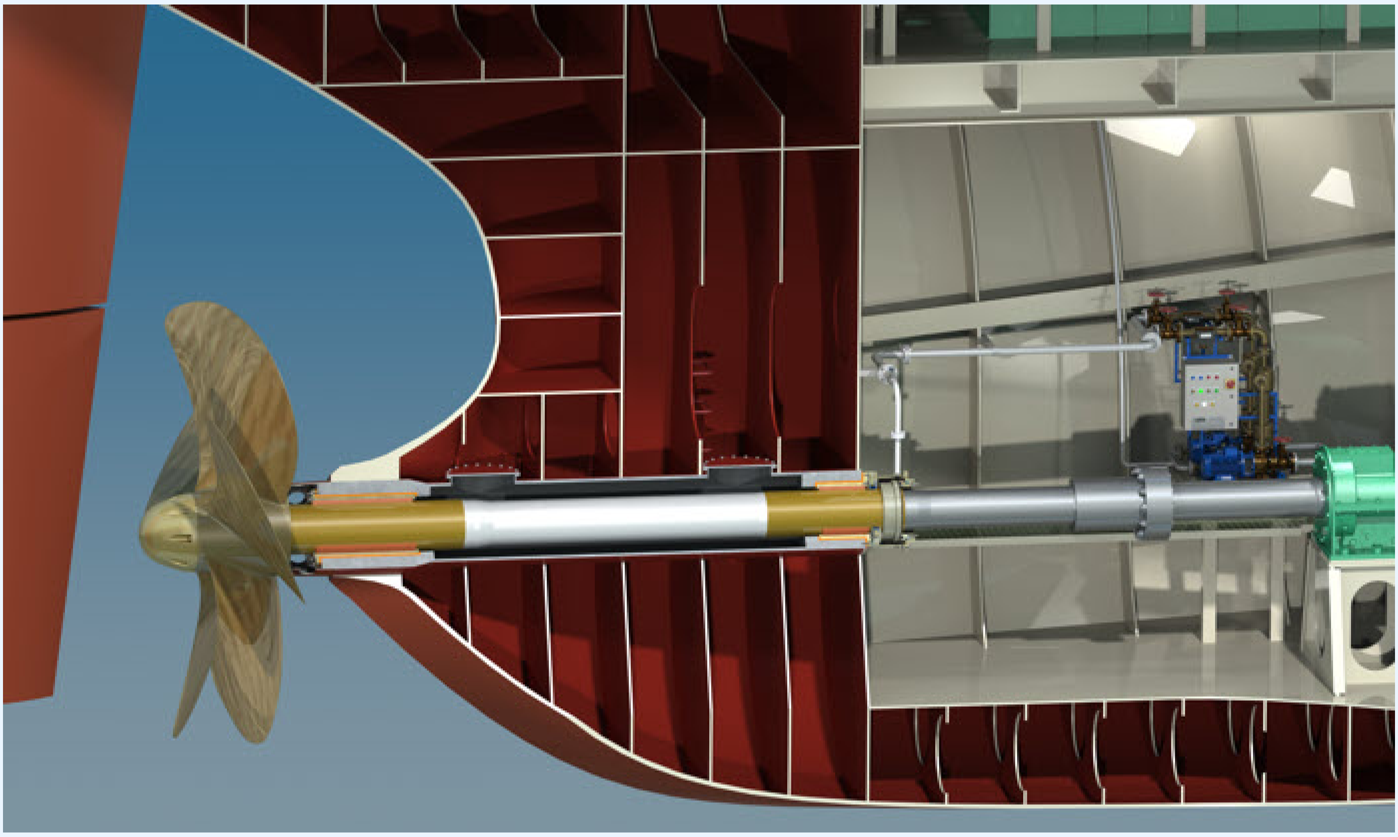
However, seawater lubricated propeller shaft bearings have always been used by most of the world's Navies and Coast Guards for safety reasons and non-catastrophic failure mode. For example, if a naval ship took a torpedo hit and the shaft seals were damaged, use of an oil lubricated system would mean all the oil would leak out and the shaft would seize on the bearings and the ship would be stranded, with no propulsion. With seawater lubricated bearings, they still have propulsion capability.

EVOLUTION OF THE WATER-LUBRICATED SHAFT

Thordon Bearings gained its early experience with seawater lubricated propeller shaft bearings with many of the world's Navies and Coast Guards, starting with a COMPAC propeller shaft bearing order for 12 Canadian Navy frigates in the late 1980s. Since then other commercial ship market sectors are now beginning to favour a traditional arrangement with a seawater lubricated propeller shaft, due in particular part to its well documented environmental credentials and operational cost savings. It is the cruiseship that has continued to provide a large market share.

Cruiseships continue to specify seawater lubricated propeller shaft systems to eliminate the risk of any accidental oil discharges in the environmentally sensitive areas that they operate in, such as the Caribbean, Baltic Sea or Alaska, spurring the development of new bearing designs, shaft coatings and products to ensure the system is equal or better than the oil lubricated bearing system and, indeed, a podded propulsion configuration.

Today, for example, new polymer bearing materials, shaft protection materials and monitoring packages can increase bearing wear life and reduce ship maintenance costs allowing for a controlled environment. The advancements in low-friction polymer bearing technology is the primary factor in increased bearing wear life along with complementary technologies that offer shaft



EVOLUTION OF THE WATER-LUBRICATED SHAFT

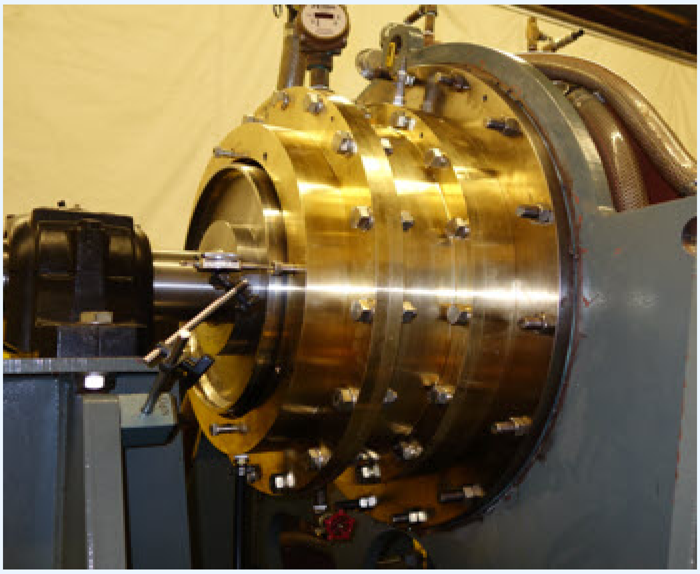
corrosion protection and improved monitoring and inspection techniques all of which meet class rules for extended shaft line docking cycles and reducing operational costs.

Recent bearing wear measurements taken from large cruiseships that were installed with seawater lubricated propeller shaft bearings in 1998 show that bearing life is expected to be 20 years or more.

Traditional propeller shaft corrosion protection coatings have been considered the "Achilles' heel" to the open water system due to their tendency to develop cracks during service operations. Existing marine epoxy systems use fibreglass tape in an attempt to produce a reliable covering. Thordon Bearings however has developed its ThorShield system -– a toughened, modified epoxy coating – to meet extended shaft withdrawals. It is applied to exposed steel areas of the shaft between the liners to eliminate the need for a five-year shaft withdrawal, once the main deterrent to the wider take-up of a water lubricated propeller shaft system. In the event of damage, seawater cannot wick under the ThorShield coating or liner along the shaft.

Seal integrity is another advancement that has been incorporated into Thordon Bearings' COMPAC seawater lubricated propeller shaft system. While the system negates the need for an aft seal - the main component of an oil lubricated system prone to failure - the new SeaThigor seal developed by Thordon Bearings is the only water-lubricated shaft seal on the market that allows the shaft to turn in the event of a primary seal failure. SeaThigor incorporates an emergency "Safe Return to Port' seal and while not meant to be completely water tight, unlike other "maintenance seals", the shaft can be rotated and the vessel can proceed to a repair facility on its own power, at reduced speeds.

Thordon Bearings' Safe-Return-to-Port Intermediate Bearing also has the added advantage of performing equally well in oil, water or indeed any lubricating medium, to provide the operator with real in-service advantages. It is also proven to be much more tolerant to misalignment than a white metal bearing, a potential failure point of traditional shaft lines.



A SeaThigor forward seal provides a 'safe-return-to-port' capability

SEAWATER LUBRICATED PROPELLER SHAFT ADVANTAGES

The developments in seawater-lubricated propeller shaft bearing systems have solved the cardinal problems of the past while providing cost, operational and performance benefits that compare more favourably than both oil lubricated and podded propulsion arrangements. The main advantages are:

LOWER INITIAL COST

The purchase price of a complete seawater lubricated propeller shaft bearing system is typically 1/20th the cost of a podded system. Cruiseships typically have to carry a spare pod in inventory in case of emergency replacement increasing the CAPEX by even more.

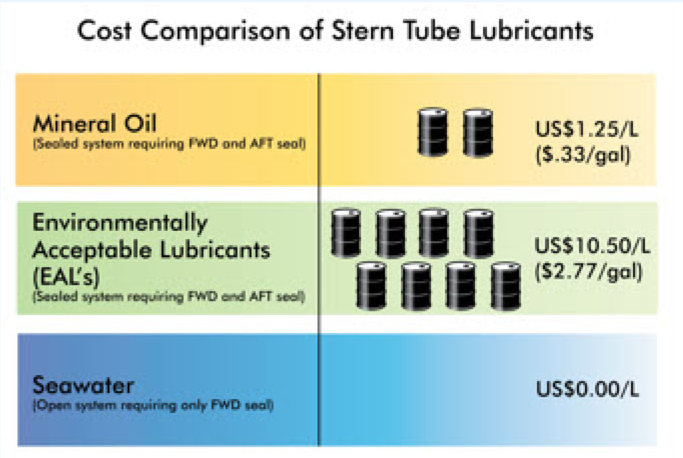
REDUCED OPERATING COSTS

The operating cost of a seawater-lubricated shaft is substantially lower that than the costs associated with a podded propulsion system. A seawater lubricated propeller shaft bearing system offers reduced operating costs as follows:

- **No oil seals to maintain as there are no oil seals;**
- **Elimination of oil or EALs;**
- **No purchase of oil or EALs;No storage of oil;**
- **No disposal of oil;**
- **No labour required to top up oil tanks;No emergency pod seal repairs - no risk of rope/line damage to aft seal;**
- **Maintenance of the water quality package is minimal.**

ZERO POLLUTION RISK

A water-lubricated propeller shaft completely eliminates the risk of pollution from operational oil leaking from a pod, and the environmental penalties associated with this pollution. Ships operating in U.S. waters in particular must be mindful of the regulations set forth by the Environmental Protection Agency of the environmental consequences and operating costs when selecting a lubricating medium. While environmentally acceptable lubricants (EALs) are a viable option, they do have performance limitations and do not necessarily avoid the risk of pollution or the need for upgrade or replacement parts.



In DNV GL's newsletter 12-77, the classification society states that there are different drawbacks in

SEAWATER LUBRICATED PROPELLER SHAFT ADVANTAGES

the way EALs react to the challenges of lubricating machinery. More specifically, biodegradable oils deteriorate when mixed with water, and the inevitable result is that the "lubricating capabilities will be adversely affected".

CONTROLLED BEARING ENVIRONMENT

A complete seawater-lubricated propeller shaft bearing system offers a controlled environment. The COMPAC elastomeric polymer bearings, Thordon Water Quality Package, bearing monitoring system, ThorShield shaft corrosion protection, bronze liners and SeaThigor forward seal, allows for shaft withdrawal periods of 18+ years if certain monitoring conditions are met.

LONG BEARING WEAR LIFE

Based on over 2000 installations to date, a seawater lubricated propeller shaft system will typically have a wear-life of twenty years or more. For example, after 17 years of operation on two twin screw cruiseships, no seawater lubricated bearings have been replaced due to wear, no shafts have been withdrawn and no corrosion issues have occurred.

INSTALLATION SIMPLICITY

Low complexity for shipbuilding and crew operation compared to oil systems and podded propulsion systems. There is only one shaft seal, no header tank is required, reduced pipe work and wiring can reduce install costs.

NOISE & VIBRATION

Low noise and vibration is a key benefit of a podded propulsion system for cruise lines, but with a substantial number of references across the world's navies, where underwater signature is imperative to operations, many seawater-lubricated propeller shaft systems are proven to have low noise and vibration levels.

Thordon's low acoustic signature led to Thordon COMPAC being installed on four of the U.S. NOAA FSV's since 2003, where the vessel specifications featured the most advanced noise suppression technologies in the world. Currently over 40 Navies and Coast Guards use Thordon propeller shaft bearings including German Navy (K130, F125), Italian Navy (FREMM), Swedish Navy (Visby), Argentinean Navy (MEKO), New Zealand and Australian Navy (ANZAC), Dutch Navy (Holland), Brazilian Navy (SSK), Hellenic Navy (MEKO) and U.S. Navy Seawolf submarines.

SURVIVABILITY

Non catastrophic failure mode with seawater lubrication allows vessel to get back to port.

PROP DISADVANTAGES

MANOEUVRABILITY

While the main advantage of a podded propulsion system is the high level of manoeuvrability it affords, a water lubricated propeller shaft system can provide optimum manoeuvring if combined with a twisted leading edge flap rudder design and thrusters.

FUEL EFFICIENCY

Claims that a podded propulsion system is ten per cent more efficient than a propeller shaft arrangement have not been verified by cruiseship owners. However, using a rounded skeg configuration with a seawater-lubricated propeller shaft arrangement can significantly improve fuel efficiency.

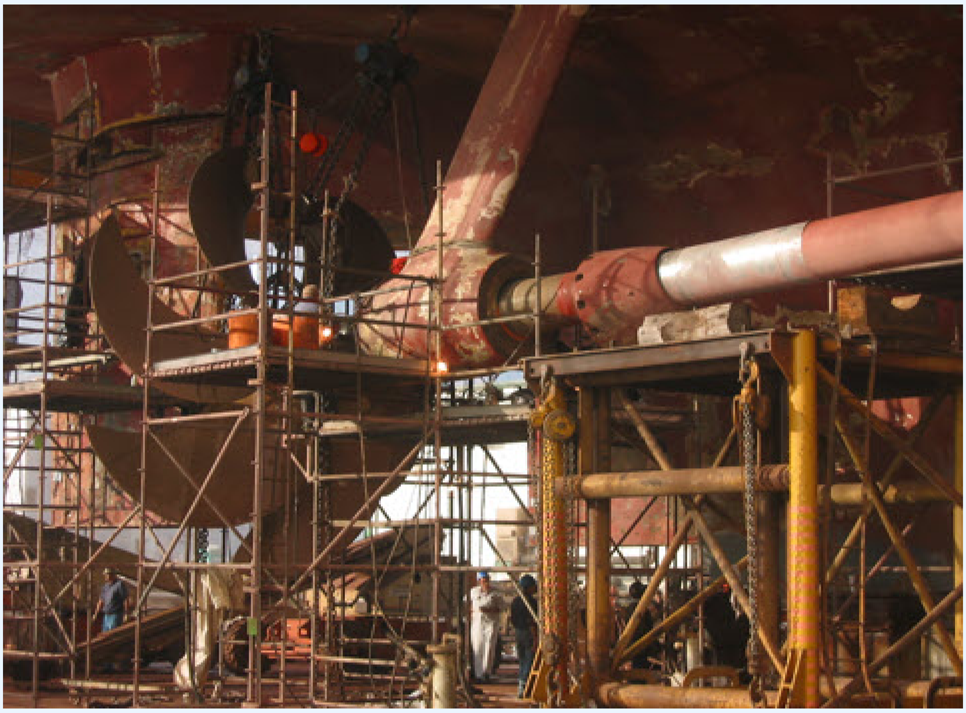
THE CASE FOR THE PROPELLER SHAFT

The first application of pods on a cruise vessel was *Carnival Elation* but the other vessels in the Fantasy Class had diesel electric propulsion with cyclo-converter drives and variable pitch (CPP) propellers on traditional shaft lines. To manage the electrical network on the earlier ships of the class, the propellers operated in constant speed, variable pitch mode, in some conditions, which is very inefficient.

Speaking on the basis of anonymity, a former marine engineering director of a major cruise line, with experience of both shaft and podded propulsion arrangements, told Thordon Bearings that many of the benefits from a podded drive could have been available simply by changing the drive system and fitting fixed pitch propellers to the existing shaft lines.

This arrangement, however, was not considered by cruise lines that selected pods and it is therefore difficult to quantify the true benefit of the podded system. An added complication was that there is an added parasitic load for the pods in terms of the cooling and other auxiliary services and again whether this was taken in to account is unknown.

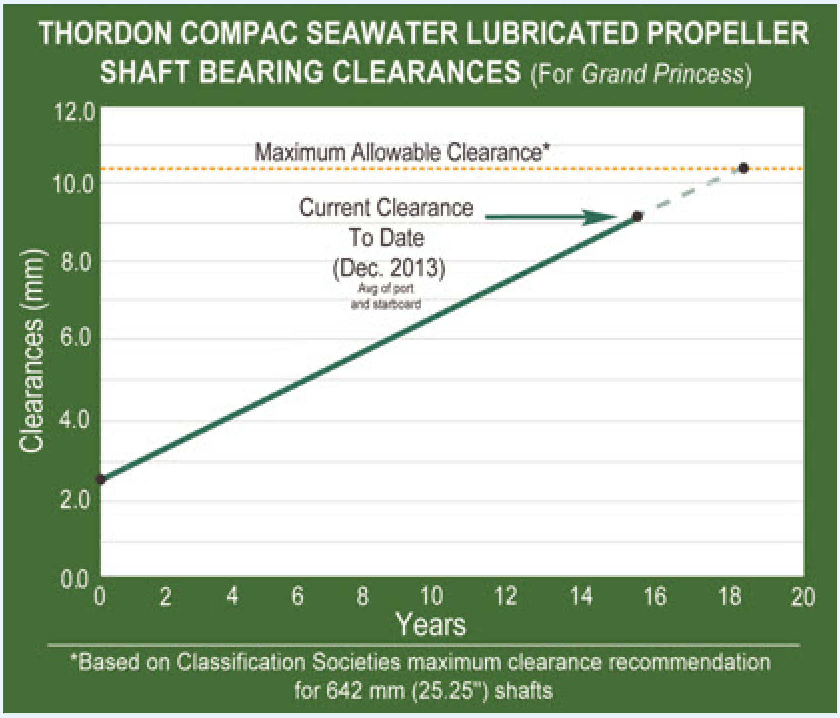
The engineer added: “Having said all this, the argument that the propeller on a twin screw vessel with pods is working in a less disturbed wake field than the propellers attached to a shafting system is compelling. Note that it is a ‘less disturbed’ wake field since clearly the ship’s hull design has an influence on the wake and also the pod body and strut affects the wake around the pod propeller. This is why the pod promotional literature always talks about a ‘slim body’ and a ‘streamlined strut’ etc. However, to achieve this, compromises have to be made in the motor electrical and mechanical design and also in terms of accessibility, all of which have contributed to some issues with podded propulsors.”



A COMPAC water-lubricated propeller shaft

THE CASE FOR THE PROPELLER SHAFT

He furthered that the decision to use a pod is largely a matter of pride. Once a commitment has been made to go for podded drives it is difficult to acknowledge it may not have been the optimum solution in terms of capital cost and the through life costs which are very difficult to obtain.



“I was never able to ascertain with any certainty they are less than those for conventional drive arrangements with shafts,” he said acknowledging that the propulsive efficiency will probably be similar.

One Carnival cruise line has completely avoided the pod, continuing to favour the conventional arrangement. This is largely due to the ambiguities over the claimed increased propulsive efficiency, increased capital costs and the problems of reliability. As far as capital costs are concerned, however, it is up to the major cruiseship builders like Fincantieri and Meyer Werft to actually state that it is cheaper to build a ship with pods than with conventional shaft lines by such and such an amount. They have not done so as yet.

THE RANSE CODES

With regards to fuel consumption, if we estimate that a cruiseship the size of the *Elation* would consume on average 100 tonnes of fuel a day for propulsion, at say $500 per tonne, the 8% to 10% fuel reduction claims by the pod manufacturers are compelling, even if the additional capital cost for a ship with pods was $2 to $3 million.

Yet, if the ship has to be taken out of service then this could cost about $1 million per day so any fuel savings, even if they existed, are quickly eroded.

Additionally, it is thought unlikely that pod manufacturers, whilst willing to replace parts that have failed, will not accept consequential damages, i.e. the cost of taking the ship out of service, compensation to customers, etc.

One major cruise line looked at the cost of normal repair and maintenance at Finnish yards and found that repair costs remained very high. These and the costs of the special tools and the cost of the replacement parts all added to the operating costs of pods.

Other cruise lines have tried to offset this by manufacturing their own tools and training up a lower cost workforce to do most of the work with only one or two supervisors from the manufacturer, but it is still a substantial amount of delicate work to do during any drydock.

While acknowledging the vast improvements made to pod reliability along with a better understanding of how the bearings and other components behave, it has been alleged that at one point Carnival was ready to ditch the whole podded drive concept (especially after the problems with *QM2*) but they were committed to a series of ships with pods and therefore found it difficult to change the specification or design without incurring substantial costs and delays.

“I do not want to denigrate what pod manufacturers have achieved but I have always found it very difficult to obtain reliable information,” an industry source explained.

There are other detractors. In a paper presented to the Royal Institution of Naval Architects in 2007, Fincantieri’s Giampiero Lavini and Lorenzo Pedone, concluded that a passenger ship with a rounded skeg hull shape, twin six blade fixed pitch propeller and a seawater lubricated shaft line, with appendages optimised using computational fluid dynamics, would be comparable to a podded cruiseship. Oil leakage is avoided, while the intermediate bracket provides a stiff shaft configuration that reduces bearing mechanical and thermal stresses, especially during manoeuvring or crash stops.

SEAWATER LUBRICATED PROPELLER SHAFT BEARING CONFIRMATION

In a scenario requiring low fuel consumption, high comfort onboard, low environmental impact and reliability of the propulsive system, the proposed configuration provides a very appealing and economical choice compared to the podded solution," reported the *Naval Architect* journal.

The Ranse Codes application outlined by Fincantieri in the *Naval Architect* report demonstrated that a well designed twin screw vessel with slim shafts and water lubricated bearings would have as a good a propulsive efficiency as a ship with podded propulsors

The authors stated that while conventional shaft configurations are oil lubricated, and located inside the tube case with a diameter larger than the shaft itself, an alternative solution is represented by water lubrication, which offers some consequent benefits.

"First of all the inflow water meets a smaller diameter and so the wake peaks on the propeller plane are reduced. Furthermore, the water through frictional effect is trailed in rotation towards the propeller with a significant benefit for propulsion efficiency (about 2%). The water-lubricated shaft line is practically maintenance free and represents a "green" solution as the risk of oil leakage is avoided."

This was confirmed by the aforementioned marine engineering director, who said Thordon seawater-lubricated propeller shaft system "is a good solution for water lubricated shaft bearings. It has a low coefficient of friction at low shaft speeds so when operating with boundary lubrication there is not too much energy released to damage the material. It is slightly elastic which helps it conform to the shaft shape which is important to allow hydrodynamic lubrication to start at low shaft speeds but it is still strong enough not to deform significantly under load. The maintenance costs are proven and negligible."

Stuart Hawkins, a former newbuilding manager for Princess Cruises and current senior vice president, marine, with Virgin Cruises, is another proponent of the direct-drive arrangement.

Acknowledging that the pod builders have overcome some of the problems encountered with earlier designs, Hawkins said in the February 2015 edition of *Cruise Industry News* that his "personal preference is not for pods. I do not believe they offer significant energy benefits but the manoeuvring is definitely better."

Chris Joly, Principal Manager, Marine Engineering, Carnival Corporation & plc (U.K.), also said: "One anti-pollution measure that has proved its worth is Carnival's choice of Thordon COMPAC water lubricated prop shaft bearings, which are, in my opinion, one of the best investments any operator can make. As well as eliminating pollution risks, they have proven themselves to be so robust, it's likely they will outlast many of the vessels."

PRESS REPORTS

The following press reports indicate that vessels with pod propulsion systems can cost the shipowner in emergency repairs, drydocking, vessel downtime and disgruntled passengers.

“Initially scheduled for December 2015, the drydock operation involving Cunard’s 90,049 grt *Queen Victoria* has been brought forward to enable the line to replace a bearing on one of *Queen Victoria’s* propulsion units. According to Cunard, this has no impact on the safety of the ship but it is ‘timely’ for the bearing to be replaced prior to the ship’s ‘Round World Cruise’ beginning January 20 2015. Angus Struthers, Cunard director: ‘While we are sorry to be cancelling two cruises, we are looking forward to welcoming all those affected back aboard a Cunard ship in the near future...’.” - **Ship Repair Newsletter, Issue No: 1528, 3 October 2014.**

“We’re now reporting of a second cruiseship coming to a halt in a North American harbour due to propulsion issues. Just yesterday *Cruise Hive* reported on the Holland America operated *Maasdam* being stranded in Boston harbour. In this case the ship was the *Celebrity Summit* which is operated by Celebrity Cruises. The ship had not long left the Berth in Bayonne, New Jersey when it came to a halt in New York harbour. According to reports the problem is with the ship’s pod propulsion system and as a result was anchored in a safe position in the harbour. The 91,000gt vessel then moved slowly with the help of tugs back to Cape Liberty, New Jersey so that repairs can be made.” - **Emrys Thakkar, Cruise Hive, 6 July 2015**

“Propulsion pods may be the greatest thing that ever happened to cruiseships. Or maybe the worst, when they don’t work, which is far too often.... The problem is that all of the thrust of the propeller is transmitted to the ship’s hull by the circular bearing that connects the pod to the ship — the bearing that also has to rotate through 360 degrees. These bearings have been failing far more frequently than they should. This is apparently what has happened on at least one of the three pods on the *Allure of the Seas*. Because RCCL detected excessive bearing wear, they initially slowed the ship to reduce the load on the bearing and then decided to take the ship out of service. This is by no means the first time that propulsion pods have knocked cruiseships out of service. In 2000 the *Carnival Paradise* was pulled from service due to failed pods.... Last March, *Carnival Legend* limped into port with pod problems.... Propellers on shafts in front of rudders are looking better and better.” **Rick Spilman, The Old Salt Blog, 20 November 2013**

PRESS REPORTS

"A propulsion problem is preventing *Celebrity Silhouette* from reaching its normal speed, forcing the cruise line to shorten select port calls through much of the fall. The line is not yet sure when the problem will be fixed.... Last year, another Celebrity cruiseship, *Celebrity Millennium*, also had trouble with its propulsion system, resulting in multiple delays, port call cancellations and culminating in the cancellation of the ship's entire Alaska season. In *Millennium's* case, an entire propulsion pod system needed to be replaced. It is unknown whether *Celebrity Silhouette's* propulsion problem is any way similar to what happened on *Millennium*." **Dori Saltzman, Cruise Critic, 12 July 2014**

"Royal Caribbean's *Allure of the Seas*, the [then] world's largest cruiseship, is experiencing a problem with a propulsion unit that is forcing it to operate at slower-than-normal speeds. The mechanical issue with one of the 225,282gt vessel's three propulsion pods has resulted in shortened calls in ports during its past two Eastern Caribbean sailings." **Gene Sloan, USA TODAY, 5 November 2013**

"Passengers aboard NCL's *Norwegian Star* are telling me that the ship's pod system has failed. The cruiseship is skipping Miami today and is heading for Tampa one day early. One passenger said that the next cruise is reportedly cancelled. Another passenger said that he did not know whether the next cruise on Monday is cancelled.... This ship experienced propulsion problems earlier this year which were supposedly fixed while in drydock." **Jim Walker, Cruise Law, 17 October 2015**

"Coast Guard officials have said the damaged pod has been replaced and officials are examining it along with the ship's lifeboats and other safety equipment to see if they meet standards. The ship can safely manoeuvre with one pod... The United States Coast Guard reports that the major storm Royal Caribbean's *Anthem of the Seas* ran into last week damaged part of its propulsion system." - **Royal Caribbeanblog, 12 February 2016.**

Since 1988, when the first Thordon seawater-lubricated propeller shaft bearings were installed to two cruiseships, Thordon has been installed to more than 25 cruiseships. In that time there has been no reported instances of cruiseship downtime or emergency seal repairs to vessels equipped with the seawater-lubricated propeller shaft system. Indeed, many operators are still using the same bearing installed more than twenty years ago.

SUMMARY

Property	Podded Propulsion	Direct Drive
Purchase Price	High purchase cost ($$$$$$$$)	Low purchase cost ($)
Annual Maintenance Costs	Technical concerns related to sophistication of unit. Specialists required ($$$)	Practically maintenance free
Reliability	Over 20 operational problems cited publicly in cruise ships operating with podded propulsion since 2002	No known operational issues
Manoeuvrability	High manoeuvrability	Use of a twisted leading edge flap rudder design and thrusters can increase a vessels manoeuvrability
Oil Pollution Risk	Complicated sealing system - bearing oil seal separated from water seal	Zero
Operator Training	Simulation training required for navigating officers and pilots	No additional training required
Noise and Vibration	Extremely low vibrations	Low vibration and low acoustic signature
Fuel Efficiency	Claimed to have up to 10% better fuel efficiency	Using a rounded skeg configuration can significantly improve efficiency

Despite the advances manufacturers of podded propulsion systems have made to improve hydrodynamic efficiency, reliability and maintainability, cruiseships fitted with pods continue to suffer from system failures, resulting in downtime, emergency repairs and drydocking, all of which add to the high capital and operational costs of installation.

There have also been incidences of total power loss and while this may be due to the loads placed on a diesel-electric configuration rather than the pod itself, it could be cause for concern in terms of passenger safety.

Concerns have also been raised about the handling of ships with propulsive pods in certain manoeuvring conditions, which is different to the handling of a direct-drive vessel. According to research, while the turning ability of a pod driven ship is much improved, as the azimuth unit can rotate 360deg, course keeping ability is known to be worse than for conventional vessels, due to the different flat aft hull form required to accommodate the pods. There are a number of vessel handling limitations the operators need to be aware of, requiring additional training for masters and senior officers.

A conventional seawater-lubricated propeller shaft arrangement on the other hand offers many of the advantages of a podded propulsion system for substantially less capital investment. Moreover, the reliability of conventional arrangement is proven and requires no additional training, while there is no risk of polluting the marine environment.

While much of the research to date has focused on the manoeuvrability and hydrodynamic efficiency benefits of cruiseship with podded propulsion, it is believed that comparative research into the environmental, operational, safety, CAPEX and OPEX differences between podded and direct-drive diesel-electric propulsion configurations is required so that the cruiseship sector in particular can make more informed procurement decisions.

ABOUT THORDON BEARINGS

Canada-based Thordon Bearings is the global leader in seawater lubricated propeller shaft bearing systems with over 35 years' experience developing environmentally-friendly polymer bearing technologies.

Its award-winning COMPAC seawater-lubricated propeller shaft bearing system has proven performance with large commercial cruiseships that have not changed bearings in over 17 years. The system also reduces operating costs for the ship operator, as seawater is free and the system maintenance is minimal.

Italian shipbuilder Fincantieri, a long-time builder of vessels with a direct-drive configuration, has built over 15 cruiseships and super yachts that are equipped with Thordon COMPAC systems, with several more on order.

For further information about this White Paper or seawater-lubricated propeller shaft propulsion arrangements, please contact:

Craig Carter
Director of Marketing & Customer Service
Thordon Bearings' Inc
A Thomson-Gordon Group Company - Innovating since 1911
3225 Mainway
Burlington, ON L7M 1A6
CANADA
www.ThordonBearings.com
Tel: +1.905.335.1440
Email: craigc@thordonbearings.com

THORDON

August 2016