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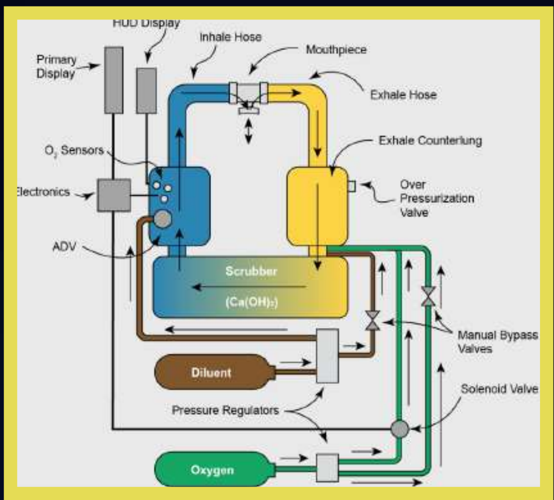

Deep Dive Technologies

The Institute of Marine Engineers (India)

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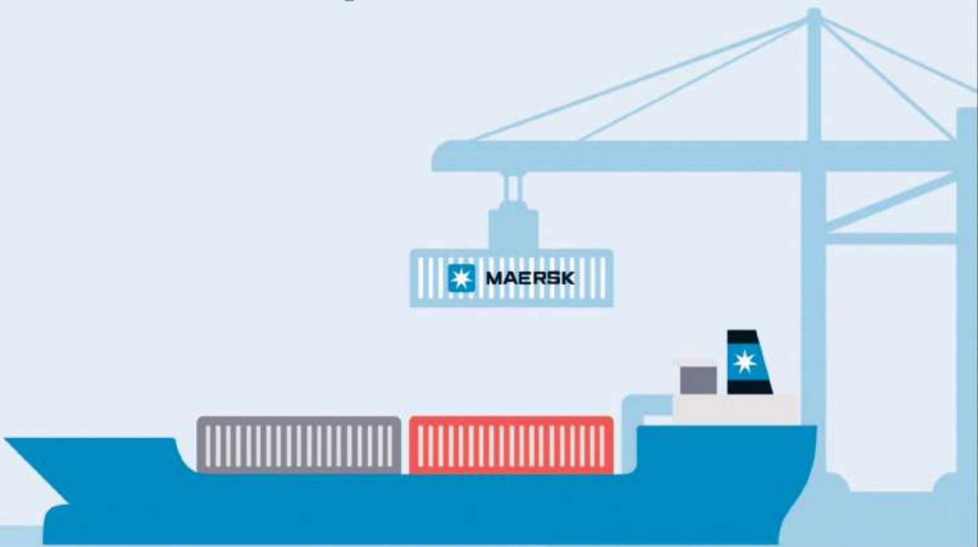
MAERSK

EDITORIAL

If you want to build a ship, don't drum up people to collect wood and don't assign them tasks and work, but rather teach them to long for the endless immensity of the sea.
– Antoine de Saint-Exupery

Maritime news hogged many a media space in the last few weeks. Amongst the packed Agenda of MSDC*, there were congratulatory exchanges on the launch of India Maritime Centre and the deliberations on the India International Maritime Dispute Resolution Centre. The announcements of India Maritime Fund and fillip to shipbuilding (Japan & Korea to help with the clusters) have brought cheer and concerns as well.

A major driver for this ship construction craving stems from the need to have more Indian tonnage, which can lift and carry cargoes for India. A look at the commercial shipbuilding chronicles would help. While the cluster model sounds good, the constituents need to be capable of feeding the building yards. This would require a manufacturing mindset and boosting of the ancillary units. As such Indian yards have issues of getting spares and components due to poor supply chains and connectivity to manufacturing units (can read: **MSMEs). Financial woes come next. The sector has a high percentage of suffering when it comes to settlement delays and cash flow constraints and strained operating budgets. The envisaged Fund is supposed to address this.

An organic way to go about for shipbuilding is to establish a couple of robust design centres and build a repository of design prototypes. Importantly, institutional engagements for developing designs, skill development based on need analyses, portals to store, share knowledge and industry info have to be energised. The ambitious plans make an academia-industry synergy imperative. On shipbuilding, what the aviator-writer, de Saint-Exupery spoke of wooden ships applies to steel ships. And the primary feeling has to be the passion for building crafts for the immense oceans. The panacea for all other age-old debilitating problems haunting the ship building industry could be found in that.

*Maritime State Development Council; **Micro, Small and Medium Enterprises

In this issue...

We begin by diving deep into the ocean depths. Many sailing engineers would have experienced employment of divers for checking damages, welding repairs etc. Divers are often called into regular service at SBMs and offshore platforms for checks on the seabed valves etc. In this article Dr. Veda educates on the deep ocean divers. The risks associated with deep dives and the physical discomfort process are explained also tracing how the equipment were developed to ensure safety of the divers.

Discussing Saturation divers, diving bell architectures, the article describes the Distress Submarines in an interesting way. MER readers would find this educative.

Following this is an analysis of the stands taken by India and China with particular focus on the pollution. Dr. Shantanu Paul threads through the areas requiring attention and resolution as also how China goes about ratifying such international instruments. The discussion on oil spill liability provides some interesting insight. Dr. Paul provides a few directions for India to act in reference to pollution liability and compensation.

Next, we carry another discussion by Prabu Duplex on Predictive Maintenance (PdM) methods. Discussing the demerits of a few methods. Prabu proposes ways for selecting 'suitable candidates' for PdM. The Criticality Classification with 'Clustering' and feasibility approaches makes an interesting reading. The example of ship's propulsion system using the 4-quadrant method puts things in better perspective. The explanations on the logic of 'showstoppers' and the rationale for condition based maintenance makes it a case for ship maintenance managers.

The 'Spanner in the Works' column carries a real engineering, operational problem described and explained by Ramesh Vantaram. MER Archives has a few interesting features and I recommend the discussion on matrix for shipboard management and the letters to the editor (extract inserted).

The Paralympics has brought cheers to our Sports aspirations. Para athletics led the lot (17 in all) of the total 29 (7G+9S+13B). On that high note, here is the October issue for your reading pleasure.

Dr Rajoo Balaji
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MARINE ENGINEERS REVIEW INDIA

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In This Issue

ARTICLES

COLUMNS

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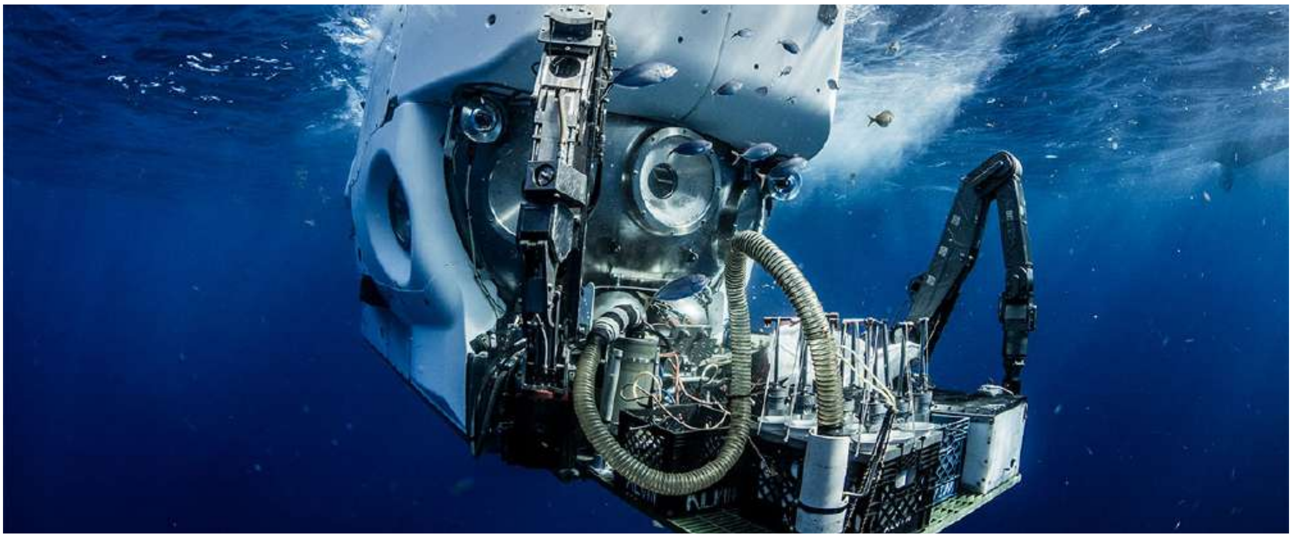
Technological Maturity of Deep-ocean Human Diving Systems – Part A



N. Vedachalam

Introduction

Despite the fact that the ocean covers ~70% of Earth's surface and plays a critical role in supporting life on our planet, from the air we breathe and the food we eat to weather and climate patterns, our understanding of the ocean remains limited. Rigorous ocean observations and documentation of biological, chemical, physical, geological and archaeological aspects allows us, collectively, to protect ocean health, sustainably manage our marine resources, better understand our changing environment, and enhance appreciation of the importance of the ocean in our everyday lives. There are multiple technological challenges in exploring the deep-oceans characterised by high ambient pressure, low temperature, absolute darkness and salinity that prevent access to global positioning systems and radio signals. These hostile environmental conditions make deep-ocean human missions equally or even more complex than space missions. The challenges involved are evident from the fact that only a few have descended to the deepest part of the oceans (~11km deep Mariana Trench) compared to twelve people who have landed on the moon.

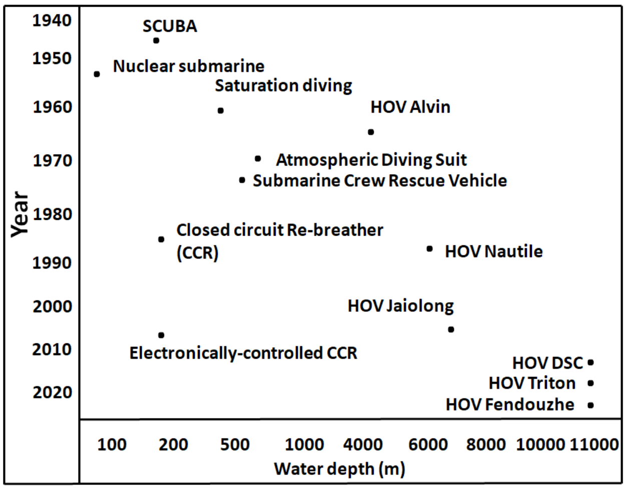
Part A (this part) of the article discusses the significant technological advances since the 1940s hitherto in the areas of underwater breathing systems, saturation diving, and distressed submarine crew rescue vehicles.

The next part (Part B) shall describe the developments in deep-ocean human-occupied scientific submersibles that have made it possible for humans to safely and effectively explore the deep-oceans including its true mysteries, living and non-living resources.

Underwater Breathing Apparatus

The beginning of the technical diving using Self-Contained Underwater Breathing Apparatus (SCUBA) in the mid-1940s changed the way the diving operations that were performed by hard-hat divers using surface-supplied air with decompression status monitored by surface tenders. SCUBA diving (up to 300m water depth) involves suiting-up topside and descending to depth, breathing gas mixture from compressed air tanks, and then returning to the surface, themselves responsible for their own decompression status under-water. Divers experience barotraumas due to pressure changes. Any non-vented gas-containing space in the body (such as thorax, middle ear, sinus, or intestines) is susceptible to barotrauma.

During descent, due to the increase in ambient pressure at depth, there is an increase in the amount of gas that dissolves into the liquid portion of the blood and tissues when divers breathe compressed gas underwater. Metabolically inert gases, particularly nitrogen, are often a component of these gas mixtures and the body does not metabolise these gases. **According to Dalton's law of**



partial pressures, the partial pressures of O_2 and N_2 change with depth for divers breathing air or 100% oxygen. Breathing air under pressure causes nitrogen narcosis that usually starts to become a concern at depths >30m, but its influence differs between divers. At depths >55m, the pO_2 increases the risk of oxygen toxicity, which impacts the central nervous system.

Breathing air under pressure causes nitrogen narcosis that usually starts to become a concern at depths >30m, but its influence differs between divers

When the diver ascents after a long or deep-dive, the inert gases come out of the blood. If the ascent is slow enough, the inert gas diffuses from the tissue into the blood and is filtered out by the lungs. During a rapid ascent (if the ambient pressure is decreased too rapidly) bubbles form within tissues or the vasculature, resulting in **Decompression Sickness (DCS)**. Once bubbles form, they cause mechanical damage to tissues and endothelium, obstructing the blood flow. These bubbles interact with formed elements within the blood resulting in inflammatory and pro-coagulant reactions. To prevent DCS, while returning to the surface after long or deep-dive, **decompression stops** (also known as "the bends") are obligatory at various depths so that the dissolved gases are released slowly from the body tissues so as to restrict the formation and growth of bubbles.

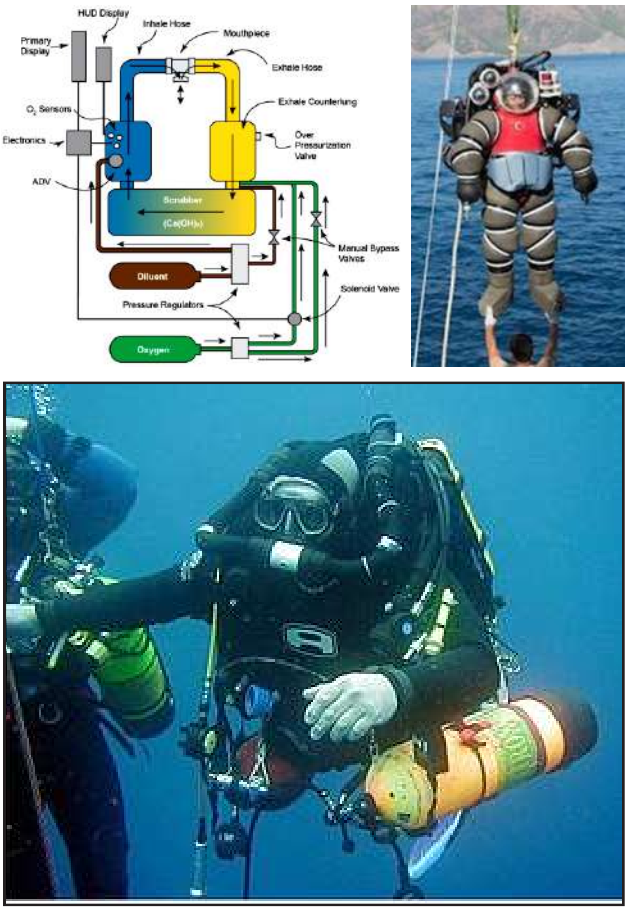


Figure 1. Rebreather (top left), Atmospheric diving suit (top right) and re-breather diver at 163m water depth (bottom).

Decompression penalty is reduced by having divers breathe specialised gas (hypoxic) mixtures at various depths during the decompression phase, such as heliox (He & O_2) and trimix (He, O_2 and N_2 or H_2/Ar). As a result, divers can stay down longer or require less time to decompress. Use of oxygen-enriched breathing gas mixtures and pure oxygen during long-duration decompression increases the rate of inert gas elimination. The uses of these hypoxic breathing gas mixtures lower the level of O_2 in the mix to reduce the danger of oxygen toxicity. Nitrox is a gas mix, while it reduces the maximum allowable depth as compared to air, it also allows greater bottom time by reducing the build-up of N_2 in the diver's tissues by increasing the percentage of O_2 in the breathing gas. By adding helium to the breathing mix, these effects can be reduced, as helium does not have the same narcotic properties at depth.

The advent of Closed-Circuit Re-breathers (CCR) since 1995 enabled deeper dives. CCR processes all or part of each exhaled breath for re-use by removing the CO_2 and replacing the O_2 used by the diver. In a diver-wearable CCB **(Figure 1),** the pO_2 is controlled (<1.6bar), so it can be maintained at a safe continuous maximum, which reduces the inert gas (nitrogen and/or helium) partial pressure in the breathing loop **(Figure 1).**

Minimising the inert gas loading of the diver's tissues for a given dive profile reduces the decompression obligation. This requires continuous monitoring of actual partial pressures with time and for maximum effectiveness requires real-time computer processing by the diver's decompression computer. The gas exhaled is carried via an exhalation hose to a canister containing a chemical absorbent that removes the exhaled CO_2.The gas then travels to a breathing bag, where it is available again to the diver. Metabolically consumed O_2 is then replaced by an O_2 addition system.

The first electronically-controlled CCR specifically intended for sports divers was introduced in 2009. Modern computing devices worn on the wrist by the diver is programmed with decompression model-driven algorithms, derived from mathematical calculations as decompression tables.

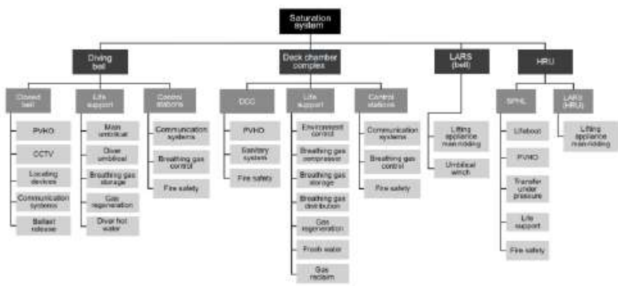


Figure 2. Subsystems of a ship-deployable saturation diving system

A decompression model is a mathematical representation of the kinetics of inert gas exchange in body tissues with rules to preclude ascents that might result in unsafe bubble formation or growth. Because the understanding of decompression physiology is incomplete and as there are differences among individuals, no decompression model is totally effective in preventing DCS. However, with current algorithms the incidence appears to be <1%.

A decompression model is a mathematical representation of the kinetics of inert gas exchange in body tissues with rules to preclude ascents that might result in unsafe bubble formation or growth

In order to enable still deeper diving, the first one-person atmospheric diving suit (ADS) was first commercially developed in 1974 is matured with elaborate pressure joints to allow articulation while maintaining an internal pressure of 1 atm and enables diving up to 700m water depths **(Figure 1).** The occupant of ADS does not need to decompress, and there is no need for special breathing gas mixtures, so there is little danger of DCS. However, it permits less skilled swimmers to complete deep dives, albeit at the expense of dexterity.

Saturation diving

Manned underwater operations still remain the most cost-effective modus of intervention. For instance, hyperbaric welding currently requires human intervention. Saturation diving was developed and first used in the mid-1960s, for commercial diving. The first commercial saturation diving operation was conducted at the Smith Mountain Dam in Virginia in 1965. Relatively shallow saturation diving has been utilised by scientific divers using habitats for underwater living experiments. SEALAB-I was deployed off-Bermuda in 1964 at 58m water depth, and was later followed by SEALAB-2 at 62m water depth off-California. Commercial divers working on deeply submerged facilities (such as oil pumping equipment on the seafloor) need to stay down longer than the very limited time that SCUBA would allow at such depths, and also beyond a certain depth SCUBA becomes far too dangerous for regular commercial applications. To improve both bottom time and safety, saturation divers live and work from sealed pressurised chambers supported by on surface ships. Divers enter the chambers, which are then gradually brought to the pressure the divers will experience at working depth (up to 500m). The term "saturation" refers to the diver's body tissues being saturated with the maximum amount of dissolved gasses possible at that depth.

The subsystems of a ship-deployable saturation diving system **(Figure.2)** include diving bell, Deck Chamber Complex (DCC), Launching and Retrieval System (LARS) and the Hyperbaric Rescue Unit (HRU).

In the ship-based DCC **(Figure.3)** the saturation divers live in a surface chamber known as Deck Decompression Chamber (DDC) at a storage pressure that is shallower than the diver site. When the DDC is on the surface ship, the divers transfer to a Personnel Transfer Capsule (PTC) through a mating hatch in the DDC. The PTC (diving bell) is lowered to the dive site (or required working depth) and the divers exit the diving bell to work. A diver remains on-board the diving bell to monitor the working divers. Once the divers have finished their shift, they re-enter the bell, hoisted back to the surface, and the next shift begins.

Once the tissues become saturated, the time to ascend from depth and to decompress safely will not increase with further exposure, and this enables the divers to live and work at depths for days to weeks. After the work, they rest and live in a dry pressurised habitat on the ocean floor at the same pressure as the working depth. From the operational perspective, the depth at which the diver's tissues become saturated (storage depth) and the vertical range over which the diver can move (excursion depths) are important.

For their ship-based DCC, divers use surface-supplied umbilical diving equipment, utilising breathing gases such as He and O_2 mixtures. The diving bell is fed via a

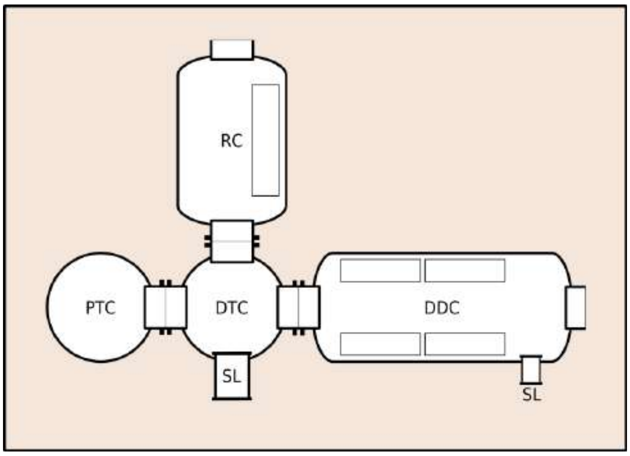


Figure 3. Deck chamber complex and diving bell interfaces

Figure 4. Diving bell launched using ship LARS

large umbilical that supplies breathing gas, power, communications and hot water **(Figure 4).** The bell is also fitted with exterior-mounted breathing gas cylinders in the event of contingency. The hot water from the boilers is pumped down to the bell through the umbilical for protecting the divers from cold ambience.

Upon completion of the underwater operations, the diving team is decompressed gradually back to atmospheric pressure by the slow venting of the system pressure at an average of 1.8 bar/day, travelling 24h a day, depending on the depth, length of time at that depth and the composition of the breathing gas. Thus, the saturation process involves only one ascent, thereby mitigating the time-consuming and comparatively risky process of in water, staged decompression normally associated with traditional diving.

Long-term exposure to breathing gas under high pressure may cause aseptic bone necrosis, susceptible to High-Pressure Neurological Syndrome-HPNS (described as dysfunctions in neurologic and cognitive states with changes in EEG), insomnia and fatigue during the decompression period. Decompression time may be longer if the diver experiences DCS symptoms (that

To improve both bottom time and safety, saturation divers live and work from sealed pressurised chambers supported by on surface ships

cannot be predicted or prevented with absolute certainty because of its probabilistic nature which varies with the diver). During this time, diver must be recompressed until the symptoms are relieved and the decompression reinitiated at a slower rate. The observations by the ship decompression team are shown in **Figure 5.** Biochemical decompressions are also in practice to reduce the decompression period.

Amazingly enough there appear to be few ill effects if any associated with working as a saturation diver (a few individuals seem susceptible to bone loss) and if done carefully, saturation diving is completely safe. However, the divers must remain in a pressurised environment for the duration of their work time, which can be as long as 3 weeks or more. This means living in a high-pressure habitat at very close quarters with other divers, under constant video surveillance (a necessity for safety reasons) with no privacy. Food and other supplies enter and exit the habitat via a small airlock and any carelessness in ensuring that the chamber is kept completely sealed would be fatal. Major decompression accidents fortunately have historically been very rare. Should a support ship suffer an emergency which necessitates abandoning ship, divers do have an exit

Figure 5. Deck Decompression Chamber

Table 1. Largest nuclear-powered submarines in the world

Class	Country	Length & Displacement	Crew	Endurance
Typhoon	Russia	170m, 48000t	167	4 months
Borei	Russia	170m, 24000t	107	3.3 months
Ohio	USA	167m, 19000t	90	2 months

Table 2. Major global submarine accidents post-2000

Year	Submarine	Country	Damage/ Causality
2000	Kursk K-141	Russia	Sinkage, Explosion, 118 crew
2003	Changcheng 361	China	Damage, 70 crew
2008	Nerpa K-152	Russia	Damage, gas leak, 20 crew
2016	Yono class	North Korea	Sunk, 8 crew
2017	ARA San Juan S-42	Argentina	Sunk, 44 crew
2019	Losharik As-31	Russia	Damaged, 14 crew
2021	KRI Nanggala 402	Indonesia	Sinkage, 53 crew

strategy. An escape trunk leads from the on-board pressurised habitat to a pressurised (hyperbaric) escape module, allowing the divers to egress a stricken vessel safely.

> *Distress Submarine (DISSUB) is a submarine which is unable to return to the surface, and has surviving crew trapped inside the hull*

DISSUB Localisation, Support and Crew Rescue Systems

Submarines are used for a variety of applications, primarily for strategic and military purposes. It was in 1776 the first submarine *Turtle* was designed by David Bushnell and built with the intention to break the British naval blockade in New York harbor (an attempt to attach a time-bomb to HMS Eagle) during the American Revolution. During World War II (1939-45) submarine technologies advanced significantly. The Germans, who were operating their U-Boats in the Atlantic Ocean, adopted the principle of a 'snorkel' (allowing the boat to recharge its batteries while staying submerged). During 1941, Japan utilised the 'midget subs' for a coordinated attack on Pearl Harbor in the Pacific Ocean, where the United States had been operating their submarines. The Cold War (1945-91) dictated much of the advancement in subsea warfare capabilities. During year 2000, 47 nations were operating >700 submarines, in which 300 were nuclear-powered. Present submarines target use of Air Independent Propulsion (AIP) for improved stealth capability. As on date, 42 countries have submarines as a part of their naval fleet. The submarine count by North Korea, the United States, China, Russia, Japan, South Korea and Iran are 71, 67, 59, 49, 22, 19, and 17, respectively. The details of the largest nuclear-powered submarines in the world are summarised in **Table 1.**

Submarines are designed to be neutrally-buoyant when their main ballast tanks are full of water. This allows them to dive and operate safely. Even if all electrical and propulsive power is lost, the submarine crew blows the water out of the main ballast tanks, and other compensating tanks, to give the submarine positive buoyancy to get it to the surface. However, if a large quantity of water floods into the pressure hull of a submarine, after a catastrophic accident or due failure of a sea water system which cannot be isolated, a point will be reached during the flooding when no action taken by the submarine crew can compensate for the increased mass of the submarine and it will sink to the bottom. A **Distress Submarine (DISSUB)** is a submarine which is unable to return to the surface, and has surviving crew trapped inside the hull.

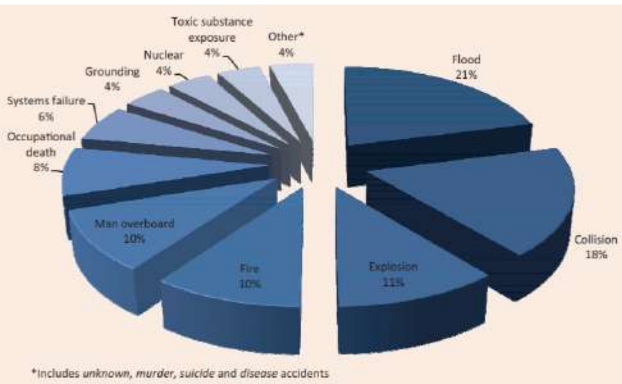


Figure 6. Contributing factors to submarine accidents

During a DISSUB event, in addition to monitoring and controlling the internal atmosphere, any additional actions on the part of the crew are kept at a minimum to reduce the physiological effects of the confined and austere environment while awaiting rescue. All submarines are outfitted with Submarine Escape and Surface Survival Protection Equipment (SESSPE) suits that allow for escape from a submarine at-depth. Survivors can escape through the escape trunk by charging the trunk with air from regulators prior to flooding the trunk and opening the upper hatch. The trapped air within the suit provides positive buoyancy and breathable air to the escaper until they reach the sea surface. Once on the surface and self-contained, single-man lift-raft can be inflated using a compressed CO_2 cylinder, allowing for a minimum of 24h of surface survivability. The rapid flood-up time reduces the risks associated with decompression obligations once at the surface. However, due to the higher risk, rescue is the primary procedure used for submarines.

Prior to 1939 it was generally considered that if the crew could not escape the DISSUB then there was little that could be done to rescue them. The scenario changed dramatically in 1939 with the sinking of USS Squalus. Submarine rescue philosophies evolved in the 1960s following the loss of two American nuclear-powered submarines, US Ships Thresher and Scorpion, despite both being lost in waters that precluded escape or rescue. The major global submarine accidents post-2000 is summarised in **Table 2.**

Various factors contributing to the submarine incidents are represented in **Figure 6.**

During 1968, operational submarines including Alvin, K-129, Scorpio, Darkar, Minere were lost, resulting in 3262 causalities. The study of submarine accidents during

Table 3. Submarine sinkage and fatalities

Reason	Period	Description	Statistics
Sinkage	1946-1974	Out of 500 available subs	~1 sub/year
	1975-2005		~0.3 sub/year
Fatalities	1946-1974	Out of 30000 submariners	38/year
	1975-2005		12/year

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1946-2005 has shown that the number of these incidents has declined roughly 3-fold between 1946 and 1974, and during the period 1975-2005, 1974 represented the beginning of a period with fewer accidents **(Table 3).** It is opined that nuclear accidents have not dominated the accident record, a testament to the scale of safe design, built-in redundancy, and operational effectiveness stemming from a near-zero tolerance of such incidents.

All submarines are outfitted with passive CO2 removal curtains and O2 candles to support seven days of survivability for a full submarine crew

The standardisation of the submarine design with double hull, shock and collision withstand capabilities, and the definition of Safety Operational Envelope (SOE)/ Manoeuvring Limitation Diagram (MLD) significantly contributed to the reduction in submarine incidents. The SOE is defined as the region that guarantees the safety of a submarine from accidents, such as jamming and flooding. The relation between the submarine speed and depth is used to define the SOE. SOE/MLD refers to the area obtained by defining the excursion depth during accidents, such as jamming and flooding, for various speed conditions. The definition for SOE/MLD include maximum safety depth (maximum depth in a normal operation condition), maximum excursion depth (depth limit according to which the submarine does not exceed the collapse depth by jam-to-dive or flooding when it takes a recovery action), minimum safety depth (depth limit to avoid a collision with surface ships), periscope depth (depth limit to operate the periscope or snorkel), flood avoidance zone (limited zone to prevent sinking of the submarine by flooding in a low-speed range), broach limited zone (limited zone to avoid a collision with a surface ship or exposure above the free surface by a jam-to-rise), and the pitch limited zone (limited pitch angle to prevent the malfunction of the on-board machinery and equipment by excessive pitch). The maximum pitch angle applied in practice is conventionally limited to 5°-10°.

DISSUB Search and Localisation

They key aspects of DISSUB crew support include alerting, search and localisation (ASL) of the DISSUB, on-board DISSUB survival of personnel, escape of survivors from depth to surface and rescue of personnel from depth to the surface. In order to enable the surface rescue ship to locate the DISSUB, the DISSUB releases a buoy/s (using a rope wound on a spool) that surfaces with a locator beacon and a satellite transponder. The spool shall have adequate cable length and buoyancy enough to surface by overcoming surface currents. The buoys consist of an inflatable collar to support a radio unit that transmits on international distress frequencies, (121.5, 243 or 406 MHz). They are fitted with a flashing light. Because they have a low margin of buoyancy they are not easily visible in any appreciable sea state except at short range; it is also possible that they may not be seen in a strong tideway. Some indicator buoys transmit a unique three-figure serial number. National Authorities hold to date lists of the indicator buoy numbers of all their submarines. Some nations, although allocated indicator buoy numbers, have buoys which have no means of transmitting the allocated number.

Figure 7. ELSS delivered to DISSUS using IROV

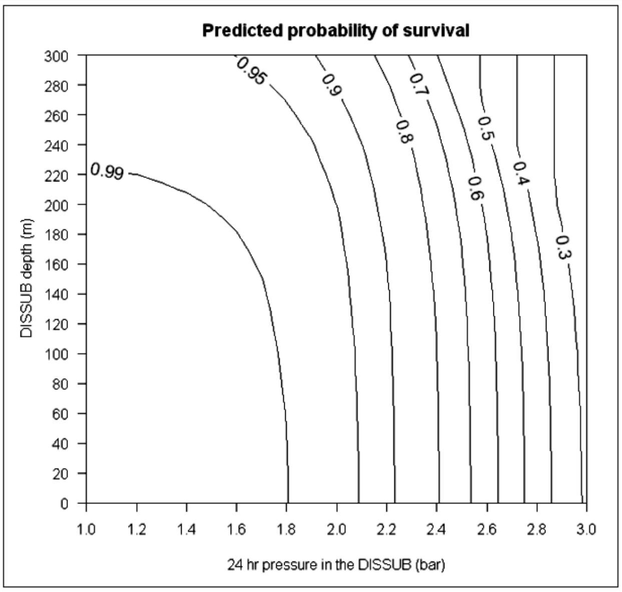

Figure 8. Effect of different DCS symptoms on surface survival

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Some buoys also transmit on the COSPAS/SARSAT frequencies. These buoys, named SEPIRB (Submarine Emergency Position Indicator Radio Buoy), are normally floating. They transmit a string containing a certain number of datapoints such as the position coordinates (typically fixed once the buoy gets activated), the time and an ID string identifying the single submarine. The information is received and automatically routed to the COSPAS/SARSAT ashore station, automatically decoded by the agency owning the submarine and, in some cases, automatically sent directly to the Subopauth for subsequent actions. A communications buoy that can be launched by a DISSUB from a Submerged Signal Ejector (SSE), when on the surface it operates on a predetermined UHF frequency and when released in the emergency mode transmits an emergency DF beacon which can be detected by satellites or other receivers.

On-board DISSUB survival of personnel

The submarine escape and rescue (SMER) equipment and gear inside escape compartments consists of a release gear for indicator buoy (or messenger buoy, submerged signal ejector and stores (having smoke candles, grenades and communications buoys), emergency underwater telephone, means of providing oxygen, means of absorbing Carbon Dioxide, atmosphere monitoring equipment, instruments for monitoring O_2, CO_2, CO, Cl_2 and NO_x levels, absolute pressure gauge., an escape tower with a common rescue seat around its upper hatch, hood inflation system (HIS) to provide a supply of air to escapees whilst flooding up in the escape tower immediately prior to escape and/or a built-in breathing system (BIBS) to provide air for compartment escape and Personal Locator Beacons (PLB) to be worn by some or all escapees and equipment for receiving ELSS by pod posting. Some submarines can release a life raft, which remains tethered to the DISSUB.

During a DISSUB event, the crew may be exposed to several hazards that limit survivability and directly affect the stay-time prior to escape and/or rescue. The most critical factors include uncontrolled flooding of the hull, internal pressure rise, toxic atmosphere, temperature, and loss of life-support capability. During the waiting time between location and rescue, but also during the rescue itself, it may be necessary to maintain conditions on the DISSUB by providing Emergency Life Support Stores (ELSS) either in the “wet re-supply” mode, using pressure-tight pods posted into the escape tower by intervention remotely operated vehicle (IROV)/divers, or in the “dry” mode by a Submarine Rescue Vehicle (SRV) or Chamber (SRC). Some classes of submarine can accept an air supply connection and maintain a breathable atmosphere.

During a DISSUB event, there will be a loss of normal power and therefore a loss of normal operations of atmospheric and environmental control. Survivors will have to rely on available emergency battery capabilities and passive technologies to provide CO_2 scrubbing, O_2 generation, contaminant monitoring, humidity and temperature control. The short and long-term effects of personnel subjected to increased air pressures (due to water entry and resulting compression of internal air) while awaiting rescue or sustained exposure to atmospheric contaminants is also a concern. The decision to escape versus await rescue is a result of atmospheric and environmental conditions onboard the DISSUB. All submarines are outfitted with passive CO_2 removal curtains and O_2 candles to support seven days of survivability for a full submarine crew. Determining the toxicity levels of constituents with the primary focus on seven Submarine Escape Action Limit (SEAL) gases (Carbon Monoxide, Hydrogen Cyanide, Ammonia, Chlorine, Hydrogen Chloride, Sulfur Dioxide, and Nitrogen Dioxide) is important.

The ROV helps with DISSUB localisation using DR, hatch clearing, ELSS pod posting, submarine ventilation system connection, salvage and general intervention purposes. The ELSS pods are pressure-vessels that carry food, water, medical supplies, oxygen candles or CO_2 scrubber materials. They are used to extend life while rescue assets are being mobilised. The pods are transferred individually into the DISSUB through a hatch

Figure 9. DSRV with hatch mating system

Figure 10. DSRV mated with a submarine

or escape tower ROV **(Figure 7)** or divers. The pods are standardised in accordance with STANAG 1391 (that allows interoperability with the systems and submarines of other nations) that meet the same standards to fit the escape tower of submarines.

As the DISSUB internal ambient pressure increases, the time between surfacing and onset of decompression illness (DCI) shortens and these rescues may be at significant risk of DCI during this period with consequent requirement for prolonged decompression and therapeutic treatment. Estimates of the effect of different DCS symptoms on surface survival released from the RN Institute of Naval Medicine and Suitably Qualified and Experienced Personnel (SQEP) from QinetiQ Maritime Life Support are depicted in **Figure 8.** The escape survival curves only account for the effect of DCS on the first 24h of surface survival, assuming surface forces are not present and recompression is not available.

Rescue of DISSUB personnel

Rescue following prolonged exposure to a hyperbaric environment also introduces its own problems including risk of pulmonary O_2 toxicity and pulmonary damage from atmospheric contaminants at high partial pressures. Whilst rescue enables controlled decompression, DCS is still a risk, especially at greater depths and pressures and with potentially significant demand on recompression. Decompression Illness (DCI), Cerebral Arterial Gas Embolism (CAGE), barotrauma and the physical and psychological consequences of DISSUB and sea survival adds to survivor's treatment.

After considering a variety of options, including submarines with in-built escape pods (similar to the Russians) and submarines with front ends that could be blown to the surface, the US Navy developed the Deep Submergence Rescue Vehicle (DSRV) in 1970s. The DSRV is one type of submarine rescue submersible, which can carry submariners from a DISSUB to the surface. The function of the SRV is the same as the submarine rescue bell. The typical difference between them is that the rescue bell is a bell shape submarine rescue system, while the SRV is a free moving human submersible. As a special human occupied submersible, it consists of four major components: human pressure hull, propellers system, observational system, and rescue system.

The technologies and techniques developed for human survival in the ocean depths required to support the oil and gas industry have been adapted to provide a faster, highly mobile and comprehensive rescue capability for the world's submariners in the event of a survivable submarine accident. Submariners trapped in a DISSUB require the intervention of both the external saturation divers, pressurised rescue submarines with mating hatches **(Figure 9)** and surface recompression facilities to deal with the physiological effects of deep submergence during their rescue. The hull may or may not be compromised and thereby partially flooded. The survivable dry section may therefore become pressurised. In a situation where a DISSUB is partially flooded, survivors in the remaining sections of the submarine are likely to be subject to increased pressure in their environment. This increased pressure exposes the submariners to the same issue as divers.

This creates a requirement to ensure any rescue of the crew prevents rapid "decompression" to atmosphere resulting in DCS. Rescues are therefore carried out using the same "transfer under pressure" (TUP) and decompression technologies are applied. The challenge to rescue submariners, who have been subjected to air saturation therefore, are to provide a means to evacuate them from the DISSUB under the same ambient pressure as their stricken submarine, and transfer them on the surface to a decompression facility. As submarine complements can range from 30 to over a hundred crew, who could have been exposed to pressures as high as 4 bar for as long as 5 -7 days the logistics of a rescue are demanding. The decompression requirement can be as long as 24h and therefore the requirement to rescue and decompress large numbers of the crew is a significant challenge.

The SRV "mates" with the DISSUB on a dedicated escape hatch **(Figure 10),** and the pressure inside the rescue compartment is equalised with the submarine. The submersible mates under pressure with a pressurised "holding" chamber allowing the submariners to transfer under the same ambient pressure as the submarine into the decompression facility. The facility has multiple pressure "locks" to allow staged decompression to be undertaken.

Presently 15 countries in the Asia-Pacific region (including China, Japan, India, Singapore and Korea) have DSRV capable of carrying out DISSUB rescue capabilities. DISSUB rescue missions are carried out in three phases including reconnaissance (using ROV), rescue (using DSRV) and crew decompression (using TUP chamber). The systems are made air-transportable to the port near the DISSUB in multiple sorties and integrated rapidly. Following the disaster of the Russian submarine K-141 Kursk, the International Submarine Escape and Rescue Liaison Office (ISMERLO) was established in 2003 by NATO with the objective of coordinating international submarine search and rescue operations. The office aims to provide an international liaison service to prevent peacetime submarine accidents, and to quickly respond on a global basis if they do occur.

In the second part….

The second part shall discuss in detail on the developments in deep-ocean and full-ocean depth human-occupied scientific submersibles that have made it possible for humans to safely and effectively explore the deep-oceans including its true mysteries, living and non-living resources.

ABBREVIATIONS

ABS	American Bureau of Shipping
ADS	Atmospheric Diving Suit
AIP	Air Independent Propulsion
ASL	Alertment, Search and Localization
AUV	Autonomous Underwater Vehicle
BIBS	Built-in Breathing System
CAGE	Cerebral Arterial Gas Embolism
CCR	Closed-Circuit Re-breathers
DCS	Decompression Sickness
DDC	Deck Decompression Chamber
DISSUB	Distressed Submarine
DNV	Det Norske Veritas
DOF	Degree of Freedom
EEG	Electroencephalogram
ELSS	Emergency Life Support Stores
HIS	Hood Inflation System
HPNS	High-Pressure Neurological Syndrome
HRU	Hyperbaric Rescue Unit
HOV	Human Occupied Vehcile
IMCA	International Maritime Contractor Association
IMO	International Maritime Organization
ISMERLO	International Submarine Escape &Rescue Liaison Office
MLD	Manoeuvring Limitation Diagram
MOSHIP	Mother Ship
MSC	Maritime Safety Committee
NATO	North Atlantic Treaty Organization
PLB	Personal Locator Beacons
ROV	Remotely Operable Vehicle
SARSAT	Search & Rescue Satellite Aided Tracking
SESSPE	Submarine Escape and Surface Survival Personnel Equipment
SEPIRB	Submarine Emergency Position Indicator Radio Buoy
SEAL	Submarine Escape Action Limit
SOE	Safety Operational Envelope
SRC	Submarine Rescue Chamber
SSE	Submerged Signal Ejector
SRV	Submarine Rescue Vehicle
SCUBA	Self-Contained Underwater Breathing Apparatus
SMER	Submarine Escape and Rescue
STANAG	Standardization Agreements
UHF	Ultra High Frequency
ULB	Underwater Locator Beacon
WHOI	Woods Hole Oceanographic Institution

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IMO Conventions on Pollution Liability and Compensation: A Discussion on Indian and Chinese Positions

Shantanu Paul

Abstract: IMO conventions for pollution liability and compensation are for the benefit of Member States as well as the global population. Two Asian powers and top populous nations, India and China, have not ratified many of them either due to national interest or procedural complicacy in the legal system of the State. While the Chinese regime is attributed to the former and is covered by national law, the Indian system suffers from the latter and the existing gap for bunker oil pollution from non-tanker, which needs urgent Government attention.

Keywords: Costal population, Pollution compensation, Bunker convention

Introduction

Two rising Asian powers and top populous nations, India and China, have become more prominent at IMO, among Member States as well as within the IMO Council, hence more responsible for taking forward various good work done at IMO, internationally as well as domestically. Nevertheless, both countries have not ratified several IMO conventions, created for the benefit of member States, including liability and compensation issues due to various losses and ship source pollution damage. This is more important for both countries due to their long coastline with numerous ports. Although China's figure is almost double in both, length of coastline and number of major and non-major ports, as far as the country's population as well as coastal population is concerned, India has already surpassed China (WPR, 2024).

The land area of China is three times greater than that of India hence the higher population density and greater impact of pollution on the Indian coastal population. Hence, the liability and compensation issues due to ship source pollution need to be reviewed specifically by India when maritime dependence is high in the country's foreign trade that supports economic growth (% GDP), of which India is the global topper.

Recent studies have shown that the overwhelming bulk of humanity is concentrated along or near coasts on 10% of the earth's land, and the Indian scenario is no different. The Indian coastal population is increasing at a faster pace and is expected to reach 411 million by 2035 from 364 million in 2020 (Maul & Duedall, 2021). Hence, the coastal community is considered one of the key stakeholders in the Sagarmala Programme of the Govt. of India to ensure their socio-economic well-being. Any pollution on the Indian coast will highly disrupt their livelihood and require urgent, suitable compensation. Indian ports are now continuously improving in various aspects and creating new records to handle not only a higher number of ships but also higher capacity in terms of GT (Gross Tonnage) or TEU (Twenty Foot Equivalent).

In May 2024, a container vessel of 19,200 TEU docked in Mundra port, which is the largest container ship ever to visit an Indian port. (ET 2024). In July 2024, Visakhapatnam Port created history by berthing a bulk carrier of GT two lac tons, the biggest cargo ship ever visited any Indian port (Hindu, 2024). These large vessels with huge bunker oil capacity, certainly increase the risk of accidental pollution; hence, ratification of all IMO conventions that are adopted to ensure adequate, prompt, and effective compensation to persons who suffer damage caused by pollution, mainly oil spills are more relevant for India now.

India has already ratified important IMO Conventions in this matter, such as the Civil Liability Convention (CLC) with its 1992 Protocol and the Fund Convention with its 1992 Protocol but a gap still exists as they do not cover bunker oil pollution from non-tankers such as bulk carriers and container ships, which is covered under the Bunker Convention (BC) 2001 to which India is not yet a party.

The Indian coastal population is increasing at a faster pace and is expected to reach 411 million by 2035 from 364 million in 2020

All recent analyses of Indian shipping and related matters have always considered China for comparison, be it the Indian Ministry of Shipping (MOS), Govt. of India, or any private agencies, and China's progress in the 21st century in the maritime domain is often considered a benchmark for India to achieve higher goals. The following discussion is not to describe details of various IMO conventions on liability and compensation for oil pollution but will try to highlight the complexity and benefits of such conventions that are already enforced globally, for various losses and ship source pollution by "oil" and their ratification and implementation by India as done by China for their national interests.

Indian Incidents and Initiative

The collision incident of the containership MV MSC Chitra with the bulk carrier M.V. Khalijia-III in 2010 while approaching Mumbai port that caused spillage of its bunker oil, of around 800 tonnes, and its aftereffects are still fresh in the memory of many sufferers, mainly poor fishermen of coastal Maharashtra. In India, over 67% of marine fisherfolk families are living below the poverty line, as per a report by the Ministry of Fisheries and Animal Husbandry and Dairying (Federal, 2020). It was acknowledged by the DGS vide explanatory note that in India, it is often difficult and sometimes impossible to obtain compensation for pollution damage caused by bunker oil spills or leakage from ships other than tankers hence invited comments from stakeholders to give effect to the BC by the Merchant Shipping (MS) Amendment Bill (DGS, 2014). It was reported in the Lok Sabha in 2021 that annually around one lac ships transit through the Indian Ocean, and these movements of ships and associated activities have resulted in some incidents of bunker oil pollution in the Indian Maritime Zones. In June 2015, the Union Cabinet, chaired by the Prime Minister, thoughtfully approved the proposal of the Ministry of Shipping (MOS) for India's ratification of the IMO BC 2001 as well as to amend the Indian MS Act 1958, to give effect to the BC (BS, 2015). Since then, various Govt. documents have reported that India is in the advanced stage of ratification for the BC, but surprisingly, nothing has happened yet. MIV (Maritime India Vision) 2030 (MOS, 2021) has also highlighted the need for reforms by the Merchant Shipping Bill to adopt all such IMO conventions that India has not yet ratified for accidental pollution liability and compensation, primarily the BC 2001 as well as some operational pollution prevention conventions such as the London Convention 1972 with 1996 Protocol and the Ballast Water Management Convention 2004, all of which are already ratified by China (Table-1). Now, with the changed scenario, urgent action needs to be taken by the Indian government and possibly not by the Indian shipping industry.

Table 1.

As of July 2024 Nominal GDP (in trillions) GDP Growth GDP Per Capita				London Convention 72	London Convention Protocol 96	CLC Protocol 76	CLC Protocol 92	FUND Protocol 76	FUND Protocol 92	FUND Protocol 2003	LLMC Convention 76	LLMC Protocol 96	BUNKERS CONVENTION 01	BALLESTWATER 2004	NAIROBI WRC 2007
China	$18.53	4.6%	13,140	x	x	d	x						x	x	x
Germany	$4.59	0.2%	54,290	x	x	x	x	x	x	x	d	x	x	x	x
Japan	$4.11	0.9%	33,140	x	x	x	x	x	x	x	d	x	x	x	x
India	$3.94	6.8%	2,730			x	x	x	x		x	x			x
x=Ratification															
d=Denunciation															

Source: IMO Data and IMF Data, July- 2024

Ratification and Implementation

IMO conventions are ratified and easily made applicable in China since the Constitution of China is silent on the way international conventions ratified by China are to be applied domestically, neither dualistic nor monistic, hence there is no uniform practice regarding whether they can be applied directly or only after their incorporation into domestic legislation and done as suitable under the circumstances (CMI, 2017).

However, in the prevailing Indian legislative system of dualism; suitable incorporation of international convention in the national law is necessary and often delayed inordinately due to the existing process. Now BC is being considered as part of the revamped version of the MS Act 1958, for which approval is still pending. However, unlike India, China has not ratified LLMC (Limitation of Liability for Maritime Claims) and its 1996 Protocol which is linked with the compensation under the BC, so similar contents has been incorporated in the CMC (Maritime Code of the People's Republic of China). (CMI, 2017). LLMC is a global liability limit for a ship, for personal injury or death and loss of or damage to property. Ship-owner can limit "total liability for claims of a single event". It also applies to damage caused by pollution or ship wrecks such as BC and IMO Convention on the Removal of Wrecks. China has also not ratified the Fund Convention (FC), possibly due to national benefit as perceived and established the Chinese Oil Pollution Compensation Fund in 2012 in

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similar terms with contributions from oil cargo owners in China (UK P&I, 2015).

International shipping depends on the global regulatory framework provided by IMO and its effective implementation. This is absolutely true for several conventions including operational pollution prevention conventions but may not be for liability and compensation conventions. When any such conventions are not ratified by the States, this is probably that the perceived benefit of the convention is considered by the State not bigger than the cost (Ma, 2008). China not having ratified the FC is an example.

Historically, the principle was that a shipowner could not be liable in an action in rem beyond the value of the res (ship and freight) for various losses of property as well as personal injury or death

Complexity in Liability and Compensation Regimes

Maritime liability and its limitation have attracted controversy throughout its existence and IMO conventions are no exception as they are negotiated under the influence of several interest groups, ratified as per perceived national benefit and decided by courts often contrarily with the intention of the convention. Historically, the principle was that a shipowner could not be liable in an action in rem beyond the value of the res (ship and freight) for various losses of property as well as personal injury or death. As ships became bigger and value increased, the shipowner's liability was made limited as per the size of the ship for maritime commerce to flourish as we see now under the LLMC but with different limit for property loss and personal injury or death (Gaskell, 2022). This concept was further extended to pollution damage with shipowners' "strict liability" and compulsory insurance by the "blue card" of P&I Clubs for guaranteed payment to victims for "consequential economic loss" and "pure economic loss" as well as environmental damage cost for technically justified reasonable restoration measures up to the country's EEZ (exclusive economic zone). This is applicable for CLC and BC as latter is modelled as per the former with some differences. Unlike CLC, BC does not contain provisions for the ship-owner to limit liability, if ship-owner has a right to limit liability under LLMC, that limit can be used but higher limit of LLMC 1996 is also lower than the CLC 1992. However, the limit of BC will be the LLMC as enacted in the State (Jacobsson, 2008).

Moreover, under LLMC, as the ship-owner can limit total liability for claims of a single event, if bunkers pollution damage is suffered together with other property damage, prospects of recovery in full for all claimants including pollution victims will be much less as no distinction is made for bunkers pollution claims and other claims (Jermolajeva, 2010). These shortcomings of BC were realised prior to adoption and during initial discussions in the IMO Legal Committee, many States were keen to see a separate free-standing fund provided by shipowners to be exclusively available to satisfy bunker pollution claims. However, due to strong opposition from the ship owning and insurance sectors, it was finally agreed that bunker pollution claims would be subject to existing laws of LLMC (Griggs, 2001).

BC applies to any sea-going vessel or craft and a single tier compensation mechanism for pollution caused by "bunker oil", defined as any hydrocarbon used or intended to be used for operation or propulsion of the ship including non-persistent oil. Conversely pollution caused by oil tankers from persistent oil, cargo as well as bunker, is covered by two tier compensation mechanisms up to total 203 SDR (Special Drawing Rights) that is CLC and Fund, in many countries. CLC varies with the size of the ship and the maximum liability is limited to 59.7 million SDR for ships over 140,000 GT. However, in a few States, it is three tiers, created after the Prestige oil spill disaster, with additional coverage up to a total 750 million SDR under the Supplementary Fund but India is not party to it and not applicable to China as a non-member Fund State. (Fig-1). The Fund is financed by contributions levied on private company or other entity in a 1992 Fund-Member State that receives an annual quantity of more than 150,000 tonnes of crude oil and or heavy fuel oil ('contributing oil') following carriage by sea. The oil may be imported from abroad, carried from another port in the same State or transported by ship from an offshore production rig (IOPC, 2022). India being

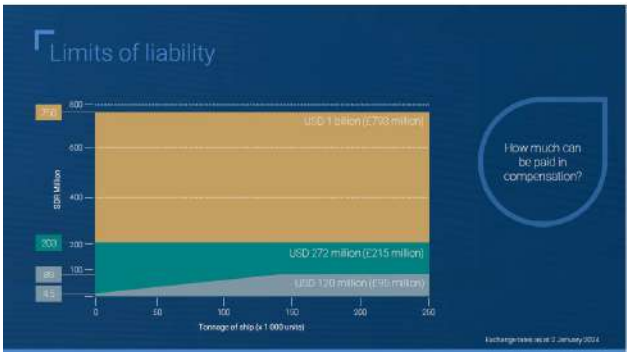

Fig. 1 CLC (grey), FUND (green), Supplementary Fund (beige)

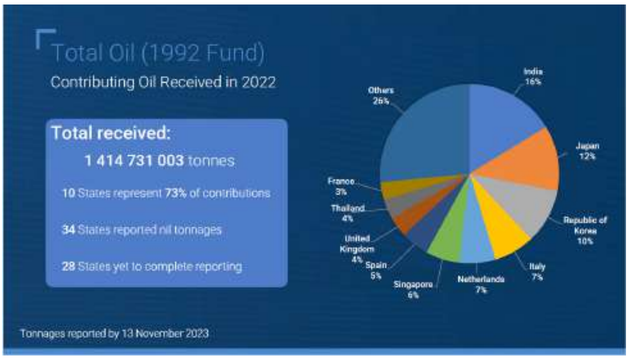

Fig. 2 Contributors to the Fund (India 16%)

a party to the Fund Convention, almost 100% of Indian crude oil is accounted for contribution and India has now become the highest contributor globally (Fig-2) as China is not a party to it although the largest crude oil importer globally. This is often debated in India as an undue burden to Indian companies and Fund membership is more of a cost to India rather than a benefit.

CLC varies with the size of the ship and the maximum liability is limited to 59.7 million SDR for ships over 140,000 GT

Nevertheless, there is no such cost attached to the BC rather Indian flag ships plying internationally, need to procure certificate from other flag that ratified BC on a chargeable basis based on the bunker Blue Card from P&I Clubs. However, foreign ships coming to India, although having the required certificate but bunker pollution in Indian waters will not be under its purview and Indian national law will be applicable for compensation but within India's Territorial water i.e. 12 Nautical Miles (KTS) and not till 200 KTS i.e. Exclusive Economic Zone (EEZ), where States have the sovereign rights for exploring and exploiting, conserving and managing the natural resources, living or non-living as per UNCLOS (United Nations Convention on the Law of the Sea), as covered under IMO liability and compensation conventions. Polluter pays principle is followed in the Indian legal system and under the new NGT (National Green Tribunal) Act 2010, environmental damage cost for full restoration is to be paid by the polluter (Bhattacharya, 2023) and not just technically justified reasonable restoration actually undertaken or to be undertaken as mentioned IMO conventions allows. However, national law can impose penalty of any amount but recovery or enforceability of a court order, will depend if assets of the foreign ship-owner are in India and long litigations will only increase the suffering of victims.

Polluter pays principle, is also one of the key characteristics of the IMO convention for vessel source marine oil pollution liabilities i.e. oil spilling vessels can only be sued for pollution liabilities. In 2019, the Chinese Supreme Court issued a landmark judgment on the bunker oil pollution from the container ship CMA CGM Florida due to collision with the bulk carrier MV Chou Shan, that the non-spilling vessel should also be liable as per its proportion of liability in the collision accident as the issue of liability of non-spilling vessel in ship collision is not very clear in international conventions (Tianbao & Xianwei, 2020). Apparently, the judgment is to satisfy the national interest to get total maximum compensation from foreign ship owners due to lower limit for bunker oil pollution, similar to LLMC, as enacted in CMC. The case of bunker oil pollution in 2019 from an oil-chemical tanker M.T.V. Bow Jubailin of 23196 GT, in the port of Rotterdam when the vessel was in ballast also created much controversy and the matter went up to the Supreme Court of Netherlands to decide whether shipowner's liability to be limited as per CLC or BC which is much lower than the increased limit of CLC due to STOPIA (Small Tanker Oil Pollution Indemnification Agreement) applicable to small tankers (29 548 GT or less). STOPIA is to indemnify the 1992 Fund by the shipowners P&I Club to reduce the burden of oil industry in the member-state. Further details are not discussed due to limitation of this article size. However, the definition of "Ship" in IMO pollution liability conventions may need new clarification as opined by the Director of the International Oil Pollution Compensation Funds (IOPC) Fund in the 2023 governing body meeting (IOPC, 2023).

Ship-owner's limitation of liability is virtually unbreakable under the IMO conventions except for wilful misconduct, committed with the intent to cause such loss, or "recklessly" and with "knowledge" that such loss would probably result. In the case of oil tanker "Prestige" disaster, the judgment of the Supreme Court of Spain in holding the ship-owner and its P&I Club liable for amounts over the 1992 CLC limit, considering that the Master had acted recklessly, became highly controversial. Hence in January 2022, IMO came out with a clarification by Unified Interpretation that "recklessly" is to be accompanied by "knowledge" in combined totality and should not be considered in isolation of each other for the necessary culpability to break the limitation (IMO,2022). Nevertheless, with all such complexity and controversies, IMO International Conventions on Pollution Liability and Compensation have been proven beneficial to States numerous times. India is a party to LLMC and embraced its latest amendments which should be the limit of BC in India. **Hence Indian Government should ratify BC and incorporate in the MS Act without further delay.**

Lessons to be Learnt

The sinking of the foreign flag bulk carrier M.V. RAK in August 2011, 20 KTS from the coast of South Mumbai, created much pollution from its bunker oil, 290 tonnes of fuel oil, and 50 tonnes of diesel oil. The Maharashtra Pollution Control Board had initiated criminal action against the ship-owner under the provisions of the Environment (Protection) Act, 1986, and other national laws and issued a notice to remit Rs. 3 crores. It was contested that notification applies only up to territorial waters (12 KTS), and the spill occurred at 20 KTS off the Mumbai coast. The case was then referred to NGT which also noted that provisions of BC are not part of the MS Act 1958 and the tribunal had to refer to several other related national laws as well as UNCLOS to conclude their judgement in August 2016 for compensation of 100 crores to the registered owner and its sister concerns (WWF, 2016). However, information regarding its recovery is not yet available in the public domain.

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On 25 July 2020, M V Wakashio, a Panama-flag, Japanese owned 203,000 DWT Bulk Carrier ran aground around Mauritius, creating pollution from its around 4000 Ton bunker fuel. Mauritius, Panama, and Japan have ratified the IMO BC 2001, and as per the vessel's capacity, liability for the incident under the Convention was 46.19 million SDR which was apparently not adequate to cover all costs and losses, including environmental damage in Mauritius.

> *Polluter pays principle, is also one of the key characteristics of the IMO convention for vessel source marine oil pollution liabilities i.e. oil spilling vessels can only be sued for pollution liabilities*

However, the question remains: **can a State recover any or more compensation than the convention limit as per their national law when the foreign shipowner does not have any assets in that State?** This was the main reason for IMO to create such conventions after the Torrey Canyon disaster in 1967. Hence, in August 2020 UNCTAD (United Nations Conference on Trade and Development) reminded the importance of adopting all legal instruments of the IMO in this field (UNCTAD, 2020). Oil tankers are not the only vessels that cause oil pollution damage at sea. Numerous spills at sea have been of heavy fuel bunker oil from non-tankers. India, being close to main shipping and oil trade routes like Mauritius, should take a lesson from it and act prudently to fill the gap of bunker oil pollution compensation that does not cost anything to India as well as Indian oil companies. Now India is the fifth largest economy and is aspiring to acquire the third position by surpassing much wealthier Council Members in terms of per capita GDP, Japan and Germany, both countries with high maritime dependence in foreign trade like India, hence protecting them by ratifying (Table-1) all IMO Pollution Liability and Compensation Conventions as accidents are unpredictable. It is unrealistic to consider that large unfortunate marine pollution incidents from tanker or non-tanker will not affect India as fortunately, it has not happened in the past. Hence, the debate on India's Fund membership is unwarranted for long-term risk mitigation, and ratification of BC is an imperative for India now.

Conclusion

IMO conventions for pollution liability and compensation are for the benefit of Member States and the world in general. World's top two populous nations, India and China, have not ratified many of them. While China has filled the gap with relevant national legislation but gap exists in India for bunker oil pollution from non-tankers. Now India's population as well as coastal population density is higher than China. So, India needs to fill up the gap as large bulk carriers and container vessels with huge bunker oil capacities are calling Indian ports and increasing the risk of accidental pollution. Union Cabinet has already approved the ratification of the IMO BC 2001 and amendment of MS Act, 1958 in 2015, however, it is trapped in the prevailing Indian legislative system of dualism and lacking required Govt initiative. The reason for this inordinate delay to ratifying BC by India can only be inferred that- it is due to the fortunate lack of major bunker pollution incidents in India, the public uproar might not have reached the levels that can shake up the politicians in the Indian Government machinery to sweep away all issues stretching it so long.

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Candidate Selection for Predictive Maintenance

Prabu Duplex

Abstract

Preventing unexpected failures from occurring is important for many complex systems such as ship systems. Executives in such asset intensive industries often regard unexpected failures of their physical assets as the primary operational risk to their business. Such unexpected downtime can be disruptive in complex supply chains and imposes high costs due to imposed downtime. Competitive pressure therefore forces companies to use the reliability and dependability of their equipment as a competitive. Typically, a lot of preventive maintenance is conducted to avoid negative impacts (such as safety hazards, production losses, logistic costs, or high repair costs) caused by failures. Ideally, predictive maintenance strategies are employed to provide insight in the future state of assets. Predictive maintenance (PdM) techniques inform the asset owner or operator about the current and preferably also future state of their assets. PdM thereby helps to reduce unexpected failures, improve the reliability and dependability of equipment and prevent unnecessary replacement of components. However, PdM techniques cannot be implemented for the whole systems under consideration. To choose wisely where to implement such techniques this work proposes an implementable framework for the same.

Introduction

Predictive maintenance is enabled by PHM (prognostics and health management) technologies in response to the indicated deteriorated condition, performance or the remaining useful life (RUL) of a component or system. Although predictive maintenance is often referred to as CBM (condition-based maintenance), predictive maintenance goes further than CBM by also taking prognostic information into account. Typically, two motivations for implementing PdM can be discussed.

Either (1) practitioners look for the best maintenance approach (also termed: maintenance policy selection) for their high-impact components and systems, and PdM appears to be the most suitable approach. Or (2) opportunities arise that make the application of PdM feasible. By having the desire to implement a PdM approach, by either of these two motivations, the first step is to consider whether PdM is indeed the most suitable approach (for candidates from the first perspective) or to identify the most suitable candidates (i.e. systems or components) for PdM (for candidates following the second perspective). The purpose of selecting the most suitable candidates for PdM is to assess where PdM would provide the greatest benefit in terms of performance and/or cost of downtime. Since many maintenance techniques that enable PdM are costly to develop, it would not be cost-efficient to apply them on all equipment. That is to say, almost 30% of industrial equipment does not benefit from applying techniques (i.e. condition monitoring) that enable CBM (or similarly PdM / PHM). It is therefore often stated that CBM should only be applied where it is suitable, not as an overall policy. It is therefore critical to select the suitable candidates for a PdM application to achieve the optimal benefits. Therefore, in this work, a method is developed to identify and select suitable candidates for predictive maintenance. Overview of current methods, problem exploration, solution proposal and a case study forms the framework.

Existing Methods

The literature describes various well-known and accepted methods to select suitable candidates for PdM. The shortcomings of current methods is discussed in [1], out of which a few of them are discussed in this section.

a. Methods based on risk assessment and dependability of components

An often applied approach is to define critical components as a component whose failure leads to unavailability of the whole system, and/or a component which has a high failure rate . The reliability-centered maintenance (RCM) method uses systematic logic to rank the criticality of failure modes and provides guidelines for selecting the applicable maintenance task. RCM is normally performed at the system level since the criticality of failures at the component level can only be judged on the basis of its impact on delivering the required system functions.

Although predictive maintenance is often referred to as CBM (condition-based maintenance), predictive maintenance goes further than CBM by also taking prognostic information into account

b. Maintenance policy selection methods

Maintenance policy selection methods do not directly help to select the most suitable candidate for predictive maintenance. The starting point for many companies is to find a suitable policy for their high-impact components and systems. When PdM is selected to be most appropriate, a check on the suitability of the candidates might prove valuable. Moreover, reviewing these policy selection methods may provide valuable insights into when to select PdM for a (component in the) system as it provides rules or criteria for when to apply predictive maintenance strategies. Different goals and criteria can be considered in the selection of the most suitable maintenance policy. A maintenance policy can be defined as a rule or set of rules that describe the triggering mechanism, such as time, usage or an expression of deterioration, for the different maintenance actions (repair, replace, monitor, shutdown. To take these various criteria and goals into account, multi-criteria decision making (MCDM) methods can be used for maintenance policy selection (MPS). The MCDM approach [1] is typically suitable in contexts where the goals and criteria are difficult to express in monetary terms and are therefore difficult to quantify. For MPS, these criteria include the investment required for implementation, safety aspects, environmental issues, failure costs, reliability of the strategy, and manpower utilisation of the facility.

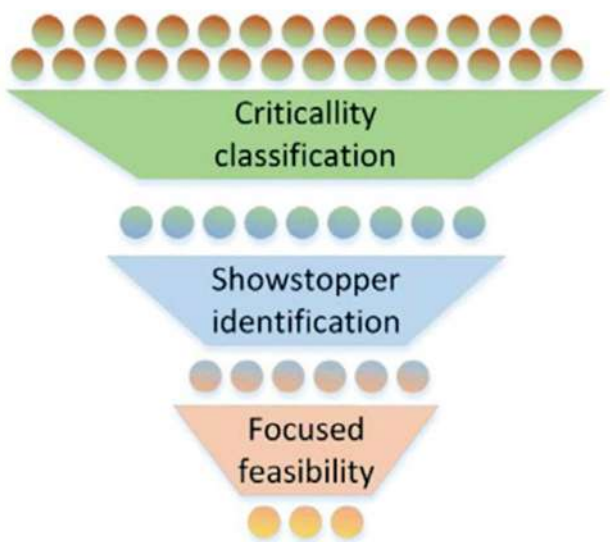

Figure 1. Proposed funnel approach for the identification of suitable candidates for PdM [1]

Solution Development: Proposed Solution for Identification of Suitable Candidates for PdM

The proposed method **(Figure 1)** consists of three stages: the criticality classification, the identification of showstoppers, and a focused feasibility study. The method works as a funnel, the first stage aims to reduce the number of potential candidates significantly to reduce the required efforts in the two following stages. Each of the three stages will be elaborated in the following subsections, and demonstration of the proposed method in a real case follows.

Criticality Classification

The initial criticality classification acts as a filter to significantly reduce the number of possible candidates from a list of components. The four-quadrant chart based on the work of Tinga et al. (2017) helps to bring focus to only the most promising candidates, namely those with a low frequency of failure and a high associated failure consequence (e.g. failure, costs or downtime). The improved focus [1] established by the introduction of a lower limit (in addition to the upper limit) on the failure frequency helps to only select those candidates that fail often enough for a positive business.

Identifying Showstoppers Related to Desired Outcome

Showstoppers are factors that can make the prognostic approach infeasible or providing no added value. In [1] several factors were identified that hinder the use of PdM / PHM. These are clustered in the potential showstoppers (PS) as listed in **Figure 2.** Firstly, a differentiation can be established between three ambition levels, the desired result of prognosis as follows: *Detection*: used as safety warning or last resort; *Diagnosis*: determine fault state and short-term (failure) behaviour forecast; and *Prognosis*: long-term (failure) behaviour prediction. Determining the desired outcome by differentiating between detection, diagnosis, and prognosis helps to firstly describe the requirements of the prognostic system and secondly explore the possibilities and impossibilities by recognising the potential showstoppers. Next, when considering technical feasibility, a choice must be made whether additional research may be conducted, or only existing technologies can be applied.

For each approach, it is then determined whether the potential showstopper is present in the situation under analysis, which then prevents that approach to be successful. For practitioners, it will however not always be trivial whether a factor will be a showstopper. Three possible outcomes can therefore be chosen: *Yes* (it is a showstopper), *No* (it is not a showstopper), or *Maybe* (it might be a showstopper). In the final stage of the procedure, the focused feasibility study, these *Maybe*'s will be looked at in more detail. When no other showstoppers have already made the desired approach infeasible, the *Maybe* must be transformed in a decisive *Yes* or *No* in this final stage.

The potential showstoppers can be rectified in the following manner:

- *c1: Mission clustering:* can a possible PdM activity be conducted during or in between missions? If not, can the predicted maintenance activity be planned with a minimum of the duration of one operational period in advance (i.e. this requires a prognostic distance of at least one mission duration)?

- c2: Technical clustering: *does the predicted failure mode drive the package of clustered maintenance activities (i.e. does it drive the maintenance interval)? If not, can it be skipped one interval?*

Extending the maintenance interval of a gearwheel in a gearbox would make little sense if all other parts in the gearbox have to be maintained anyway (unless it concerns a very expensive component)

Note: this also requires considering whether all relevant failure modes of the component are listed.

- t1 / t2: Detecting/predicting with existing/additional research: *is it viable to build a model that can detect/predict the failure mode/mechanism with existing/additional research?*

- e1: Sufficient financial resources: *are sufficient resources available to cover the investment costs?*

- *e2: Enough failures during lifetime:* will sufficient failures occur (and thus be prevented under a predictive maintenance policy) to recover the investment costs? Note: the lower limit line in the four-quadrant chart also helps to cover this PS.

- *o1: Trust in monitoring system:* will the developed monitoring system be trusted by maintenance personnel and operators?

- *o2: Fit to personnel:* is sufficient knowledge, qualifications and experience with maintenance available within the company? Is there sufficient willingness to adopt PdM?

- *o3: Operational task and mission:* does the predictive maintenance fit with performing the operational mission?

- *o4: Relations and policies:* does the predictive maintenance fit with the internal and external relations of the company?

- *o5: Spare parts:* does the predictive maintenance policy fit with the type, commonality and availability of spares?

With respect to clustering, it must be emphasised that only being a critical component does not make a component a suitable component for PdM. Using prognostic methods to extend the component's lifetime is only useful when the failure prediction actually enables reducing or extending the maintenance intervals.

Interval reductions typically mean that failures that otherwise would have occurred can be prevented, thereby leading to an increase in the system availability. **Interval extensions** lead to cost reductions (conducting less preventive maintenance) and thereby also higher availability of the asset (as it is not in maintenance). Maintenance activities

	Potential Showstoppers (PS)	Detection	Diagnosis	Prognosis
Clustering				
c1	No match with production or mission planning		PS	PS
c2	No match with technical clustering		PS	PS
Technical feasibility				
t1a	Failure cannot be detected with existing technology	PS	PS	
t1b	Failure cannot be predicted with existing technology			PS
t2a	Failure cannot be detected with additional research	PS	PS	
t2b	Failure cannot be predicted with additional research			PS
Economic feasibility				
e1	Insufficient financial resources	PS	PS	PS
e2	Not enough failures (during life time) for positive business case	PS	PS	PS
Organizational feasibility				
o1	No trust in monitoring system	PS	PS	PS
o2	No fit to personnel	PS	PS	PS
o3	No fit to operational task / mission		PS	PS
o4	No fit to relations and policies		PS	PS
o5	No fit to the spare parts		PS	PS

Figure 2. Identification of potential show stoppers (PS) for the differentiated applications of PdM [1]

however, are often clustered based on a production (i.e. opportunistic maintenance planning in a production plant) or mission (i.e. docking intervals for a ship) planning. Such a planning dictates when maintenance activities can be conducted and thereby restrict shifting maintenance activities, unless these can be extended to the next planned opportunity. In these cases, preventive (opportunity-based) maintenance is sometimes more convenient than more advanced methods.

Clustering of maintenance activities can also be caused by technical restrictions. Take the example of gearbox maintenance. Extending the maintenance interval of a gearwheel in a gearbox would make little sense if all other parts in the gearbox have to be maintained anyway (unless it concerns a very expensive component). The benefits of extending maintenance of the gearwheel can only be achieved when all maintenance activities for the gearbox can be extended. Finally, a single maintenance activity can also contribute to preventing multiple failure modes from occurring. This means that it might be possible to extend a maintenance activity by monitoring a specific failure mode, but that another failure mode can become dominant when this maintenance activity is extended.

Nevertheless, other CM techniques (e.g. vibration monitoring) could still provide a way to timely predict a bearing failure, so this instance cannot be a showstopper

Figure 2. shows that each of the 11 factors can act as a showstopper for the two most ambitious (*Diagnosis* and *Prognosis*) levels, but only six of them could affect the lower-level *Detection*. Showstoppers that are identified on the aspects *"organizational feasibility"* and *"clustering"* can result in a (temporary) stop on developing the desired PdM approach. Therefore, analysis is required to see how these showstoppers can be mitigated.

For the clustering, it should be examined how the candidate can be removed from the maintenance (either mission or technical) cluster or whether the interval of the other maintenance activities within the cluster can be coupled to the selected candidate.

Table 1. Maintenance balance score card

Perspective	CM	PM	PdM
(i) innovation and growth	1	2	4
(ii) maintenance	2	3	3
(iii) production	1	3	3
(iv) customer	1	4	5
(v) society	1	3	4
(vi) financial	2	3	3
Total	**8**	**18**	**22**

For the organisational feasibility, the identified showstoppers point at factors that have to be addressed before PdM can be successfully implemented. The showstoppers on the aspects *"technical feasibility"* and *"economic feasibility"* can also result in a (temporary) stop on developing the desired PdM. However, for these factors the answer is not always a clear *Yes* or *No*, so these will be addressed in the third and final stage, the focused feasibility study.

Focused feasibility study

In the final stage of the method, the feasibility of developing a prognostic model is further examined for those candidates where a '*Maybe*' has been selected for one or several of the showstoppers (and no definite showstoppers were identified). This means that these factors will be studied in more detail. The *economic feasibility study* focuses on whether developing the prognostic model is beneficial to the firm, from a strategic point of view. This is because not all industrial equipment benefits from the application of prognostic techniques. It is difficult to assess the financial impact with a high accuracy at the start of the project, but it is important to discuss and brainstorm on the possible gains in comparison to the possible investment costs. As proposed by Tiddens [1], first a distinction should therefore be made between *explorations* and *exploitations* of PdM / PHM.

Exploitations regard applying well-known (to the firm) technologies. For these, a detailed financial modelling can be executed, using for example the method proposed by Tiddens [2]. This method helps to determine whether developing PdM for the candidate system leads to a financial justification. In these cases, it is often quite clear whether the use of PdM is beneficial to the firm and the showstopper identification can be conducted with limited uncertainties.

Explorations are those developments in which the frontiers of what is known (within the firm) are pushed. For *explorations*, a detailed cost benefit analysis cannot be made since the costs and benefits are highly uncertain. Then, a maintenance balanced scorecard approach can be used. An example of this approach is shown in **Table 1**. A multi-criteria decision-making approach could in this situation be used to compare PdM with fixed-interval preventive maintenance (PM) and corrective maintenance (CM) (or any other maintenance policy) at a strategic level. Although PdM was, technology wise, already selected as the preferable maintenance approach for the candidate system, the highest total score (22) for PdM confirms that in this case developing PdM is of strategic interest to the firm.

The *technical feasibility study* focuses on whether it is possible for the firm to develop and implement the desired prognostic approach. The technical feasibility goes deeper than the showstopper identification. Determining the feasibility is not always trivial, since for innovative PdM approaches, a successful outcome can be quite uncertain. The level of detail of this technical feasibility study should be determined per case. In case of a highly uncertain and costly PdM implementation a complete proof-of-concept might be required, whereas in case of a low cost and low risk application, only briefly discussing the questions would be sufficient. Following [1], the following questions guide the assessment of the technical feasibility:

The required data will be collected from engine operational parameters, simulations, experiments and empirical values from literature

1. *Data acquisition:* How can the failure mechanism be measured? How can the required data be acquired, back-upped and secured?
2. *Data processing:* How can the signals issued from the sensors be processed to extract features that suggest the presence of anomalies, and in the long term, represent the state of the monitored system?
3. Detection (condition assessment): *How can the real-time data be compared with expected or known values. How can alerts be generated based on criteria of performance, security, etc.?*
4. Diagnostics (not required for: 'Detection'): *How can – based on the detected state – be determined whether the monitored system is degraded? How can insight be provided on influences of interactions with other components, operating and environmental conditions?*
5. Prognostics (not required for: 'Detection' and 'Diagnosis'): *How can the current state of the monitored system be determined? How can the future state of the monitored system be determined and an estimation of the remaining useful life (RUL) be given?*
6. Decision analysis: *How can maintenance/control actions be recommended such that the system can function until the accomplishment of the mission?*
7. Presentation: *How can the results be presented?*

Solution demonstration: Selecting suitable candidates for PdM for a ship's propulsion system

Assume a ship management firm wants to introduce PdM for its vessels. As a first step the company wants to develop a PdM approach for the propulsion system of a series of their vessels. The first step therefore is determining the most suitable candidates for PdM within the propulsion system.

Criticality classification

A streamlined FMECA can be conducted to determine the most critical failure modes within the diesel-direct propulsion system. These FMECAs can be conducted using experts at the shipping company and OEM experts. The identified failures can then be plotted in the four-quadrant chart, see **Figure 3.**

The four quadrants represent the following maintenance advice: Q1 (upper right, including the cut-off regions of Q2 and Q4): fix unreliability during design; Q2 (upper left): fix failures with spare parts; Q3 (lower left): regular (OEM prescribed) maintenance; and Q4 (lower right): predictive maintenance. The dotted line indicates the lower limit for Q4, failures with a lower failure frequency are expected to lead to a negative business case. Several common failures are identified in the Q4 area in [1]. These failures cause a downtime longer than 24 hours and have a failure occurrence of more than once every 30 years (the minimum economic lifetime of the vessel). The upper limit on the failure frequency for Q4 is set at one failure every three years.

Identifying Showstoppers Related to the Desired Outcome

The desire is to do prognostics, so the associated potential showstoppers are analysed. The company operates its vessels

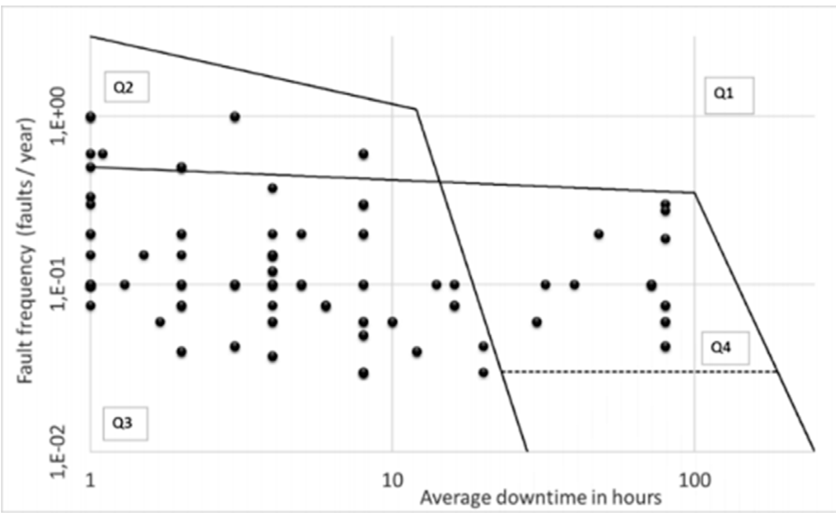

Figure 3. Four quadrant method showing failures for ship propulsion system [1]

all over the world. Consequently, their maintenance opportunities are limited. The current fixed-interval preventive maintenance policy prescribes many clustered maintenance activities. The larger maintenance activities are scheduled during docking periods. The mission schedule allows for small maintenance activities during operations and bad weather periods. However, at those moments limited tools and specialisms are available thus not all maintenance activities can be conducted.

The showstopper identification proves to be of high value for this case Initially, assume the cylinder liner selected as potential component (based on FMECA analyses and applying the four-quadrant chart). However, it can turn out that the developed physical model, that helped to prolong maintenance intervals, could not be used to its optimum. As the maintenance activities of the complete diesel engine are clustered into a use-based preventive maintenance policy, only conducting maintenance for the liners would not be efficient. **The showstopper identification, as used in the proposed method, clearly points at this issue.**

By using the proposed method, the clustering of maintenance activities could have been identified in advance as a showstopper. Further, one of the factors affecting the failure: diesel engine bearing shells worn is fouling of lubrication oil.

Periodic oil sample analysis is ongoing in many ships. However, considering the mission clustering requires checking whether the prognostic distance of these analyses is large enough. Oil samples cannot be analysed aboard all vessels. These samples are therefore sent to a lab. However, when the vessel is operating in a remote location, the period between taking the sample and receiving the analysis result can be too long to take timely measures (i.e. change the oil). Nevertheless, other CM techniques (e.g. vibration monitoring) could still provide a way to timely predict a bearing failure, so this instance cannot be a showstopper.

Next, the different crews aboard the vessels are to be trained in the use of prognostic systems. Moreover, high reliability is demanded in the industry and trust in the monitoring systems has to be gained in time. Finally, limited funds are available to invest in monitoring systems. Therefore, the cost effectivity of the investments in PdM is key for this company. [1] discusses the complete overview of potential showstoppers for the candidates remaining from the first step (the four quadrant chart).

Focused Feasibility Study

The showstopper identification [1] shows that the candidate (cylinder exhaust valve) with 'Maybe' suitable for PdM. Combining this with liner life prediction model aids possibility of clustering maintenance activities that was hindered when considering the liner model alone as discussed in the earlier section. The technical feasibility will therefore be studied in more detail in this section, focusing on the valve mechanism. Studying the economic feasibility in detail is not necessary as developing and applying a PdM approach is expected to result in financial savings. The *technical feasibility* of developing PdM for the valve mechanism has been discussed in [1], the results are presented here.

1. *Data acquisition:* based on the work conducted by Lewis et al. (2004), a physical model can be developed. This model accounts for impact (when the valve closes) and abrasion (sliding of valve and seat under combustion pressure). The former is estimated by an empirical relation used in erosion studies, and the latter by Archard's wear law. These are then summed up to make a final wear prediction. Key input parameters for the model are thermodynamic working characteristics of the engine, material properties, and engine operational scenarios. The required data will be collected from engine operational parameters, simulations, experiments and empirical values from literature. **The operational profile will be estimated in discussions with ship managers.** If the results are promising, then a data acquisition system will be installed to record actual operational hours and load conditions.
2. *Data processing:* based on the estimated or logged operational profile, a wear rate can be determined using the developed physical model.

3./4. *Detection and Diagnostics:* The model output will be compared with manufacturer instructions for rejection criteria. The actual wear profile of valves can be determined for a given or logged set of operational scenarios.

5. *Prognostics:* Based on the estimated future operational scenario, the model calculates a remaining useful life (RUL).

6./7. *Decision analysis and Presentation:* The decision support tool will be customised to determine actual wear and remaining life of valves. Subsequently, a set of working scenarios can be simulated in this tool to estimate an approximate maintenance interval or assist in mission planning.

Conclusion

Applying the four quadrant chart as a first filter has shown to reduce the time effort as it significantly reduces the number of potential candidates (up to 90%). The second stage, i.e. identifying showstoppers proves to be an important contribution as well. Several showstoppers can be identified that are easily overlooked by traditional methods. Thus, simply applying PdM / PHM on the top cost drivers or performance killers will in many cases not lead to optimal results (i.e. reducing downtime or maintenance costs by applying PdM). Besides, the value of the proposed method is not only in generating a list of suitable candidates for PdM, but also in providing a structured and traceable way to determine these candidates.

THE INSTITUTE OF MARINE ENGINEERS (INDIA)
MUMBAI BRANCH

Hydraulics Workshop – Skill Upgradation Course (Online)

for Marine Engineers, Electro Techno Officers & Superintendents

Faculty Name : Mr. Pravin R Marathe, Ex- Chief Engineer (MEO Class I)

OBJECTIVES:-

- To understand Principle of operation of various hydraulic equipments suchs as pumps, control valves and actuators.
- To understand the symbolic representation of various hydraulic equipments so as to read and analyse the hydraulic circuit diagrams.
- To know the correct dismantling and assembly procedure for various hydraulic equipments.
- To understand safe operation and trouble shooting of hydraulic systems.

Venue : Web Platform / Zoom

Time: 0900 hrs to 1700 hrs

Fees :
Members - Rs. 11,800/- (Inclusive of GST)
(IMEI, CMMI and INA Members)

Non Members - Rs. 14,160/- (Inclusive of GST)

MORE INFORMATION

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By identifying potential showstoppers in advance and conducting a structured feasibility study, the often observed trial-and-error approach in developing PdM in practice can be prevented. The proposal to select the suitable components for PdM / PHM within an asset can be implemented by ship managers and can improve their working practices. It can be concluded that the proposed three stage approach can be widely applied across the maritime sector.

Acknowledgement

This is an academic work performed during the final year of Professional Doctorate in Engineering (PDEng) program at the University of Twente (collections during literature review process [1]). As this PDEng is also an industrial project I also express my gratitude to Prof. Tiedo Tinga who headed Dynamics based maintenance (DBM), for his guidance and to sustain funding from industrial partners to support this work. The idea to introduce this work in to maritime sector was first proposed byresearcher Filippos Amoiralis (based on extensive interviews with stake holders), who worked in DBM group in the year 2015. This work is under further development now.

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About the author

Prabu Duplex had sailed as a marine engineer between 2005- 2013. He graduated from a Professional Doctorate in Engineering (PDEng) program at the University of Twente, in the Netherlands. He also worked in a research group called "Dynamics Based Maintenance (DBM)" which actively focuses on developing innovative predictive maintenance methods for a wide range of industries. His work involved in developing physics based mathematical models to predict the life time of diesel engines components in maritime propulsion systems. He has also a Masters degree in Naval Architecture. Presently, he is looking for a career in design or research activities in naval, wind, offshore or predictive maintenance domains.

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Marine Renewable Energy Scenario in India: Prospects and Challenges (Part 4)

Yash Jain

Future Prospects and Role of Marine Engineers

Marine renewable energy (MRE) holds significant growth prospects in India, with considerable market potential and the capacity for expansion in the coming years. The country's extensive coastline and maritime resources offer a robust foundation for the development of various MRE technologies, including offshore wind, tidal energy, wave energy, and ocean thermal energy conversion (OTEC).

Growth Prospects for MRE in India: Market Potential and Capacity Expansion

India has set ambitious renewable energy targets to achieve a substantial share of renewable power in its energy mix. According to the National Institute of Wind Energy (NIWE), the offshore wind potential alone is estimated to be around 70 GW, showcasing the immense opportunity for MRE growth [1]. This potential has attracted significant interest from both domestic and international investors, leading to increased market activity and project development.

The capacity for MRE expansion in India is further supported by government initiatives, such as the National Offshore Wind Energy Policy and the establishment of dedicated research institutions like NIWE. These efforts aim to streamline regulatory processes, provide financial incentives, and foster collaboration between stakeholders to accelerate the deployment of MRE projects [2].

Importance of Interdisciplinary Collaboration among Marine Engineers, Oceanographers, Policymakers, and Industry Stakeholders

Interdisciplinary collaboration plays a pivotal role in advancing MRE technologies and overcoming key challenges. Marine engineers, oceanographers, policymakers, and industry stakeholders bring unique expertise and perspectives to the table, enabling holistic project planning, design, and implementation.

For instance, oceanographers provide crucial insights into marine resource assessment, while marine engineers leverage this data to optimise the design and placement of MRE devices. Policymakers facilitate regulatory frameworks that support MRE development, while industry stakeholders contribute practical knowledge and investment.

Role of Marine Engineers in Technology Innovation, Project Development, and Capacity Building

Marine engineers play a multifaceted role in driving MRE development forward. They are at the forefront of technology innovation, designing and refining MRE devices to enhance performance, durability, and efficiency. Through collaborative research and development initiatives, marine engineers contribute to advancements in turbine design, materials science, and operational strategies tailored to the marine environment.

Moreover, marine engineers are instrumental in project development, from site selection and feasibility studies to construction oversight and operational maintenance. Their technical expertise ensures the successful implementation of MRE projects while adhering to stringent safety and environmental standards.

Furthermore, marine engineers play a pivotal role in capacity building by mentoring future generations of engineers and fostering knowledge exchange within the MRE industry. By engaging in education and training programs, marine engineers contribute to a skilled workforce equipped to tackle the evolving challenges and opportunities in the marine renewable energy sector.

In summary, the future prospects of marine renewable energy in India are promising, driven by market potential, interdisciplinary collaboration, and the pivotal role of marine engineers in technology innovation and project development. By leveraging these strengths and building strategic partnerships, India can accelerate the transition towards a sustainable energy future powered by marine renewables.

Introduction to Blue Economy

Concept of the Blue Economy and its Relationship with Marine Renewable Energy (MRE)

The concept of the Blue Economy refers to the sustainable use of ocean resources for economic growth, improved livelihoods, and ocean health preservation [3]. It emphasises the balance between economic development and environmental sustainability in coastal and marine areas. The Blue Economy encompasses various sectors such as fisheries, aquaculture, tourism, shipping, renewable energy, and marine biotechnology.

Marine Renewable Energy (MRE) plays a vital role in advancing the principles of the Blue Economy. MRE technologies harness the power of marine resources such as waves, tides, currents, and offshore winds to generate electricity [4]. By utilising renewable energy sources from the ocean, MRE contributes to reducing reliance on fossil fuels, mitigating climate change impacts, and promoting sustainable economic activities in coastal regions.

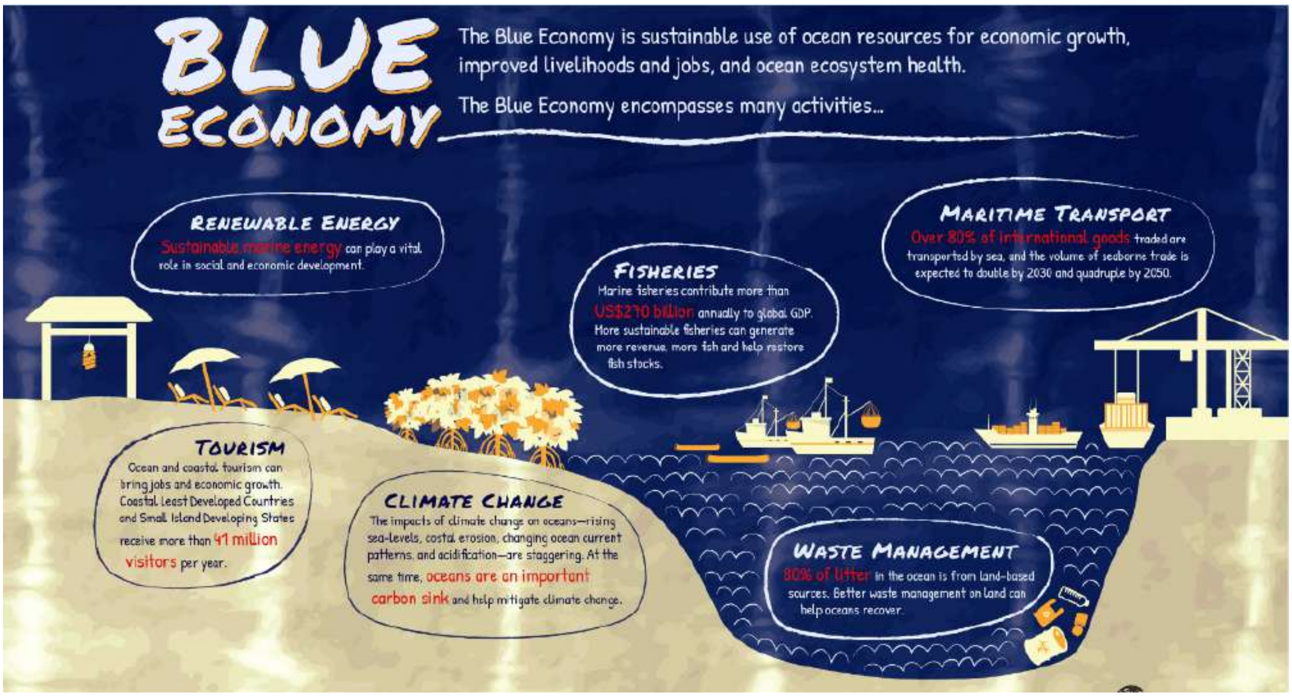
The integration of MRE into the Blue Economy framework aligns with the goals of sustainable development, fostering a harmonious relationship between economic prosperity and environmental conservation. MRE projects can coexist with other marine activities, supporting the diversification of coastal economies and enhancing resilience to climate change impacts [5].

Opportunities for Sustainable Economic Growth through MRE Development

The development of Marine Renewable Energy presents significant opportunities for sustainable economic growth in coastal regions of India [6,7]. By tapping into the vast potential of marine resources, MRE projects can stimulate local economies, create employment opportunities, and attract investments in related industries.

Key opportunities for economic growth through MRE development include:

- **Job Creation**: MRE projects require skilled labor for design, construction, operation, and maintenance. This can contribute to the growth of a specialised workforce and create new employment opportunities in coastal communities.
- **Local Supply Chains**: The establishment of MRE projects promotes the development of local supply chains for equipment manufacturing, installation services, and marine operations, fostering economic growth in nearby regions.
- **Tourism and Recreation**: MRE infrastructure, such as offshore wind farms, can become attractions for marine tourism, generating revenue and supporting local businesses.



- **Technological Innovation**: Investments in MRE research and development spur technological innovation and knowledge transfer, driving economic diversification and competitiveness.

By capitalising on these opportunities, MRE development can promote inclusive growth and enhance the overall well-being of coastal communities while advancing sustainable economic practices aligned with the principles of the Blue Economy.

Contributions of MRE to the blue economy and the energy transition. Photo by IRENA (2021)

International Cooperation and Knowledge Exchange

Marine renewable energy (MRE) development in India is not only a national effort but also benefits from international collaboration and knowledge exchange. Collaborative efforts with international partners play a crucial role in advancing research and development (R&D) in the field of MRE.

Collaborative Efforts with International Partners in MRE Research and Development

India actively engages in collaborative R&D initiatives with international partners to leverage global expertise and resources in the development of marine renewable energy technologies. For instance, the National Institute of Wind Energy (NIWE) collaborates with organisations such as the International Energy Agency (IEA) and the Global Wind Energy Council (GWEC) to exchange knowledge, share best practices, and conduct joint research projects on offshore wind energy [9].

Additionally, Indian research institutions and universities collaborate with counterparts from countries like the United States, United Kingdom, Norway, and Denmark, which are leaders in offshore wind and tidal energy technologies. These collaborations facilitate technology transfer, joint experiments, and data sharing to accelerate the development and deployment of MRE projects in India [10].

Participation in Global Initiatives and Forums Promoting MRE

India actively participates in global initiatives and forums that promote the advancement of marine renewable energy. For example, India is a member of the International Renewable Energy Agency (IRENA) and collaborates with other member countries to drive the global adoption of renewable energy, including MRE [8].

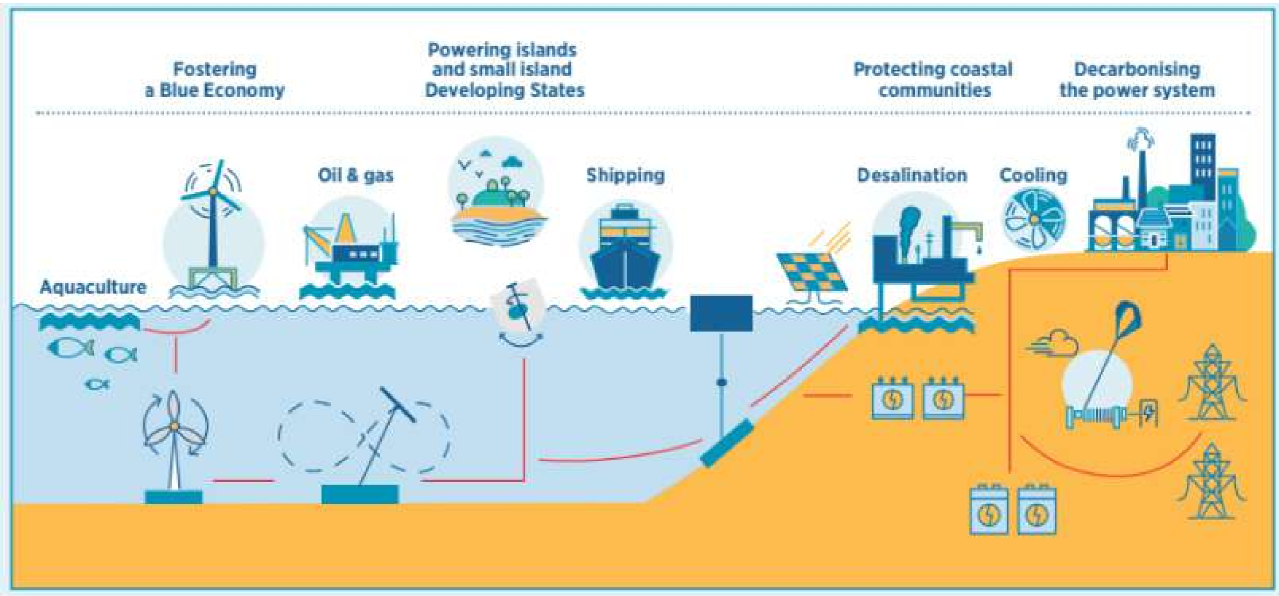
India also participates in international conferences and workshops focused on MRE, such as the International Conference on Ocean Energy (ICOE), where researchers, policymakers, and industry stakeholders gather to exchange ideas, showcase innovations, and discuss policy frameworks for advancing MRE on a global scale [11].

Furthermore, India's engagement in initiatives like the Mission Innovation Clean Energy Materials Innovation Challenge and the Clean Energy Ministerial's Ocean Energy Systems (OES) ensures alignment with international efforts to accelerate the deployment of MRE technologies [12].

Through these international collaborations and participations, India gains access to cutting-edge technologies, fosters knowledge exchange, and strengthens its position as a key player in the global MRE landscape.

Conclusion

Marine renewable energy (MRE) presents significant prospects and challenges for India's sustainable energy future. This article has explored various dimensions of the marine renewable energy scenario in India, providing insights into its potential and the critical factors influencing its development.



Summary of Key Findings and Insights

Throughout this article, it has been demonstrated that India possesses substantial marine renewable energy resources, including wave, tidal, ocean thermal, and offshore wind energy. These resources offer a promising avenue for diversifying India's energy mix, enhancing energy security, and reducing greenhouse gas emissions. However, the deployment of MRE technologies faces several challenges, ranging from technical complexities in harnessing energy from the harsh marine environment to regulatory and financial barriers hindering project development.

Key findings highlight the importance of interdisciplinary collaboration among marine engineers, oceanographers, environmental scientists, policymakers, and industry stakeholders to overcome these challenges. The regulatory and policy frameworks governing MRE development in India play a crucial role in shaping the trajectory of this sector. Government initiatives, such as the National Offshore Wind Energy Policy, are instrumental in fostering MRE projects and attracting investments.

Call to Action for Accelerating MRE Development in India

To accelerate the development of marine renewable energy in India, concerted efforts are needed from all stakeholders. There is a pressing need for increased research and development (R&D) investments to advance MRE technologies and address technical challenges. Industry collaboration and partnerships should be encouraged to drive innovation and scale up project deployments.

Furthermore, policymakers must prioritise MRE in national energy strategies and establish clear pathways for project permitting, grid integration, and market incentives. Capacity building initiatives, including skill development programs for marine engineers and technicians, are essential to build a skilled workforce capable of supporting the growth of the MRE sector.

Recommendations for Policy Interventions, Investments, and Capacity Building Initiatives

Based on the insights and challenges identified, the following recommendations are proposed:

- Implement supportive policy frameworks that incentivise MRE investments and facilitate project development, including streamlined permitting processes and financial incentives.
- Foster public-private partnerships to mobilise capital for MRE projects and promote technology transfer and knowledge sharing.
- Prioritise R&D funding for the advancement of MRE technologies, focusing on improving efficiency, reducing costs, and addressing environmental impacts.
- Strengthen interdisciplinary research collaborations between academia, industry, and government institutions to address technical and environmental challenges.
- Establish demonstration projects and pilot initiatives to showcase the feasibility and benefits of MRE technologies, attracting investor confidence and market uptake.

In conclusion, the successful deployment of marine renewable energy in India requires a holistic approach encompassing policy interventions, investments, and capacity building initiatives. By embracing MRE as a strategic priority, India can unlock its vast marine energy potential, contribute to global climate change mitigation efforts, and pave the way towards a sustainable energy future.

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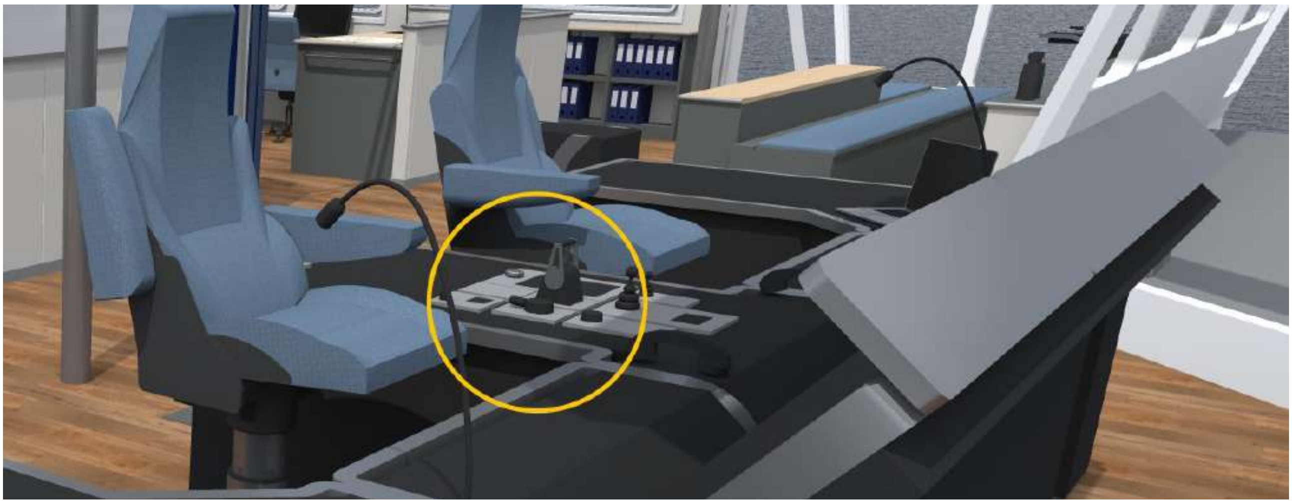
Azimuth Steering System Failure



Ramesh Vantaram

Summary

The following Report is a classic case of Single Point of Failure (SPOF) that occurred while the vessel was in operation. After the incident, the Maker was contacted but their Representative could not attend the vessel due to some other commitments. Therefore, the Owners decided to address the problem independently. During the repair it was found that the torque pin had sheared off and had to be replaced. The simple option was to replace the sheared pin with a replica. This was not an option as the system would once again go into a SPOF mode. Owners obviously did not have the wherewithal to delving into any kind of detailed design calculations. The torque pin was replaced and reinforced. Instead of a 5mm diameter torque pin, 6 Nos. of 16.5 mm diameter torque pins were introduced. Looks like an over-kill, but it was better to err on the side of caution. The vessel underwent the necessary repair/modification and was put back into service.

Based on Owner's feedback, the Maker reviewed the design and came up with a design modification what they called a Swivel Assembly Upgrade. The new assembly was installed during the next docking at their cost. They had incorporated 3 torque pins of 10mm diameter! Adequate redundancy was provided.

Overview

On 23 May 2015, the vessel reported that the DP system showed an alarm "AZIMUTH PORT/STBD PREDICTION ALARM" and until such time the alarm was not acknowledged, the Azimuth Thruster was getting locked. The OEM Technician was informed and he tried some "remote" trouble shooting with no remedy. Finally, he concluded that since the alarms were reported in both the DP Mode and the Independent Joy Stick (IJS) Mode, the problem would most likely be with the Azimuth feedback signal from the Thruster unit to DP/IJS. What was perceived to be a DP related problem, turned out to be a Thruster related issue.

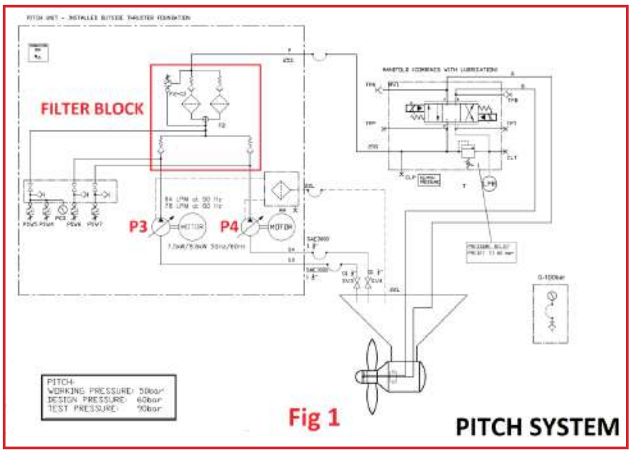
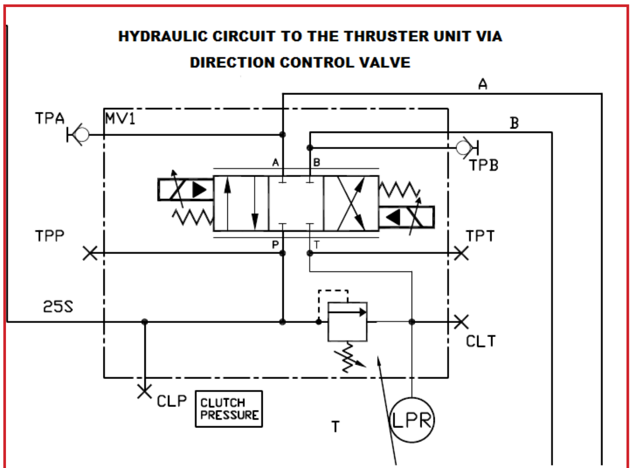
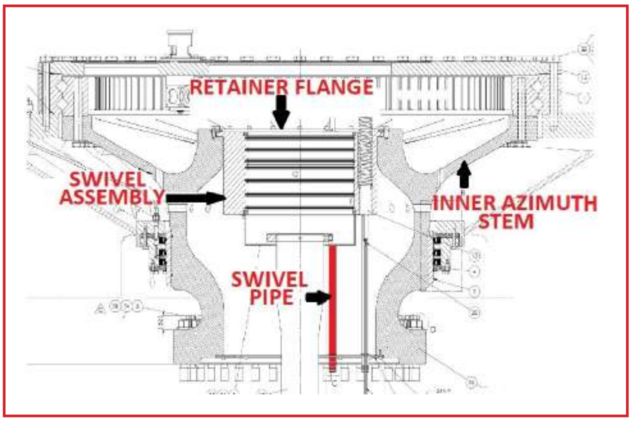


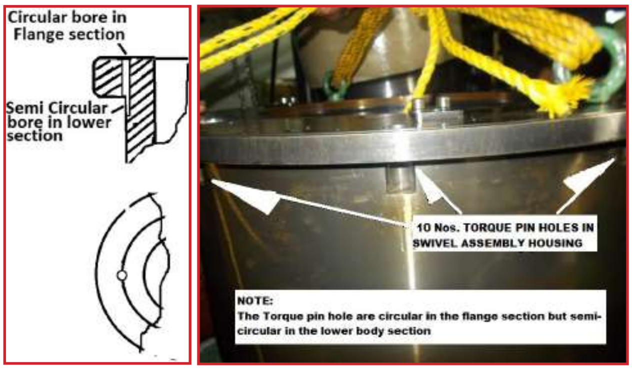
Fig 1 PITCH SYSTEM



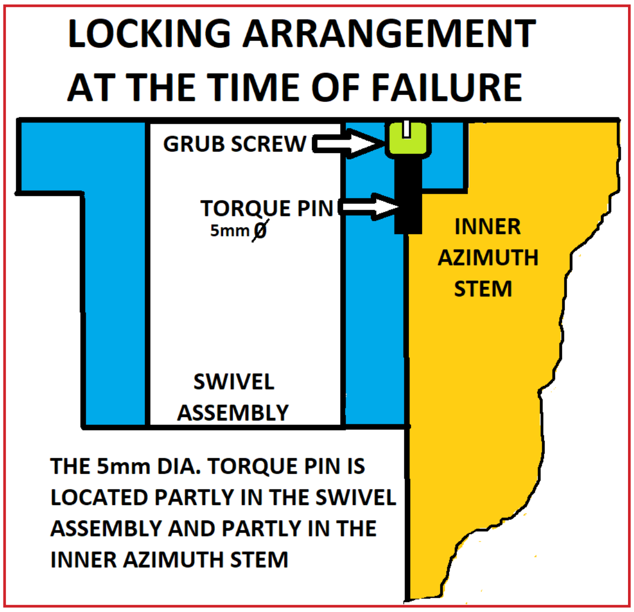
DIRECTION CONTROL VALVE



AZIMUTH UNIT - FAILED COMPONENT SHOWED IN RED



The PCD of the torque pin bore is same as the Outer diameter of the lower housing of the swivel assembly.



Port Thruster

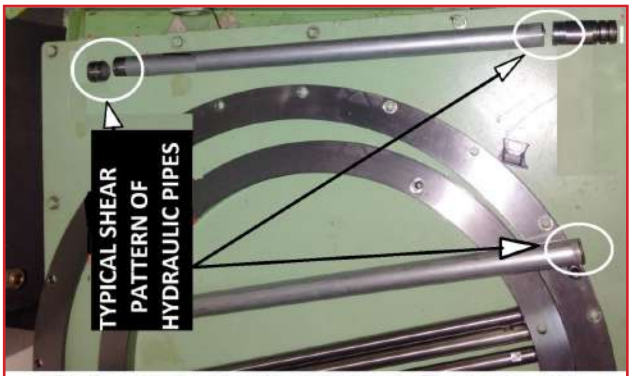
The pitch control pumps were operated and Pumps P3 and P4 appeared to have a malfunction. Since both the pumps were not able to deliver the pressure, it was suspected that there could be some blockage in the system (valves, filters, pipelines). When no blocks were found in the piping etc., it was assumed that the filter block was having an internal blockage.

A new Filter Block was ordered and when this was fitted and tried out there was no improvement. Meanwhile the OEM technician attended on board. The pressures were recorded at the various locations on the proportional directional control valve. The pressures recorded on the return lines were almost zero and so it was suspected that there was heavy leakage down-stream of the direction control valve

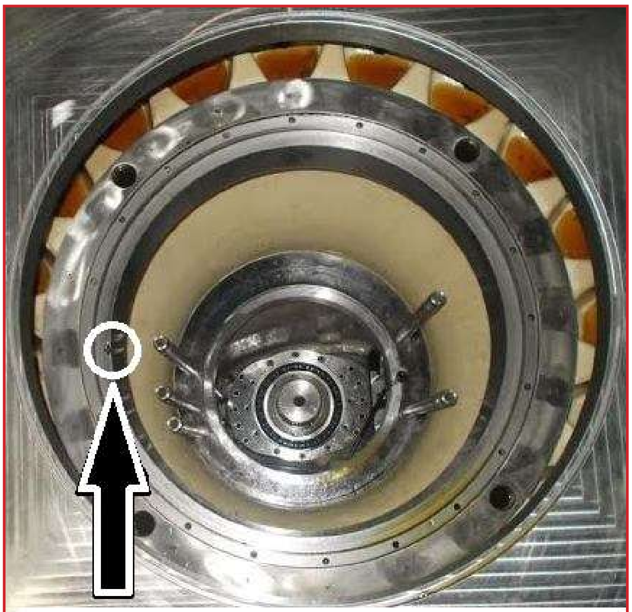
Thereafter the whole unit was dismantled and it was found that the all 5 swivel pipes that convey hydraulic oil to and from the pitch activating pistons, in the hub assembly had sheared off. The cause was identified as failure of the locking arrangement causing a relative movement between the Inner Azimuth Stem and the Swivel Assembly, the later houses the 5 swivel pipes.

Failure Analysis

To understand the incident better, it would be relevant to trace the whole slewing sequence. The slewing motors rotate the slewing gear. The slewing gear is bolted to the top flange of the Inner Azimuth Stem. Inside of the Inner Azimuth Stem, there is a swivel assembly that houses 5 hydraulic swivel pipes. The function of the pipes is to convey oil to and from the pitch activation piston that is located in the hub. The supply of oil is as per the path set by the direction control valve. The linear motion of the pitch activating piston is converted to a rotary motion of the blade via an eccentric pin. The slewing motion of the inner azimuth stem has to be transmitted to the swivel assembly. This torque is transmitted by a torque pin. One half of the torque pin fits in the inner azimuth stem, while the other half fits in the swivel assembly. By this arrangement, the locking of these two components is achieved by a **SINGLE** torque pin. This was the SPOF in the system. Failure of this pin would result in relative motion between the Inner Azimuth Ring and the swivel assembly which is not permissible. In the case in point there was a failure of the torque pin causing the relative motion of the two components. While the Inner Azimuth Stem slewed along with the motors, the swivel assembly remained stationery. This resulted in the 5 pipes housed

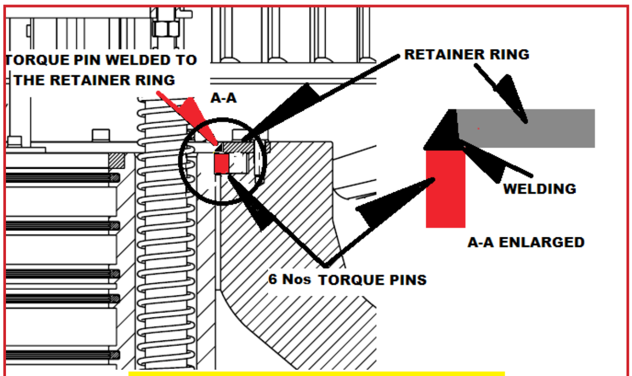


All 5 Nos. Hydraulic pipes sheared off at both ends

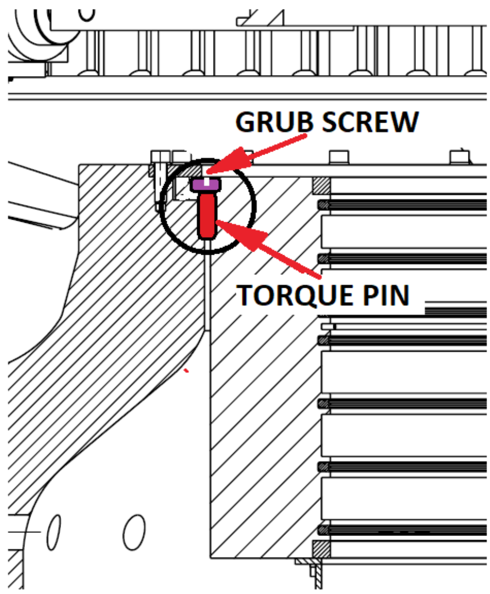


DAMAGED TORQUE PIN HOLE IN INNER AZIMUTH STEM

within the swivel assembly to get sheared off. Thus when hydraulic oil was directed to any side of the hub cylinder, the oil simply did not reach the intended location; rather it leaked off into the sheared pipes and that explained the

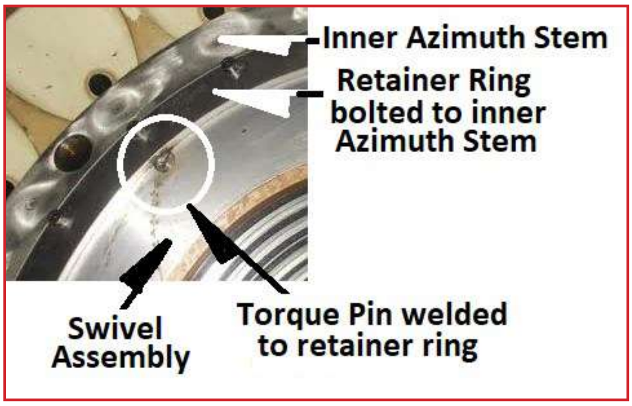


MODIFIED LOCKING



Torque pin is partly in the inner Azimuth Ring and partly in the Swivel Assembly.

ORIGINAL DESIGN



WORLD MARITIME TECHNOLOGY CONFERENCE
Chennai, India 2024

GLOBAL SHIPPING – A BATTLE FOR SURVIVAL OR A TORCH BEARER OF HOPE ?

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December 4 - 6, 2024
The Leela Palace, Chennai

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WORLD MARITIME TECHNOLOGY CONFERENCE
CHENNAI, INDIA 2024

"You Get to Make Your Own Choices, but You Do Not Get to Choose Your Consequences"

"It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of Light, it was the season of Darkness, it was the spring of hope, it was the winter of despair, we had everything before us, we had nothing before us, ..."

Charles Dickens comes to our minds as we reflect upon the state of shipping today. Juxtaposed between Trade Wars, Galloping Technology, Regulatory Challenges and Climate Change issues, we could be looking like a deer caught in the headlights, unable to comprehend where our future lies.

The Lehman Brothers crisis of September 15, 2008, now close to 15 years ago; yet we have not been able to overcome its impact, just as we have never been able to avoid the odd bout of flu every winter, and of course the Covid-19. There has been a continuous stream of regulations, in the wake of galloping technology, escalating political gamesmanship across nations, and also with safety management continuing to be an issue, duty of care towards crew remains questionable.

Is it the first choice industry for an entrepreneur? For the hopeless romantics, it is!

We would like stakeholders in the industry to come forward to make a case for Shipping. We invite you to Chennai and fearlessly present views to make the industry safe, environment friendly and investor supportive. In Chennai, one of India's largest cities and its cultural capital, you would find the rhythm and the beat to speak your mind, with an unwavering conviction and unfounded joy.

On behalf of the Organising Committee and The Institute of Marine Engineers (India), Chennai Branch, we extend a warm invitation to you and your organisation to actively participate and support the three day event, between December 4-6, 2024 in Chennai. We provide you in attachment, a copy of the canvas, and we hope to engage you in cool pre-winter periods in India.

World Maritime Technology Conference (WMTC - 2024)

"GLOBAL SHIPPING – A BATTLE FOR SURVIVAL OR A TORCHBEARER OF HOPE"?
{AMIDST TECHNOLOGY, REGULATIONS, GEO-POLITICS & CLIMATE CHANGE}

Is Shipping a good story? Let us debate.

Looking forward to meeting you in Chennai
On behalf of the Organising Committee, WMTC 2024

Hrishikesh Narasimhan
Convenor

C V Subba Rao
Chairman

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PAPERS

Papers are invited from Financial Institutions, Business Managers, Ship Owners and Managers, Shipping Associations, Regulatory Institutions, Classification Societies, Analysts, Brokerage Houses, Academic Institutions, Shipbuilding & Repair Yards, Professional Bodies, Engineers, Designers, Manufacturers, Students, Researchers, Recyclers, Salvors, Adjudicators etc.

Navigating the Future - Blockchain, AI, Data Analytics and Digital Transformation

Managing and Hedging Risk - Asset, Cargo and Currency

Ship Building and Repairs - Can India grab a share of the market?

Shipping Markets - Can we predict the future?

Marine Money - Do Banks believe in Shipping? - The Basel and The Poseidon Narrative

Duty of Care - Safety Management and Crew Welfare

Reforming (or Romancing) the Future - Is Education the same as Schooling?

Classification Society - A voice of Influence or just an IMO ally?

The Bugle of Geo Politics - Sounds of the 21st Century for Shipping

Sustainable development - Is it only about climate change?

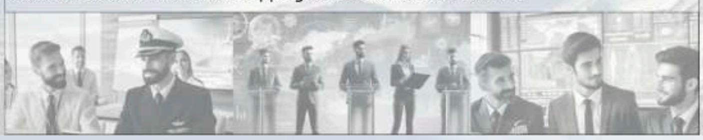
Powering Academic Research - Hulls, Propulsion Equipment, Vibration & Underwater Noise

The Connectivity Conundrum - Linking Rivers, Ports and Railways

Advancements in Product Technologies - Fuel Lubricants, Paints, Chemicals & others

Cost Leadership in Maintenance

Managing Learning - What can Shipping learn from other Industries?



low oil pressure recorded at the directional valve block. **Since the hydraulic pipes were routed within the Thruster assembly, there was no visible leakage as well as no loss of hydraulic oil. The level in the hydraulic header tank remained constant.**

Locking Arrangement

It would be interesting to reflect upon the locking arrangement swivel assembly and the Inner Azimuth stem by means of torque pins.

The swivel assembly is cylindrical in shape having a flange at the top end. The swivel assembly has 10 Nos. axial holes to locate the torque pins. The PCD of the torque pin holes is same as the outer diameter of the lower section. **Thus the bore in the flange section is circular whereas in the lower section it is a semi circlular.** Refer the sketch below and photograph.

The corresponding semi-cylindrical holes is in the inner azimuth stem, thus, the torque pin would efficiently lock the two components together.

Locking Arrangement Existing At The Time Of Failure

At the time of failure, the swivel assembly and the inner azimuth stem were locked together with a **SINGLE torque pin, of 5mm diameter!** This 5mm diameter torque pin was intended to transmit the entire torque exerted by the slewing motors. The 5mm torque pin was inserted from the top and a grub screw held the torque pin in place. Refer to the illustration below

The Torque Transmission chain was as follows:

Slewing Motors to Slewing Ring to inner Azimuth stem, via bolts to the Swivel Assembly via single torque pin.

It is still not understood why 10 torque pin bores were provided and when 10 torque pin bores were provided, why only 1 torque pin was provided. Was it supposed to be a weak-link? Not really because of the fact that the modified design (that was installed in the subsequent dry dock) included 3 torque pins of 10mm diameter!

The torque pin was found to have sheared as it could not transmit the heavy torque. Due to the shearing of the pin, the lower side of then flange and the torque pin hole in the inner azimuth stem assembly sustained damage as can be seen in the photographs. More importantly this resulted in a relative motion between to two components thus shearing the 5 hydraulic pipes (swivel pipe)

Since the repair was carried out in-situ, the ORIGINAL locking arrangement as discussed above in paragraph titled LOCKING ARRANGEMENT EXISTING AT THE TIME OF FAILURE was not replicated, instead locking arrangement was buttressed.

Modified Locking Arrangement:

To ensure that the torque is effectively transmitted from the inner azimuth stem to the swivel assembly, 6 torque pins of 16.5 mm diameter and 19.6 mm length were provided in the modified assembly. Further the bore was restricted only to the through-thickness of the flanged portion of the swivel assembly.

Modified Torque Transmission chain:

Slewing Motors to Slewing ring via Bolts to Inner Azimuth Stem via bolts to Retainer Ring via fillet weld to 6 Nos. Torque Pins to Swivel Assembly. Note that the transmission chain is different to what was originally provided.

After fitting the torque pins in the swivel assembly, the retaining ring was placed over the torque pins and secured to the inner azimuth stem with Allen bolts. The torque pins were then tack welded to the retaining ring. Thus, the torque would get transmitted from the inner azimuth stem to the retaining ring and then on to the torque pins and finally to the swivel assembly.

The sheared hydraulic pipes, 5 in all, were locally procured and machined to house the “O” Rings. Prior to assembly the pipes were hydrostatically tested to 100 bars and found satisfactory. System was tried out and found satisfactory.

About the author

Ramesh Vantaram is an alumnus of D.M.E.T. (1974-1978). The sea career started with The Shipping Corporation of India. After obtaining MEO Cl II certificate, he served with Hongkong-Borneo Shipping Company. After obtaining MEO Cl I certificate in 1983, he served with Anglo Eastern Management Services until 1987. Thereafter he was associated for 3 years with an FAO (UN) regional Project known as The Bay of Bengal Program. The objective of the project was to provide fisher-folk with a viable alternative to Outboard Motors on their FRP boats. The work-scope involved Prototype testing of power tiller engines and multiple propulsion systems.

He worked with Lloyd’s Register of Shipping from April 1992 to June 2005 at Chennai, Ahmedabad and Marmagoa. Just before and soon after his stint with LRS, he served as Chief Engineer, with South India Shipping Company and United Ocean Ship Management Co.

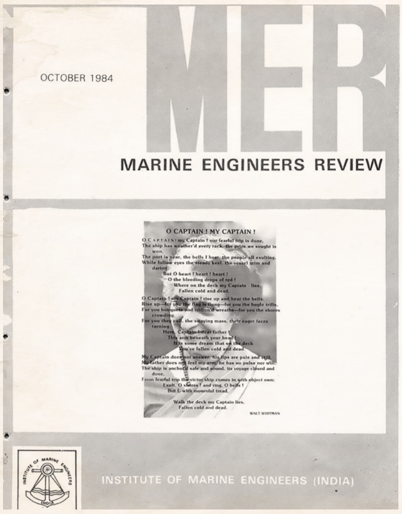
In 2008, he joined Great Offshore as Head of Quality, Health Safety and Environment, in charge of the Company’s International Safety Management and Integrated Management System Certification processes.

In 2014, he moved to Ocean Sparkle Limited as Senior Vice President and served as Regional Head of North West Region. In 2018, took over as Head of Quality in charge of the Company’s Integrated Management System and Certification.

In February 2022, he retired from Ocean Sparkle Limited and took up part-time teaching. Currently he is a visiting faculty at the Institute of Marine Engineers (India) at Navi Mumbai. He regularly writes technical articles especially for student readers in iMélange.

Email: ramesh.vantaram@gmail.com

Going Astern into MER Archives…



The issue's cover carries the photo of Smt. Indira Gandhi and the poetic lines of Walt Whitman. The Editorial captures the turbulent times and need to stick together for the common cause of the country's calls. Following this, the 'Opinion' talks of an interesting operational parameter. Both the 2S major OEMs (Sulzer & MAN B&W) had registered lower fuel consumptions than provided in the trial reports. The submission by the makers is that this was because the projected figures were only conservative. The 'Opinion' adds that the figures obtained have a good degree of accuracy while considering the variables (fuel quality, air temperature etc.).

The first article in the line is on Fluid handling. Fuel Flowmeters, complete pumping of cargoes, hydraulic hygiene are few things discussed herein. Another interesting piece was on Bitumen carriers talking about the monitoring of temperatures and strains.

Any marine engineers with bitumen experience can pitch in with some experience.

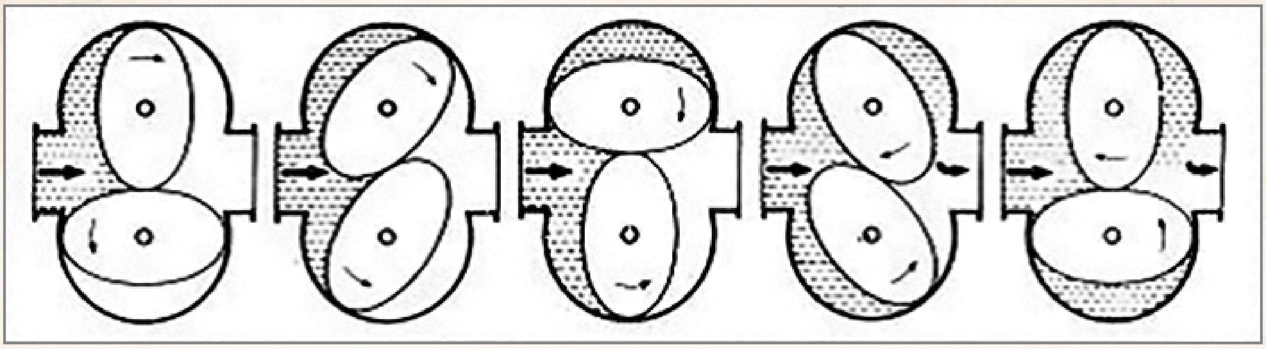
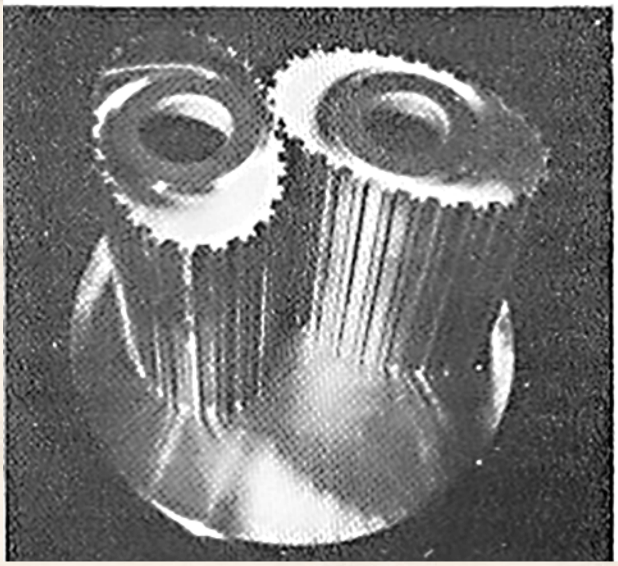


Fig 2: The oval gear wheels. ▼



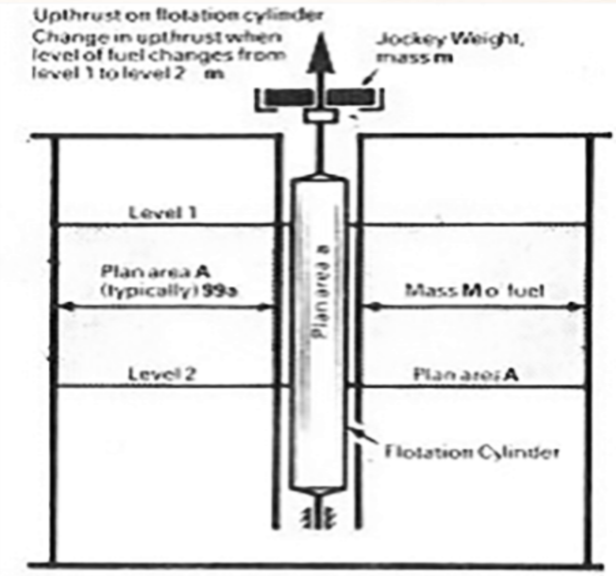


Fig 4: Principle of Plint gravemetric type.

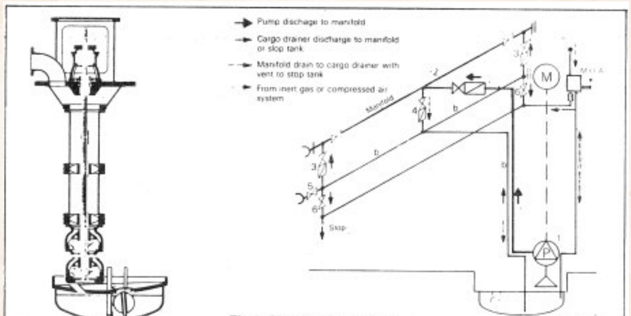


Fig 1: Vatex cargo drainer.

Following these is a 4-page interview with Shri. C.P. Srivastava particularly focussing on the IMO issues of Convention and its functioning. The talks range from improvements in safety, pollution, cost benefit analysis, and how member states can enhance the financial position of IMO etc. This is a good one from the archives dig out.

Next comes an interesting proposition of applying a matrix concept in shipboard organisation. There are some interesting (though often heard) observations on traditional shipboard organisation.

A few for your thoughts:

- Master is considered the sole authority; so 'men at bottom of the hierarchy' consider their roles as being 'non-responsible and there is hair's breadth between being non-responsible and irresponsible.
- The two-class structure of 'officers' and 'men'; this creates a caste like structure difficult to find ashore (!)

Mr C P Srivastava, was born in India in 1920. He graduated at Lucknow, India, with 1st Class Hons in 1941, 1st MA in 1942 and LLB in 1944. From 1948–49 he was Under Secretary in the Ministry of Commerce. After a spell as City Magistrate at Lucknow and Meerut, he joined the Directorate of Shipping in 1953 and became Deputy Director-General in 1954. He held this and other civil service appointments until, from 1966–73, he became Chairman and MD of the Shipping Corporation of India Ltd. From 1967–73 he was also Chairman of Mogul Line Ltd, and from 1972–73 a Director of the Reserve Bank of India. Since 1974 he has been Secretary-General of the International Maritime Organization. Among his very numerous honorary appointments are Chancellor of the World Maritime University, and board member of the International Chamber of Commerce. His even more numerous honours include Hon Member, Inst of Marine Technologists, India, FRSA, UK, Commandeur du Merite Maritime, France, Cmder of the Order of Saint Olav, Norway, Nautical Medal, First Class, Greece. His recreations are music, tennis and reading.

The master being in overall command, he and the deck officers perceive their individual positions to be superior to the corresponding positions of the engineer officers.

But since the master is not trained in engineering, engineer officers consider him incompetent in matters relating to their profession and therefore reject his interference in them.

They also feel frustrated by the generally accepted status structure. Tensions between the two departments are therefore constant and are an impediment to smooth operation.'

Generally people work to satisfy the following needs, usually in this order of priority.

1 physiological (hunger)
2 safety/security
3 social esteem
4 self esteem
5 self fulfilment

Suppose we divide the main specialisations aboard a ship as follows:

- Navigation *
- Steam engineering *
- Motor engineering *
- Electrical engineering *
- Electronic engineering *
- General engineering *
- Administration and management
- Cargo handling
- Communications
- Computing
- Refrigeration

For some more shibboleth statements, the extract will do well. We would invite readers to react to these, if they find merit.

Some more interesting sections include the MARPOL summary from ATLAS-DANMARK Press release and a transaction discussing gas turbines and their evolution. The paper was delivered under 'Parsons Memorial Lecture'. The 'Letters to the Editor' column carries a ponderable letter from an old acquaintance GKR. We can say that MER has somewhat metamorphized over the years into accommodating some part of the requests.

can write articles on this subject. M
private non-shipping companies such
Britannia, Brooke-Bond, etc employ ma
engineers but many of us are not aware
such opportunities. Further, employn
ashore can relieve unemployment amo
sea-going engineers.

(Thank you for your
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We invite observations, discussion threads from readers, taking cues from these sepia-soaked MER pages. – Hon.Ed.

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