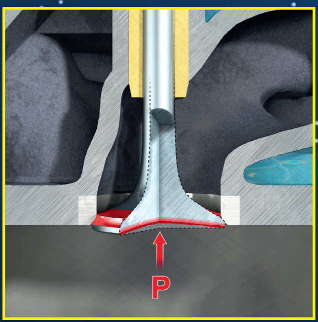
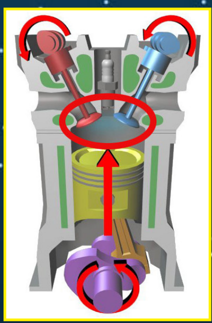
ISSN 2250-1967

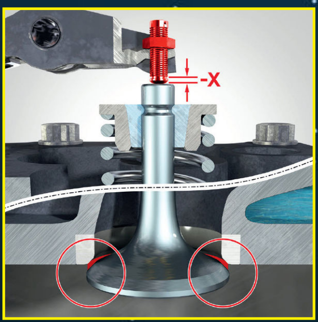
MARINE ENGINEERS REVIEW INDIA

JOURNAL OF THE INSTITUTE OF MARINE ENGINEERS (INDIA)

Volume : 18 | Issue : 1 | December 2023 | ₹ 90/-







Marine Predictive Maintenance: Analysis of Tappet Clearance Model

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EDITORIAL

The world will not be destroyed by those who do evil,
but by those who watch them without doing anything.
- Albert Einstein

Two events in this month need attention: the mid-month launch of IMO CARES and the end-month gathering of COP28. IMO CARES (Coordinated Actions to Reduce Emissions from Shipping) poses a challenge to worldwide organisations to provide a ready-to-use technology solution proposal for emission mitigation. The solution must be conducive for ports and/or ships (5000 grt). The Challenge mentions that possible applications could be on vessels employed in port services, fishing vessels and inter island vessels. Four countries have already been identified as the beneficiaries for the maritime technology solutions, which may win the favour. Apart from funding support for the technology proposal, the Challenge assures further funding of approximately US$500000 for implementation.

This is an innovative approach where manufacturing organisations and start-ups can play it out for a place amongst the pollution pacifiers. More importantly, what this Maritime Technology Global Challenge could bring in is a strong stimulus to academia-industry synergies. The CARES programme was intended to assist small-island and least developed nations but such projects will give traction to other stakeholders also to work on innovative solutions.

Next, the COP28 UAE promises to be more engaging than the previous editions and we may await the daily agenda and the content that will emerge as this MER comes out.

While the evil emissions pervade perniciously, IMO CARES Challenge is certain to add opportunities to the enthusiasts who wish to act rather than just watch.

In this issue...

Prabu Duplex comes in first with an approach to Asset Life Cycle Management. Asset management not being aligned with corporate strategies is an apparent problem in many technology-based ecosystems. With a non-contestable rationale, Prabu takes the tappet clearance monitoring as the case for his approach to optimising predictive maintenance and brings about the RAMSHEEP model in a facile manner. This will certainly be of interest to practicing marine engineers.

Next, we continue with Part B of the ASW technology deliberations. Dr. Veda and Dr. Sudarshan elucidate torpedo technologies. An interesting part lies in the decoy deployment part. Other takeaways are the talks on silencing the submarines, Thermocline hiding layers and the brief talk on the future submarine warfare.

Following this we feature another Conference paper on Hydrogen. Owing to its abundance and cleanliness, its candidature as an alternate fuel is gaining traction. Global investments in green and blue hydrogen are in the increase and investments over US$300 billion are being cited. Dr. Thangalakshmi and Dr. Balaji present a case for Hydrogen, its advantage and production methods. This is an easy, educative read.

'Lube Matters' discusses Fuel Pumps in this instance. Sanjiv pumps in VIT, lubricity, wear mechanisms etc., in a trot. This would be a very familiar discussion for all the marine engineers and the CoC exam warriors.

And Elstan Fernandez returns with his series on electrical equipment maintenance in the Competency Corner.

The picks from the MER Archives (Dec 83) has something for all the engineers. The focus on B&W engines are worth a look.

2024 is around the bend and promises to be exciting. As we approach the New Year, here is the December 2023 issue for your reading pleasure.

Dr Rajoo Balaji
Honorary Editor
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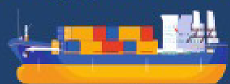

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Print Version: **Corporate Prints**

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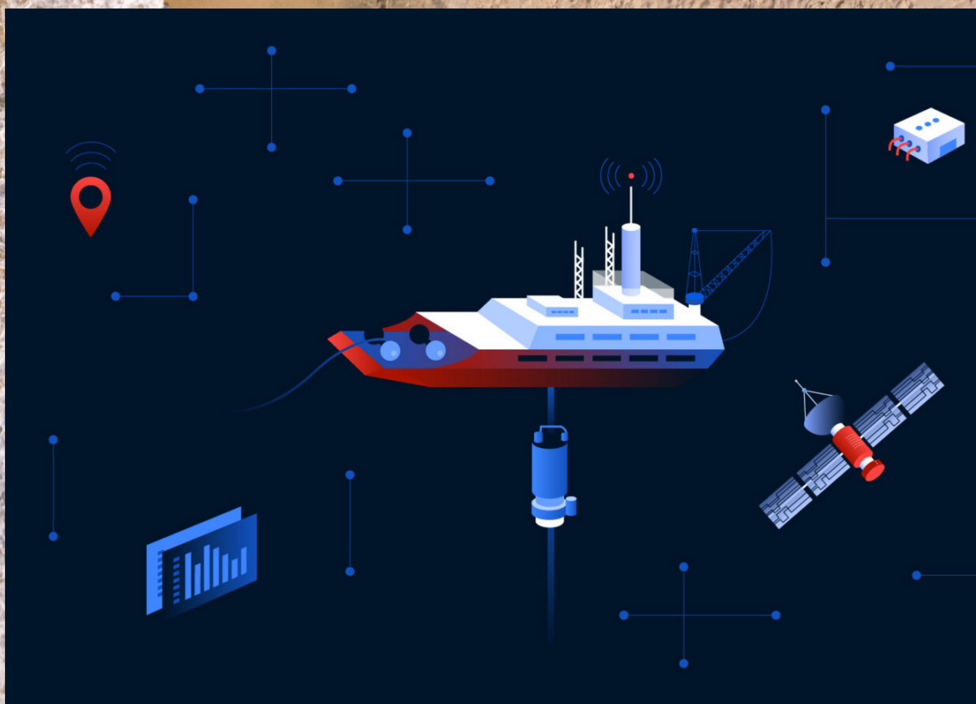

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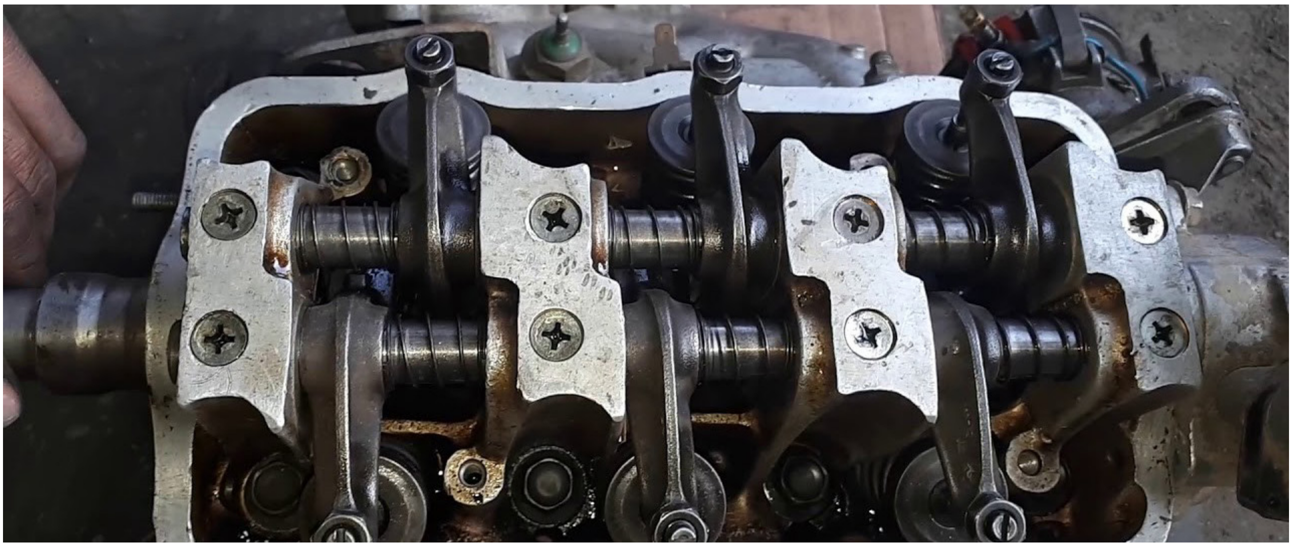
Design for Maintenance: Tappet Clearance Prediction Model, Development Roadmap and RAMSSHEEP Analysis



Prabu Duplex

Abstract

This article introduces an opportunity to improve the design and smoothly introduce alternate maintenance operations for maritime assets. Instead of designing systems to meet known requirements that will always lead to fragile systems at some degree, systems should be designed wherever possible to be antifragile: designing systems that can learn from their experience, adapt to unforeseen events they face in their environment, and grow stronger in the face of adversity. In the context of "Design for Maintenance Operations" the importance of the planning phase of the capital asset, for improving the reliability and safety of the capital asset is also discussed.

Design for Maintenance is a discipline that has become increasingly important in recent years. In the capital-intensive industry, maintenance expenditures can raise in price several times compared to the initial investment. To stay competitive in their business, owners and users of these capital assets consider the total life cycle cost at investment and the decisions renewal for their installations. Therefore, this interdisciplinary way of thinking in terms of life cycle performance gets special attention. From another point of view, risk analysis, including safety aspects performed during the initial phase of the activity, leads to obvious advantages in terms of effectiveness of the outcome and cheapness of the intervention. The necessity for a life prediction tool to predict the life of diesel engine inlet/ exhaust valves is analysed based on these aspects. The life prediction algorithm, development cycle and added value of such methods are also discussed briefly. Furthermore, the article gives an inside view of the complex working of maritime organisations.

Introduction

A ship's role is indispensable in our society. They need to perform in safe, cost-effective and reliable ways to support our daily lives. These assets represent a significant financial value for their owners and typically have lifetimes of several decades. Therefore, effective management of these assets is essential. This need is amplified by two recent developments. If one considers the existing assets in general (in other sectors as well), firstly, 44% of the assets in Western Europe are expected to reach the end of their functional lives within the next 10 years [6]. Secondly, asset managers increasingly face change in both the goals of their assets and the context in which the assets operate [6]. The first development increases the importance of managing (ageing) assets in an effective way, while the latter complicates efforts to do so. The similar scenario is expected in the shipping industry.

Asset Management is concerned with "the balancing of costs, opportunities and risks against the desired performance of [physical] assets, to achieve the organisational objectives" (ISO, 2014, p. 2). According to Pudney (2010), Asset Management has five important characteristics: 1. it is a multidisciplinary practice; 2. the whole life cycle of a physical asset should be considered; 3. the goal is to achieve certain specified objectives; 4. within acceptable limits of risk and relevant regimes; and 5. it should determine the allocation of resources. Asset Management that fulfils these five requirements will be called Asset Life Cycle Management (ALCM). However, the literature clearly shows that most approaches to

Asset Management have a singular focus on technical or financial aspects, rather than being multidisciplinary [6]. Also, often the attention is limited to certain parts of the lifetime of the assets [6], or solely on the estimation of the remaining useful life (RUL) of the assets [6]. Asset Management objectives are not always fully aligned with the corporate strategy [6]. Finally, both the literature and the recent ISO 55000 standard (ISO, 2014) on Asset Management do not offer guidance as to how to do Asset Management in a way that fulfils these five characteristics. Therefore, to address these deficiencies, this work aims *to develop methods and tools for strategic Asset Life Cycle Management in a changeable context.*

Methodology

This work is structured according to the logic of the Design Science methodology [7,8,9]. First the problem is explored in practice, using both a survey and a case study. Then, based on understanding of the problem tools and accompanying processes are developed. These can then be tested and evaluated by real time applications in successive iterations.

Component selection

Ships and other maritime systems are typically complex systems containing large numbers of subsystems and components as shown in **Figure 1**. The ship is subdivided into five main functions (e.g., platform functionality), which are each again subdivided into one up to four subfunctions (e.g., mobility/ propulsion). Finally, each of the subfunctions is realised with 1 up to 11 installations, like a diesel engine, sewage system or navigation radar. However, it should be realised that this is not the lowest level, as each of the installations consists of numerous components. For the diesel engine, these are e.g., bearings, liners, pistons, etc. Prognostic methods, especially physics of failure-based methods, are typically developed at this lowest (component) level. But asset owners and operators are interested in the functioning and maintenance optimisation on the highest (system/ ship) level. This immediately demonstrates one of the largest challenges in predictive maintenance: how can the system level maintenance optimisation be connected to the component level prognostic methods? For an effective preventive maintenance concept, ideally prognostic models for all individual components would be available. However, due to the large numbers of components and the effort required to develop prognostic methods, this full coverage of all components is not feasible in the practice of maritime assets [10]. A suitable selection method is required to select those components for which developing prognostic methods is useful, and this issue, i.e., the critical part selection, will be discussed in this section as introduced in **Figure 1.**

The first challenge lies in selecting the most suitable components for physics modelling, having the highest asset benefits and best potential for implementation.

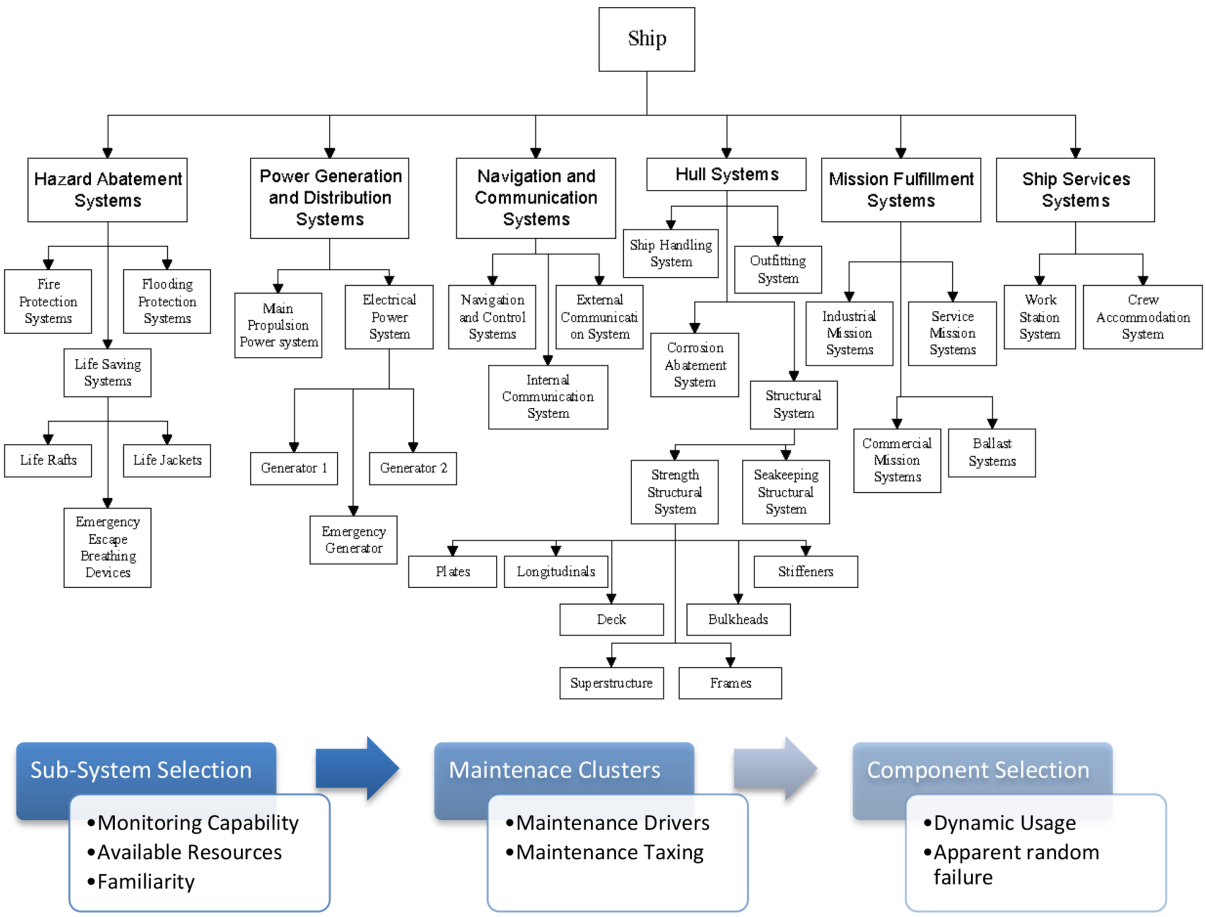


Figure 1. Ship system overview (top) [11] Sub system selection flow chart (b)

With reference to a FMECA study, four quadrant analysis (Figure 2) and discussions with maritime companies, the most common troublesome component amongst was found to be the cylinder liner and engine valves

Having identified it, the dominant material degradation parameters can be determined in relation to the component's operating conditions and incurred loads. Based on findings, a physical model can be developed and implemented considering the overall asset's maintenance policy and mission requirements.

With reference to a FMECA study, four quadrant analysis **(Figure 2)** and discussions with maritime companies, the most common troublesome component amongst was found to be the cylinder liner and engine valves [4]. Among this, developing a model for valve is most promising since it requires frequent overhaul in the engine cluster than liner. Regarding the relation to maintenance, for a normal operating engine, if valve overhaul is extended then the top overhaul can be postponed accordingly. Another frequent maintenance task performed with valves is the tappet clearance adjustment procedure which is done approximately every 1000 hours. **In reality, both maintenance tasks are postponed in case of frequent manoeuvring or other critical maintenance activities performed in other critical machinery.** This introduces uncertainty and risk in the engine operation, and the reliability is reduced. The importance of valve clearance and valve integrity to the engine functioning is well known among the marine engineers, and if there is a way to predict the actual clearance and valve condition uncertainties can be removed, thus safety and reliability of the assets can be ascertained. In case valve maintenance is done as per fixed time interval, change in engine operation (such as extended stand by operation in low load conditions) will not be considered. Subsequently valves are replaced much before its rejection criteria. In a similar logic, if tappet clearances are measured in fixed intervals, this leads to wastage of time and human resources. In line with these discussions' valves are chosen to be an ideal candidate for developing a life prediction model.

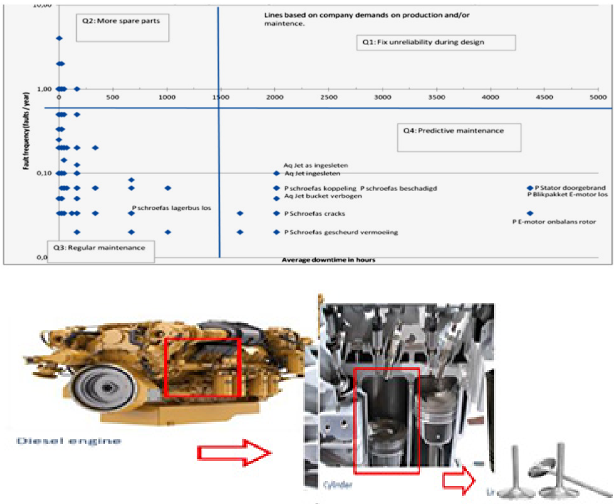


Figure 2. Four quadrant analysis (Top), Sub system selection (Bottom)[4]

Wear mechanism

The charge of fresh mixture and the discharge of combustion gases in the internal combustion engines are controlled by the intake and exhaust valves respectively. They are subjected to demanding conditions such as high temperature, variable mechanical load, and corrosion. Reduction in lube oil consumption, environment regulations (SOx emission control involves removal of Sulphur in fuel, which provides lubricity characteristics) are the main factors which contributes in increasing wear rate.

The failure mechanisms of valves described in literature are: impact wear, abrasion, adhesion or high temperature corrosion as shown in **Figure 3**. Out of all the most maintenance driving degradation is recession, which eventually, reduces the ability of the valve system to seal against the pressure, and results in failure due to guttering.

Valve recession

Impact during valve closure generates plastic deformations on the contact surfaces. This yields to surface cracking and eventually loss of material. Loading of the valve seat interface (VSI) at the instant of closing, generates time variable stresses at high frequencies and

Reduction in lube oil consumption, environment regulations (SOx emission control involves removal of Sulphur in fuel, which provides lubricity characteristics) are the main factors which contributes in increasing wear rate

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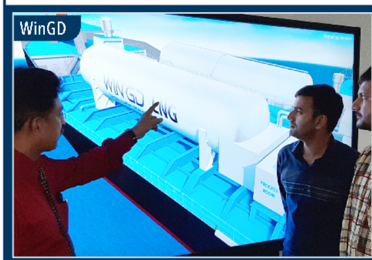

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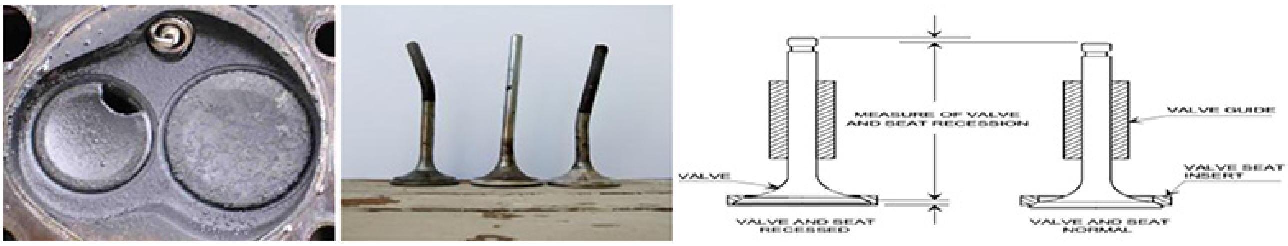

Figure 3. Failed exhaust valve due to high temperature corrosion (L), Fatigue (C), Recession (R)

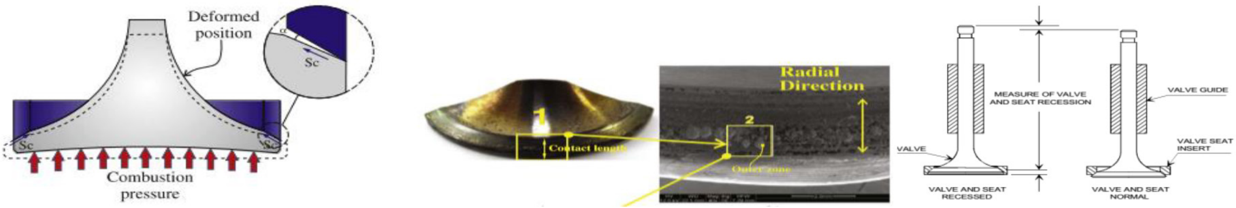

Figure 4. Micro sliding(L), Adhesive wear-material transfer (C), Recession (R)[5]

relative micro sliding between valve and valve seat insert, due to the elastic deformation of the valve head due to combustion pressure. This is termed sliding (adhesive) wear in literature. Both these factors contribute to recession as shown in **Figure 4.** Thus, if other operational conditions are met, recession is the single most reason for wear.

Model development

Abrasive, adhesive, and fretting wear were observed to have occurred because of frictional sliding between the valve and seat under the action of combustion pressure. Therefore Lewis et al.,[3] implemented Archard's wear equation to calculate wear volume in frictional sliding. This method was used successfully to model both abrasive and fretting wear in literature [3]. Deformation observed on the valve seating faces and surface cracking on the seat inserts, are the characteristics of wear features due to impact of particles. This phenomenon is observed in erosion studies and the same is implemented to model wear mass, due to the impact on valve closure. Sliding and impact wear volumes are summed together, which then converted in to wear area, and recession subsequently (based on the observed seat face width W_i and sear insert radius R_i, from geometry, an equation can be derived, relating wear volume & recession (r) as shown in **equation 1**). **Figure 5** outlines the algorithm.

$$r = \left(\sqrt{\frac{V}{\pi R_i \cos\theta \sin\theta} + w_i^2} - w_i\right)\sin\theta_s$$

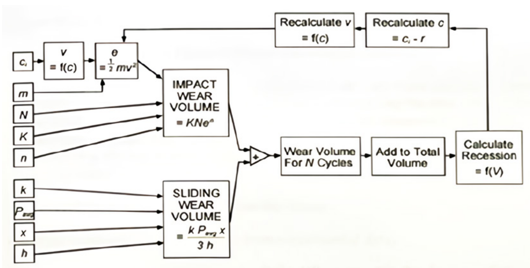

Figure 5. Valve Recession Model Flow Chart [2]

The artefact can simply be implemented in Excel. Various engine operational conditions (engine loading due to operational changes like manoeuvring, service speed and fault conditions) can be included in this model to predict actual wear of the component, and valve service life can be estimated. These analyses clearly show that a failure mechanism based predictive maintenance approach makes it possible to tailor the maintenance activities, to the specific usage profile of each individual system or asset. Instead of starting with highly accurate models, it will be preferable to develop artefacts with less accurate methods (empirical formulas), and based on preliminary prototype results, artefacts can be improved or redesigned to meet the design criteria [2]. This can be done in an iterative way as shown in **Figure 6.**

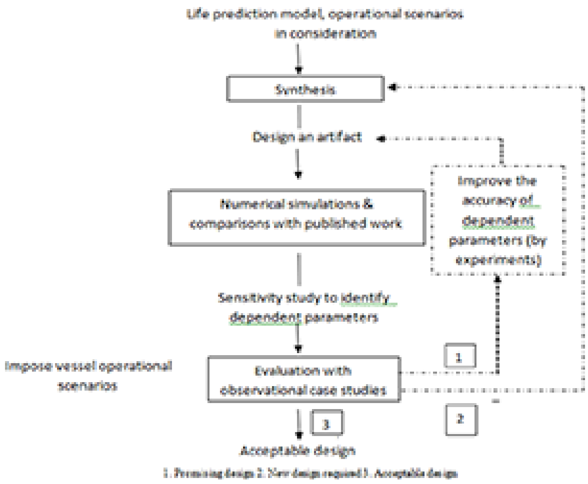

Figure 6. Design process

Various engine operational conditions (engine loading due to operational changes like manoeuvring, service speed and fault conditions) can be included in this model to predict actual wear of the component, and valve service life can be estimated

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Entry Criteria: Any seafarer who has successfully completed approved Basic Safety Training Course as per STCW Section A-VI/1, para 2.3, Tables A-VI/1-1, A-VI/1-2, A – VI/1-3, A-VI/1-4

- This Course will familiarize with the equipment, instrumentation and controls used for cargo handling on a Gas tanker. It will enhance the awareness to apply proper and safe procedures at all times when carrying out the various operations on board tanker

- The trainee will be able to identify operational problems and assist in solving them and will be able to co-ordinate actions during emergencies and follow safety practices and protect the marine environment.

Course Date: 11th December 2023

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Application of the wear model

This wear model can be applied to predict the tappet clearance. Tappet clearance is necessary to allow for thermal expansion of valve spindle length at working temperature. It also ensures the positive closing of the valve as it wears down. This is presently being checked and adjusted around every 1000 hours. During this period, the reduction of clearance due to wear, will be restored to a value prescribed by the manufacturer as shown in **Figure 7**. By doing so valve wear is accelerated as shown in **Figure 8b.** In general, after setting up a valve clearance adjustment procedure, the clearance reduces over usage. In the initial period that follows the clearance adjustment procedure, valve closing velocity will be of definite value and it reduces over usage. The same pattern is reflected in the valve wear, and in initial period valve wear will be more and it reduces over usage, as shown in **Figure 8b.** As shown in the **Figure 8b,** between 1,000 and 1,500 hours the slope of the wear (recession) curve is steeper than in the subsequent period. Therefore, frequent clearance adjustment reduces the valve life. As the wear model predicts the instantaneous clearance, an optimal clearance interval can be established just in time, and valve life can be extended subsequently.

As shown in the **Figure 8a,** with in an interval of 1,000 hours there is wide discrepancy of tappet clearance (function of wear) among various propulsion systems. In **Figure 8a** DE, CPP and WJ are assumed propulsion systems such as Diesel Engine (e.g.: electric propulsion), Controllable Pitch Propeller (engine driven) and Water Jet engine driven system, and SC1 and SC2 denotes operational scenarios (valid assumptions are made for this analysis). After a period of 1,000 hours, the clearance as an output of the model is assessed. It is observed that a minimum of 38% of remaining clearance is left if the engines are used differently; that corresponds to ~ 380 hours. These results justify the necessity of the wear model, to predict the actual tappet clearance and to plan the valve adjustment procedure in time.

Integration in maintenance planning

Figure 9 depicts the structural and functional views of the wear model (mentioned as decision support tool) in an application context, including the requirements. As shown in **Figure 9,** maintenance manager, inputs engine operational hours through GUI, which then communicates with the wear model, and displays the results in GUI. The manager then receives this output and

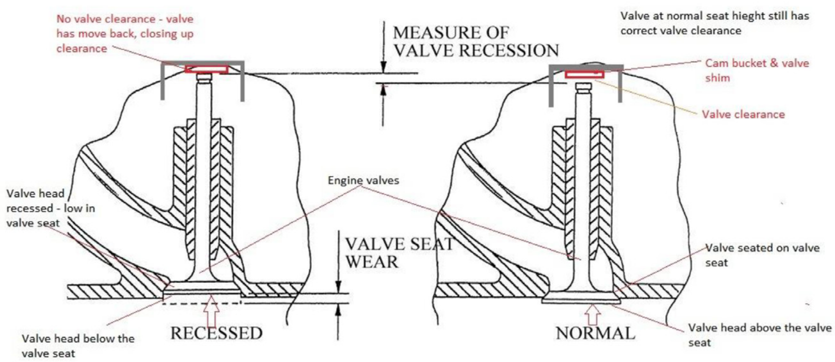

Figure 7. Valve recession adjustment procedure

As the wear model predicts the instantaneous clearance, an optimal clearance interval can be established just in time, and valve life can be extended subsequently

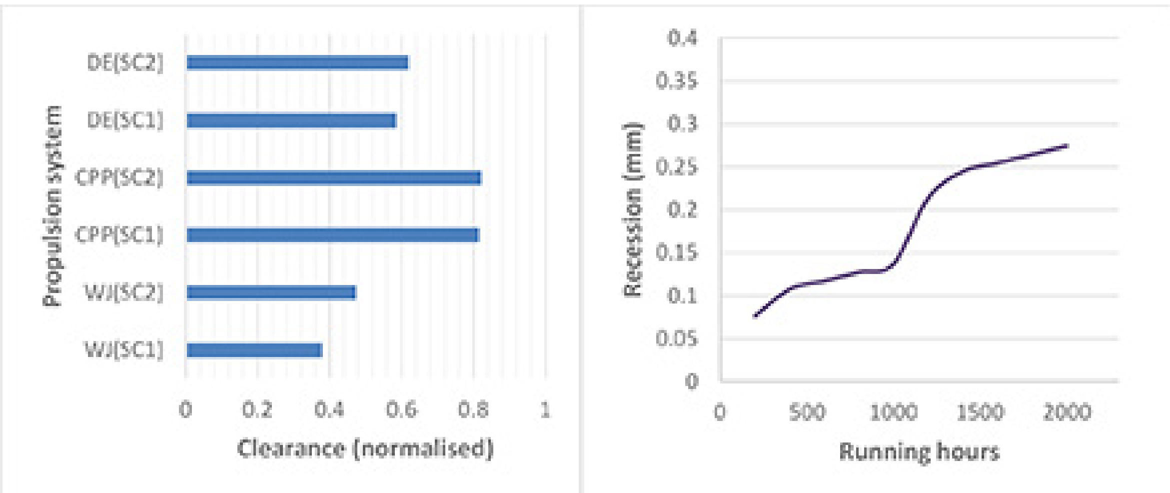

Figure 8. (a) Clearance/1000 hours, (b) influence of frequent tappet clearance adjustment

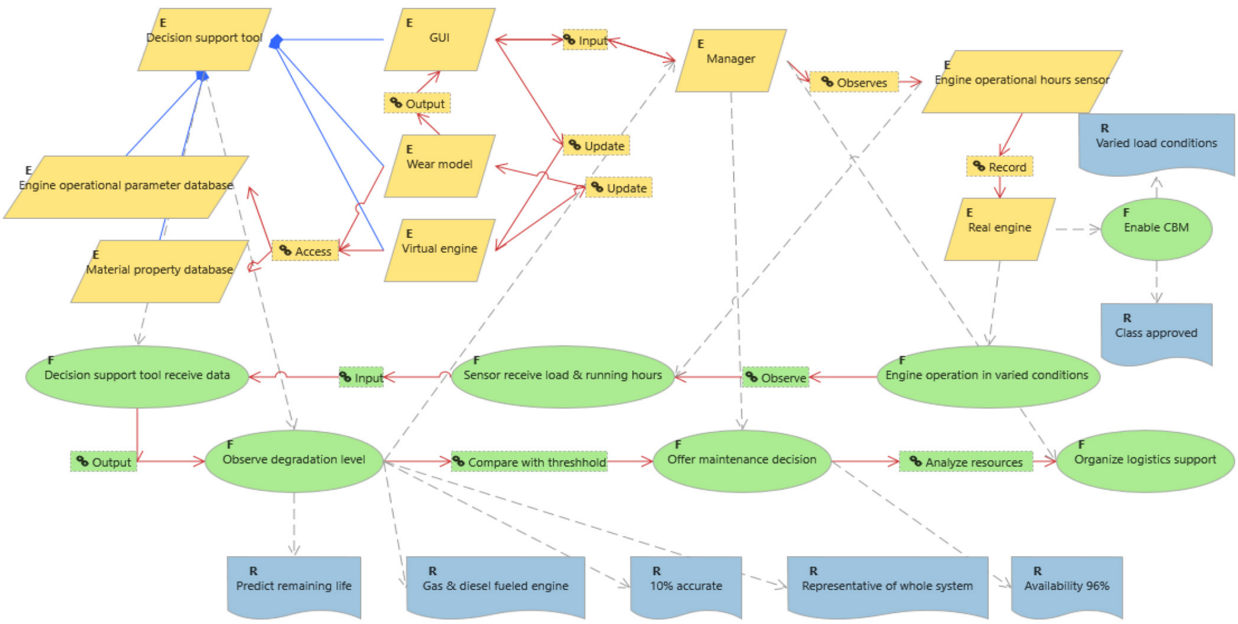

Figure 9. Project model

plans his maintenance needs through CMMS software and logistics tool.

Discussion with respect to RAMSSHEEP perspective

The lifespan to which assets can be efficiently maintained or replaced depends on the factors considered in the design phase. RAMS (Reliability, Availability, Maintenance, Safety) analysis is a proven method often used to reach this target. This approach is however not adequate for handling the complexity of changes and demands over years. There is a need to integrate SHEEP (Supportability, Health, Environment, Economics and Politics) criteria, to improve the performance of the system.

Reliability, Availability, Maintainability

The critical maintenance driving component is selected based on failure mode effect & criticality analysis (FMECA). Therefore, its usage is crucial for the engine cluster, and its condition is assessed in real time by this decision support tool. In this way unexpected failures can be reduced, and reliability of the component is improved.

This wear model is capable of considering dynamic operational scenarios and fares better than the static ones which is being considered in most of the ship management companies. **For example, if an engine is operated in part load conditions wear could be substantially less when compared to full load conditions. Even though this is fully agreed in maintenance decision making, a scientific decision making is not followed and is mostly decided based on the superintendent or fleet manager's experience.** By introducing such decision support systems, decisions can be made based on proven results and thus uncertainties can be reduced. This aids in planning maintenance interval based on actual condition or the remaining useful time of the components. Thus, maintenance activities can be scheduled (preponed or postponed) in a suitable time interval, without affecting the ship's availability.

Equipment failure most of the times affect other components in the cluster, there by affecting the maintainability of the system. By real time monitoring valve failure can be predicted to a certain extent, and as a result maintainability can be improved.

Health, Safety

Maintenance activities in ships involve high risks due to hazardous work environment and operations. By extending the maintenance interval, workers mean exposure level to such hazards can be reduced. In a similar logic if tappet clearance check or valve replacements are done prior to their actual rejection criteria, this overloads the personnel, and they will be exposed to additional work fatigue.

Economics

Ship managers are in extreme pressure to maintain ships in allocated budget. On successful implementation of this wear model, maintenance interval can be extended, and material is used to its complete life, which results in substantial cost savings to the company. If we consider an example of a tugboat management or an ownership company, clients (ship charters, port authorities, oil and gas producers etc), hire tug boats under strict contractual agreements. By optimising maintenance activities, tug's operational down time will be reduced. Consequently, ships can enter or leave ports in shorter period (the more time spent in a port or in anchorage charterers need to pay additional charges). This results in higher profit margins to the clients and added reputation for the ship managers. Harbours will operate in an efficient way, due to higher vessel availability. Vessel congestion and associated city traffic will be reduced. On successful implementation of this project, a market opens for precision measurement devices, sensors, engineering software developers.

The wear model can simply be implemented in Excel. However, based on observational case studies, it may require additional sensors to monitor cylinder head deflection or some other complexities. In any case, involved cost will be substantially lower due to the simple mechanisms or inexpensive sensors involved.

Supportability

The artefact (wear model) can be developed in Excel. Excel offers easy user interface, consistency in results and user-friendly post processing capabilities which are crucial for the success of the project.

Environment

Once the condition of the component and remaining useful lime time can be predicted in advance with the aid of such decision support systems, smart logistic solutions can be planned with respect to spare parts supply and maintenance coordination. This reduces carbon footprint and increases operational efficiency.

Politics

Such pilot projects can be developed in collaboration with a consortium of industrial partners to save initial development costs. The success of the project results in adding value for any ship management and for their clients in the ever-changing demanding scenario.

Conclusion

This work clearly shows that RAMSSHEEP Methodology covers a wider dimension than technically centred RAMS concepts. Due to changing environments and critical economic and political demands, nowadays additional factors need to be considered while designing new projects or technologies. RAMSSHEEP analysis is primarily aimed at the design phase of an asset but has potential to be used during the entire life-cycle management [1]. Further research can be done to analyse these aspects in TECCO [6] (i.e. technical, economic, compliancy, commercial and organisational) perspectives to facilitate such an approach.

Acknowledgement

This is an academic group work for, design for maintenance course, performed during the first year of Professional Doctorate in Engineering (PDEng) program at the University of Twente. The course was coordinated by Prof. Alberto Martinetti who held position in Design Production and Management (DPM) research group. I thank him for his valuable support. 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 to choose this coursework and to sustain funding from industrial partners to support this work. The idea to introduce this work in to maritime sector was first proposed by researcher Filippos Amoiralis [4] (based on extensive interviews with stake holders), who worked in DBM group in the year 2015. This wear model 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 Master's 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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Technological trends in Anti-Submarine Warfare-Part B

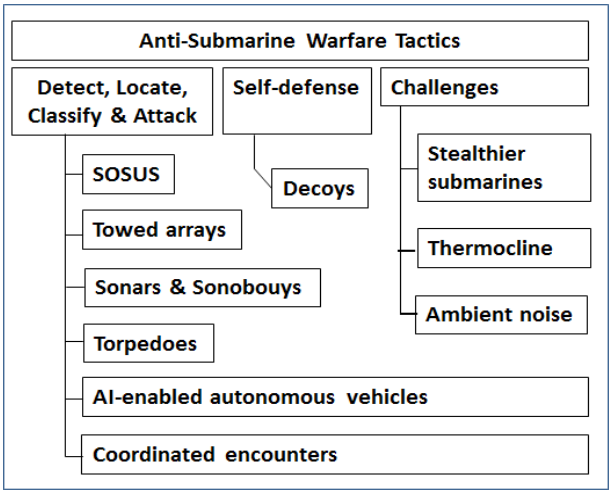
N. Vedachalam, K. Sudarsan

Introduction

Submarines are not only pivotal to naval campaigns, but with their growing cruise and ballistic missile capabilities, they are an important part of deterrence, subsea warfare, as well as capable of carrying out any major land offensive. They are most survivable for carrying out a reliable and secure retaliatory second strike. Even before a conflict arises, a submarine's ability to deploy military strength to an area without being detected is strategically invaluable. While the speed, endurance, quietness and stealth features of submarines is in the uptrend, development of Anti-Submarine Warfare (ASW) weapons and systems with abilities to neutralise an opponent's underwater force is a sine quo non. The article is published in two parts. **The first part discussed on the ASW technologies that have matured over the past few decades capable of detecting, localising, classifying and eliminating hostile submarines.** This second part details on the recent ASW systems for carrying out Intelligence, Surveillance and Reconnaissance (ISR), technical and environmental challenges in carrying out reliable ASW and the strategic technologies.

Striking the hostile submarine from ship/ another submarine using torpedo

Once the submarine is detected, localised precisely and classified as a hostile target, it has to be eliminated



by attacking using torpedoes. The concept of torpedoes dates back to the 19th century, with early designs powered by compressed air, clock-work mechanisms or steam engines. Over the years, torpedoes have advanced significantly, with efficient propulsion, precise navigation guidance systems and powerful warhead technology. Acoustic torpedoes find targets by listening for their characteristic noise signatures.

> *Over the years, torpedoes have advanced significantly, with efficient propulsion, precise navigation guidance systems and powerful warhead technology*

Later improvements included wire-guided torpedoes that received steering commands through a metal communication wire. Recently the metal wire was replaced by optical fibre, which can transmit much more information. Communication between a wire-guided torpedo and a ship is useful after launch, to confirm the torpedo is on the proper intercept course. As these torpedoes acquire a target however, they switch over to an internal guidance system and the wire is cut.

Torpedoes differ by mission payload (explosive, anti-submarine, and anti-ship warheads), type of launch platforms, operating range, depth, stealth features (that enables the torpedo to surprise and attack enemy vessels without alerting their defences) and intelligent homing systems that autonomously adjust its course to counter evasive manoeuvres and ensure a high probability of hitting the intended target **(Figure.1).** Advanced torpedoes include Black Shark **(Figure.1a),** F21 **(Figure.1b),** Spearfish, etc that could be fired from submarines or surface ships have wire-guidance, self-homing capability, contra-rotating brushless motor (to prevent roll) and skewed propellers. These torpedoes weighing up to 1.5t can attain a maximum speed of 50 kt and range of 50km.

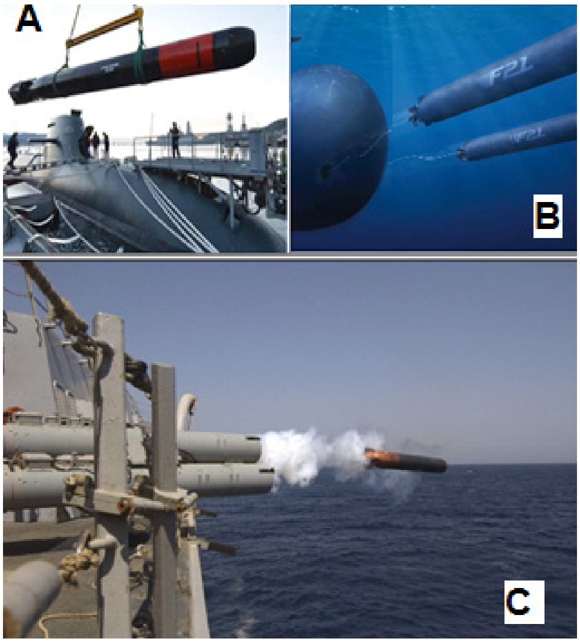


Figure.1. Torpedo launched from ASW ship and submarines

Ship and submarine-operated torpedo decoys

Ships and submarines deploy decoys to protect them from torpedoes attack by deploy their false target away from them, thus increasing their safety. Decoy systems (either towed or expendable) are capable of detecting, confusing, diverting and decoying the approaching torpedoes. The decoy helps in exhausting the energy of the approaching torpedo by running the later through long and ineffective course and preventing them from homing in to the targeted platform with its advanced counter-measures capabilities. The first submarine decoys were used World War II. They comprised of pellets of calcium hydride in a simple metal container. On contact with sea water, it produced hydrogen gas bubbles that acted as a bubble curtain creating a false target. Modern ship/submarine self-defence systems include maskers, jammers, decoys, and anti-torpedo devices. The decoy described in **Figure.2** uses a towed array which confuses attacking torpedo and sends it away from the target (ship).

Ships and submarines deploy decoys to protect them from torpedoes attack by deploy their false target away from them, thus increasing their safety

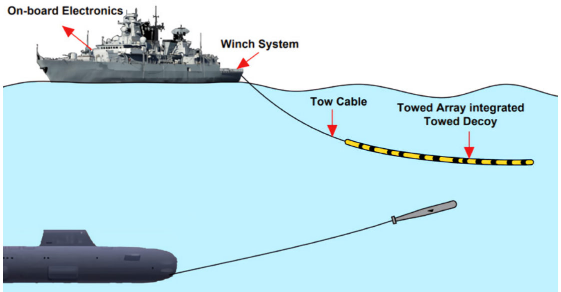


Figure.2. Principle of decoy used for ship defence against torpedo

The present generation advanced decoys, for use by surface combatants and submarines will have an active element to increase the effectiveness of the decoys and multiply the chances of survival of the ship/submarine multifold. An active torpedo decoy like Rafael's 'Torbuster' is reported to seduce and neutralise the torpedo during its run, thereby eliminating the requirement of firing multiple decoys and disabling the torpedo threat in one go. The system calculates the torpedoes range and when it reaches the closest point of approach, it self-detonates a charge capable of damaging or destroying any nearby weapon.

Modern anti-torpedo technologies such as Russia's Paket-E/NK close-in anti-torpedo torpedo and the United States Anti-Torpedo Torpedo Compact Rapid Attack Weapons program (ATT CRAW) enable widening the aperture of platforms capable of employing the weapon to smaller vessels or aircraft, and also increases number of torpedoes that any given platform can carry. They host comprehensive suite of defences to shield against anti-ship missiles, including chaff canisters, active decoys that generate confusing electromagnetic signatures **(Figure.3).**

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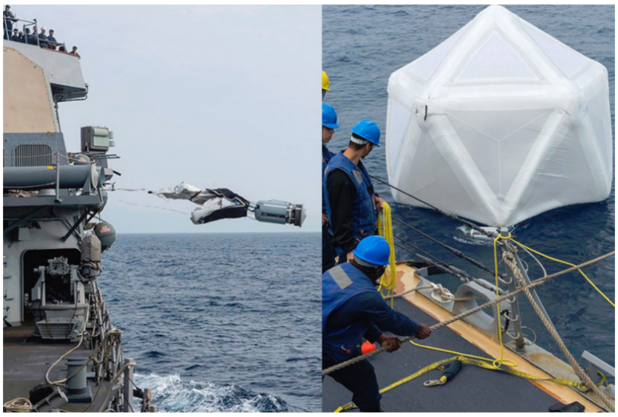


Figure.3. MK59 missile decoy being deployed

Present ASW capabilities

The advancements in the ASW technologies have reached an unprecedented level. Advances in technology will continue to make submarines stealthier and ASW systems has to be more effective. Recent US Boeing P-8I aircrafts are equipped with advanced systems that enable long-range ASW, anti-surface warfare, ISR in support of the broad area, maritime, and littoral operations **(Figure.4).** The 9-crew aircraft which is 40m long with 38m wing span can cruise at a speed of 800 km/h covering a range of 2222 km at an altitude of 12.5 km. These aircrafts have the capability to operate in low altitudes, as well as designed to perform most of the operations from high altitudes, where the thinner atmosphere allows for greater fuel efficiency. These aircrafts can loiter overhead as its lowest speed is 200 miles per hour, and it can stay on the mission for an extended period due to its in-flight refuelling capabilities. Their primary payload comprise of a diverse ray of sensors including radars for 360°coverage and advanced multi-sensor imaging and laser sensors for creating accurate situational awareness. The systems in the aircraft are designed to track submerged target submarines, the rotary launcher system can dispense sonobouys into the water. The P-8I has its own acoustic sensor and even the new hydrocarbon sensor that can sniff fuel-vapor from submarines. The P-8I computers are designed to fuse data into a single coherent picture for the operators and share the data through a secured communication link to other ASW assets.

The Virginia class, or the SSN-774 class, is the latest class of nuclear-powered cruise missile fast-attack submarines in service with the United States Navy designed for a broad spectrum of open-ocean and littoral missions, including ASW and ISR **(Figure.4).** It is a 115m long, 7800t displacement, 120 crew capacity, nuclear-powered (210MW reactor capacity) with operating depth up to 240m. Its 30MW propulsion systems enable a speed of up to 25 knots. Its armament capacity includes 12 VLS & four torpedo tubes capable of launching Mark 48 torpedoes, UGM-109 Tactical Tomahawks and Harpoon missiles. Its self-defence is enabled Mk ¾ decoy. It can be equipped with a low frequency, as well as high frequency towed sonar array.

When its lithium-ion batteries run low, Echo Voyager autonomously surfaces with its mast raised and turn on diesel-powered generators to recharge the Li-Ion batteries

The Russian's Harmony-S surveillance system is capable of detecting enemy ships, submarines, and even low-flying aircraft anywhere in the world oceans. This system termed as Autonomous Seabed Station (ASS) can be launched from a submarine into the ocean floor. Once deployed, the ASS turns into hydro-acoustic station in the seabed, the ASS has fixed sonar (retrievable) antennas that can perform both active and passive roles to detect and classify underwater and surface targets. The gathered information through pop-up buoy can be transmitted through satellite to command centres. Thus advanced countries adopt different strategies based on their geographical location and materialistic capability to build ASW systems.

The ASW technologies, with more focus on ISR are now shifting to AI-enabled autonomous/unmanned, long-range, long endurance vessels. The Unmanned Underwater Vehicles (UUV) are uniquely suited for ASW information collection with their ability to operate autonomously at long standoff distances, as well in shallow waters, and provide a level of clandestine capability that are not available with other systems. The US Defence Advanced Research Projects Agency (DARPA) has developed two systems under the program "Distributed Agile Submarine

Figure.4. Significant air-borne and submarine ASW systems

Figure.5. SHARK UUV for ISR

Figure.6. View of Orca XLUUV

Hunting (DASH)" including The Transformational Reliable Acoustic Path System (TRAPS) which is a fixed sonar node, designed to achieve large-area coverage and Submarine Hold at Risk (SHARK), an unmanned underwater vehicle (UUV) active sonar platform to track hostile submarines after initial detections are made **(Figure.5).**

The U.S. Navy has selected Boeing to develop, test and field five XLUUV Advanced Undersea Prototypes for its Orca program, a contract worth $274 million. The Orca XLUUV **(Figure.6)** is designed to be modular in construction with the core vehicle providing guidance and control, navigation, autonomy, situational awareness, core communications, power distribution, energy and power, propulsion and manoeuvring, and mission sensors.

Boeing's Echo voyager extra-large UUV **(Figure.7)** weighing ~ 50tons in air is host-ship independent with a very long range of 6500 nm equipped with advanced navigation sensor suite, active buoyancy control system, obstacle avoidance and terrain following features and with modular payload capacity. It also features a hybrid rechargeable power system.

When its lithium-ion batteries run low, Echo Voyager autonomously surfaces with its mast raised and turn on diesel-powered generators to recharge the Li-Ion batteries. It could establish a seabed-to-space network that enables the sharing of data between satellites, unmanned aerial and surface vehicles, and manned assets, delivering more comprehensive

Silencing of submarines remains a major challenge requiring intensive efforts at every stage of platform design, equipment development, construction and testing

Figure.7. View of Boeing Echo voyager XLUUV, USV Sea Hunter and Sky guardian UAV

situational awareness for ASW. **Figure. 7** shows the ASW fleet including Unmanned Surface Vehicle (USV) Sea Hunter, Boeing Echo voyager XLUUVs and Unmanned (remotely-piloted) Aerial Vehicle UAV MQ-9B (Sky guardian) for ISR designed to fly over the horizon via satellite for up to 40+ hours in all types of weather and safely integrate into civil airspace, enabling joint forces and civil authorities to deliver real-time situational awareness anywhere in the world, day or night.

Challenges in ASW

While reliable detecting, tracking, and gathering vital intelligence of hostile submarines remain a key part of any country's undersea warfare program, the six major challenges in ASW operations include proliferation of submarine operators (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), quieter submarines, air-independent propulsion (AIP) and reduced indiscretion rates, evolution of submarine weapons with terminal effectiveness and stand-off range, relative ineffectiveness of many ASW weapons, the unchanged and difficult physics of seawater. These features, while enhancing the offensive roles of submarines, also added to the difficulty in planning and carrying out ASW operations. Thus, the present and strategic ASW systems need to reliably detect (stealthier and quieter) hostile submarines, precisely locate and track (without being detected) and communicate (without getting compromised).

Stealthier submarines

The most significant component of "operational stealth" of a submarine is its underwater radiated noise (URN), which remains the primary means by which it could be detected, tracked and attacked by ASW platforms such as aircraft, warships and submarines. Silencing of submarines remains a major challenge requiring intensive

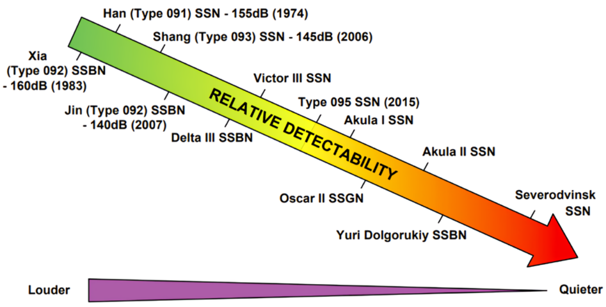


Figure.8. Increasing stealth capacity of submarines

efforts at every stage of platform design, equipment development, construction and testing. If a submarine cannot be seen or heard, then it can't be found, attacked and destroyed. As each new generation of submarine becomes quieter and harder to detect, the sensing technology used in ASW has in turn improved. Submarine hunting torpedoes have followed suit and have now also become quieter and harder for submarines to detect and avoid. The relative improvement in silencing based on the US Office of Naval Intelligence is depicted **(Figure.8).**

Over the past few decades, submarine stealth capability has increased due to the **sustained efforts in quieting technologies including use of natural circulation reactors, direct-drive electric propulsion, contra-rotating propellers (preventing roll), minimising flow asymmetries in the wake of propeller, machinery noise reduction (using quieter equipment, resilient mounts) and special hull coatings to attenuate the noise**.

The latest advancement in reducing submarine noise is the use of elastomeric tiles on the submarine hull (more than 39,000 such tiles affixed on the outer hull of the UK's Astute submarine) introduces further challenges to ASW **(Figure.9).** During 1980s, the US Navy lacked the SOSUS coverage and P-3C and SSN capacity to find and track growing numbers of quiet Soviet submarines **(Figure.10).**

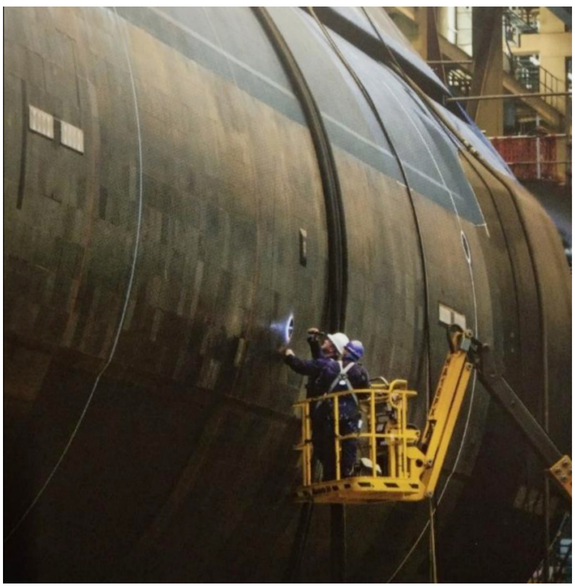


Figure.9. Elastomeric tiles pasted on Astute submarine's hull

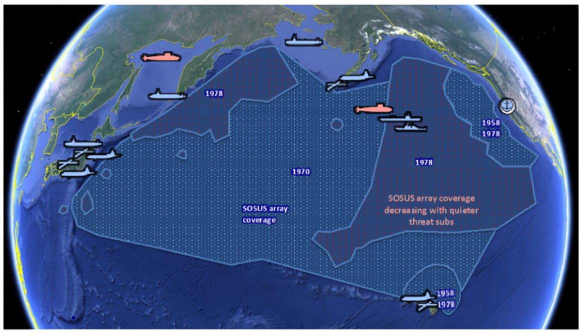


Figure.10. Changing Cold War SOSUS coverage as submarine quieting efforts improved

Simulations are carried out for understanding the ASW detectability limits with increasing 'stealthiness' using the proven Bellhop beam tracing model and sonar equation for predicting acoustic pressure fields with range dependence in ocean environments. The sound velocity profile (SVP) prevailing in a typical tropical ocean is considered as an input. Analysis is done for submarine Underwater Radiated Noise (URN) source levels of 160db (early submarines) and 120db (recent stealth nuclear submarines), ASW system detector hydrophone detector sensitivity of -240db and considering ambient noise levels of 60db, 70db and 80db. It can be understood that, for an ambient noise level of 60db, submarines with URN levels of 160db and 120db could be detected by an anti-submarine warfare (ASW) system from a distance of 10.5 km (Point A/**Figure.11)** and 2 km (Point B) respectively, which demonstrates the stealth capability of silent submarines and the shrinking boundaries of fixed SOSUS installations.

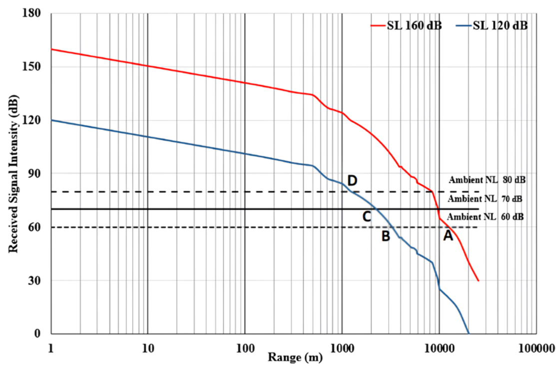
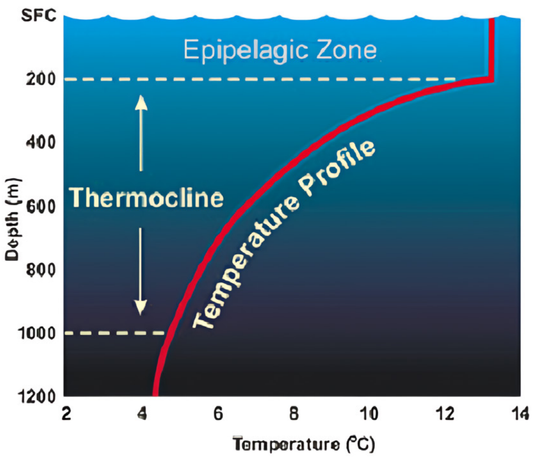


Figure.11. Sources of ambient noise in the ocean

Thermocline hiding layers

Sea water characteristics vary not only with the location, the season and the time of day, but, most importantly for submarines, with depth. The upper layer of sea water is often warmer in tropical waters, succeeded by a cooler layer. Sound transmission across this thermocline interface is lower than that within the same layer. **A hostile submarine can therefore use the thermal layers to conceal itself from detection, particularly from surface ASW platforms.** This will change the angle of the sound waves, sometimes hiding the submarine completely, other times giving a false location **(Figure.12).**



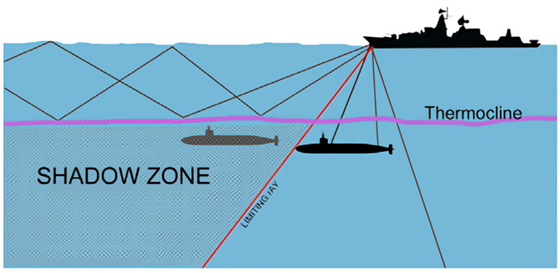


Figure. 12. Submarines concealing inside the thermocline layer

To counter the advantage of the submarine changing its depth and hiding inside the layers of ocean temperature, variable-depth, towed-array sonars and sonobouys are used by ASW ships. These is supplemented by variable depth sonars lowered by ship-borne helicopters (dipping sonars up to 500m water depth), which also reduces the influence of ASW ship self-noise **(Figure.13).** Helicopters can fly out well beyond the horizon to contribute to the ship's situational awareness thus acting as force multipliers. Sonobouys or dipping sonar are dropped at a vector at the estimated distance from the AoU centre that matches the speed of the target submarine. Dipping sonar is the most-effective airborne sonar as it is not expended during a search.

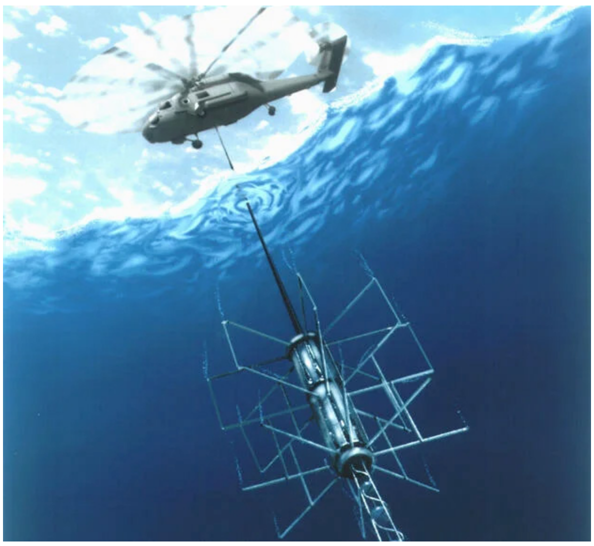


Figure.13. Dipping sonar deployed from a helicopter

A sonar search involves a series of spiral, non-disjointed dips around the centre of the AoU, ensuring overlap of the pattern to compensate for the time between dips and speed of the hostile submarine. During a submarine hunting operation, if the direction of the target submarine is known, the ASW assets employ a 3-ray sonar search. The centre ray is the general direction of motion expected from the centre of the AoU. The left and right rays are angled off-centre according to the submarine's expected speed, higher the speed, the wider the angle between the rays. Submarine hunting experts indicate that, with 18 sonobouys and an eight-knot target less than an hour to datum, there is ~33% chance of detection using these techniques if there are no oceanographic advantages the hostile submarines can use, like high sea state, thermocline layer and topographical shadowing.

Ambient noise

Ambient noises, more specifically in shallow or littoral waters, play an important role in the effectiveness/success of ASW operations. Ambient noise includes contributions from many natural and anthropogenic sources. Ambient noise includes acoustic spectrum from below 1 Hz, to well over 100 kHz **(Figure.14)** is variable, and is dependent on the location and the environmental conditions.

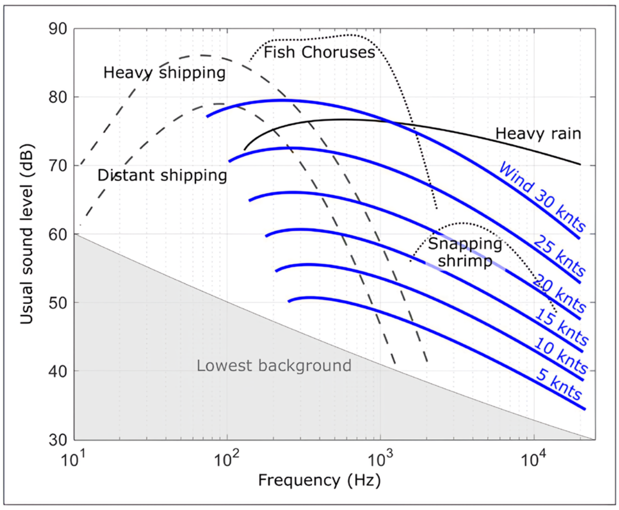


Figure.14. Sources of ambient noise in the ocean

It includes three constituents including wide-band continuous noise, tonal and impulsive noise. Impulsive noise is transient in nature and is generally of wide bandwidth and short duration. It shows peak amplitude and repetition rate. Continuous wideband noise is normally characterised as a spectrum level, which is the level in a 1Hz bandwidth. This level is usually given as intensity in decibels (dB) relative to a reference level of 1 μPa. Tonals are very narrowband signals and are usually characterised as amplitude in dB re 1μPa. These combine to give the continuum of noise to the ASW systems acoustic receivers used detect target submarines. Thus ambient/ background noise plays a significant role in the detection of hostile submarines in littoral and shallow waters. The effective detection capability of

ASW detectors in a littoral environment is based on the sonar equation which defines the ASW receiver detection threshold.

$$SL - TL - NL + DI > DT$$

where DT is the ASW receiver detection threshold, SL is the target submarine noise source level, TL is the transmission loss, NL is the ambient noise and DI is the directivity index.

With reference to the analysis on the influence of increasing ambient noise in littoral waters using Bellhop software **(ref Figure. 13),** it can be seen that for under ambient noise levels of 60db, 70db and 80 db, a submarine with an URN level of 120db could be detected by an ASW detector (with sensitivity of -240db) from a distance of 3 km, 2 km and 1.2 kms, respectively. This explains the challenges faced by ASW systems in effectively locating hostile submarines in noisy environments.

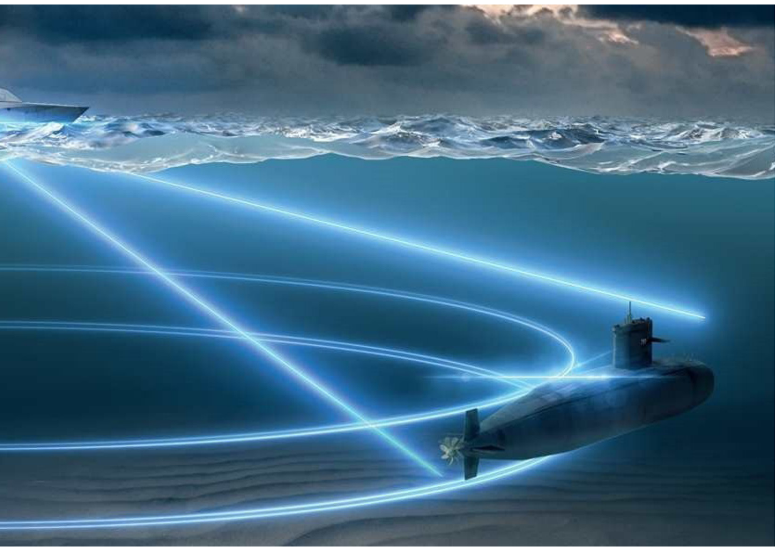
Future undersea warfare perspectives

ASW will remain a core mission area for Navies in the future. Strategic operations will be centred on dominating near-land combat, rapidly achieving area control despite difficult sound propagation profiles and dense surface traffic. The operating environment will be cluttered and chaotic and defeating stealthy enemies will be an exceptional challenge. Significant undersea warfare technology, including modern stealthy submarines and mini-submarines, Air Independent Propulsion and advanced submarine combat systems with associated weaponry (torpedoes, mines, submerged-launch missiles) is being transferred among the nations of the world. Countering these future undersea threats will become increasingly complex, specifically in littoral environments and conventional approaches to ASW and Mine Countermeasures (MCM) will not provide adequate awareness, tactical control, or force protection to achieve objectives in future contingencies.

Advanced technology solutions and new operational approaches in some of the broad capability areas such as Distributed, deployable/off-board ASW sensor networks, MCM capabilities for the fleet, advanced undersea vehicle concepts, and advanced warship self-protection measures against undersea threats are the strategic requirements. The networking of autonomous sensor fields coupled with manned and unmanned vehicles will shift ASW from "platform-intensive" to "sensor-rich" operations. Sensors and networks will enable effective employment of weapons and platforms to a greater extent than ever before. In many cases, the Sensors, Command & Control Devices, and weapons that provide precise firepower may not exist in the same platform.

Some of the near-term ASW transformation is likely to happen in the areas of enhanced Digital Signal Processing, bi-static towed arrays, low-frequency arrays, advanced rapid deployable Systems, advanced sonobouys, periscope detection systems, open architecture torpedoes and torpedo countermeasures. Strategic developments include advanced acoustic sensors including cylindrical bow/keel arrays, flank arrays on hull side, towed arrays, passive ranging sonar and acoustic intercept sonar; advanced non-acoustic sensors such as electronic support measures for signal intercept and direction finding, optical and laser rangefinders, thermal imaging sensors, and automatic rotation, recording, and display mast systems, modern communications, advanced signal processing and displays, high-performance data buses for data fusion and information management. In long term, with these developments ASW transformation will leap forward into distributed network sensors, rapid attack weapons, advanced data relays and integrated weapons systems. Networking across sensors, and cooperative engagement of platforms have also added a new dimension to the battles-pace domain awareness.

Alternate non-acoustic detection methods are being explored to complement the existing acoustic methods. The detection of objects by monitoring hydrodynamic signatures such as wakes and internal waves could be possible through space borne and moored underwater sensors. The other methods such as magnetic anomaly detection and bioluminescence offer indication of subsurface objects in some cases. A successful non-acoustic detection system complementing the existing acoustic methods can be a distinct advantage.



Strategic ASW aims in collection and fusion of data from all-source intelligence, surface assets, underwater assets, aerial assets, space-based assets and seabed sensor arrays. Advances in unmanned vehicle technology in terms of aerial drones, underwater surface vehicles and autonomous underwater vehicles (AUV) as well as developments in sensors like advanced sonars, radar, electro-optical sensors, lasers and MAD provide a better tactical and decisive edge to the forces equipped with these. The introduction of the AI/ML will also significantly improve the capabilities of manned and unmanned ASW mission in future bringing major structural changes to the ASW capability by improving the accuracy and reliability in detecting, tracking, classifying and eliminating underwater targets in the future.

AI is the latest battleground technology for major military superpowers like the US, China, and Russia. It promises to automate and enhance all aspects of modern warfare, including training and simulation, command, control, communications, computers intelligence, surveillance, reconnaissance (C4ISR), electronic warfare, and frontline service. AI integration presents many ethical challenges across the defence sector ranging from humanitarian to regulatory concerns raised by lethal autonomous weapons and disinformation. These issues raise serious questions about the use of AI within the military and the extent to which governments should regulate its development or restrain its employment.

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Potential Challenges of Hydrogen as a Fuel for International Maritime Transport

Dr. S. Thangalakshmi,
Dr. Rajoo Balaji

ABSTRACT

Maritime shipping is an important component of the global market, yet the burden it places on the biosphere is growing rapidly. Approximately one-quarter of all emissions from the international transportation sector are attributed to maritime shipping. The shipping industry, which emits almost one billion tonnes of CO_2 annually, is under great pressure to decarbonise in the next decades. As the use of fossil fuels becomes increasingly constricted, there is a growing demand for alternative fuels at sea. Several initiatives have proved the use of compressed hydrogen as a roadway transportation fuel. Green hydrogen has the potential to significantly reduce carbon footprints in the shipping industry. The utility of hydrogen as a fuel for seagoing ships is studied in this paper. Because hydrogen has a low volumetric energy density under typical settings, efficient storage of this fuel is critical. The fundamental processes of hydrogen utilisation are described, as well as hydrogen synthesis from fossil and renewable sources. The discussion will centre on whether and how hydrogen could be used to replace fossil fuels in long-distance sea cruises. This research also offers a conceptual overview of various hydrogen storage mechanisms. The main challenges and roadblocks to developing hydrogen storage for the maritime industry are investigated.

Keywords: alternate fuels; hydrogen storage; maritime transportation; decarbonisation; green hydrogen

INTRODUCTION

Sea transportation accounts for a sizable share of total global transportation. It is primarily utilised for the movement of commodities, liquid fuels, other items, and people. Ocean tankers, freight ships, and barge tankers all require a large quantity of energy to operate, which is typically provided by diesel or residual fuel oils. Conversely, because of the increased global warming effect, alternative fuels are being studied to replace existing hydrocarbon fuels (Bicer & Dincer, 2018).

There are currently 198 LNG-fuelled ships in operation worldwide. LNG is now the eco-friendliest fossil fuel available for maritime use. LNG fuels emit no SOx, minimal particle concentrations, and NOx emissions that are lesser than any of those produced by traditional carbon fuels (Nerheim et.al, 2021). When compared to common fuel oils, the combustion of LNG lowers SOx and particulate pollutants by approximately 100 % and NOx emissions by 85 to 90 % (IMO, I., 2016). Barely a few marine vessels had utilised hydrogen as a fuel. "Hydra" was the first watercraft to run on hydrogen in 2000 (Raucci et.al, 2015), followed by "Zemships" in 2008 (El Gohary et.al, 2014). Both these vessels were operated with compressed hydrogen (Bach et.al, 2022, Fonseca et.al, 2009). Hydrogen (H_2) and hydrogen carriers are being studied as alternative fuels for power generation, particularly in the maritime sector (Van Hoecke et.al, 2021). In contrast to typical tanker/freight vessel fuel, which is predominantly heavy fuel oil or diesel, hydrogen produces greater energy per mass. The use of hydrogen in nautical applications is ultimately dependent on the capacity to produce cleaner as well cheaper energy (McKinlay et.al, 2020). In addition to several initiatives to minimise ship-based emissions such as SOx and NOx, the IMO chose to limit Carbon footprints in shipping.

In this context, the IMO adopted steps to improve the overall ship efficiency of both new and current vessels. In this regard, the key tools are the "energy efficiency design index" (EEDI), the "energy efficiency operating indicator" (EEOI), and the ship energy efficiency management plan (SEEMP) (Vogler, F., 2016). Many studies have been conducted using the aforementioned approaches to investigate alternative fuels for ships. Hydrogen is gaining popularity as the most environmentally friendly fuel alternative for the future; in this regard, many shipping stakeholders recently sent a letter to the EU Commission encouraging it to foster the use of green hydrogen by vessels as part of the impending marine fuel regulation (Hydrogen as the fuel of the future: Key considerations for shipping, 2021). With no adjustments, hydrogen fuel could replace 43 % of cruises between the United States and China, and 99 % of voyages with modest improvements to fuel infrastructure or operations (Reinsch, 2021). The fundamental advantage of hydrogen energy is that it produces no emissions. When utilised in fuel cells, it also produces less vibration and noise. The downsides of this energy include poor energy density, cryogenic storage, difficulty in handling, limited bunkering facilities, and metal brittleness. India joined the International Partnership for the Hydrogen Economy in 2003. Since then, the country has created a National Hydrogen Energy Roadmap and has provided funds for research and development as well as pilot projects for hydrogen generation and storage, as well as fuel cells.

> **"When compared to common fuel oils, the combustion of LNG lowers SOx and particulate pollutants by approximately 100 % and NOx emissions by 85 to 90%"**

DEMAND FOR LOW-CARBON FUELS

Hydrogen is a type of energy carrier that can be formed from a number of sources. It has a well-established market, with global demand presently hovering about 8-10 exajoules (EJ), the majority of which is utilised in the chemical industries. Currently, fossil fuels account for around 95% of global hydrogen generation. Today, the majority of hydrogen is obtained by steam reforming methane in natural gas and is thus classified as a fossil fuel (Hydrogen Production: Natural Gas Reforming, 2022). Green hydrogen produced through renewable electrolysis, on the other hand, is expected to become cheaper and more widely available in the future, making it a major zero-emission energy and transportation fuel source. **Figure 1** depicts the predicted demand for low-carbon fuels by 2050 (The New Era of Hydrogen is Coming - knoema.com, 2022).

As the globe works to reduce carbon emissions, renewable energy has emerged as an important energy source. Nonetheless, combustible fuels will be required for a variety of reasons in transportation and production industry. Such requirements might be satisfied by hydrogen, which may be synthesised using renewable energy.

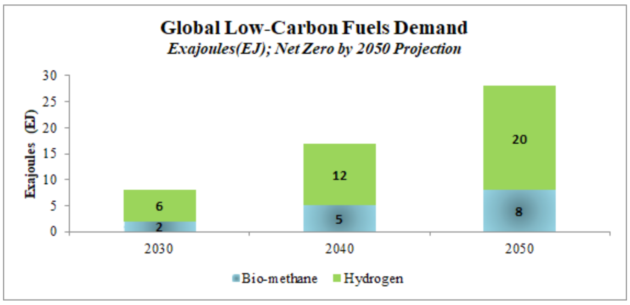

Figure 1. Projected Low-Carbon Fuels Demand

METHODS TO PRODUCE HYDROGEN

Though hydrogen is plentiful on Earth, it is invariably found as part of some other component, such as water (H_2O) or methane (CH_4), and must be split into pure hydrogen (H_2) for use in fuel cell electric vehicles. Through an electrochemical mechanism, hydrogen fuel interacts with oxygen from the air in a fuel cell to produce electric power and water. Hydrogen could be generated using a variety of domestic resources, such as fossil fuels, biomass, and water electrolysis with electricity. The environmental effect and energy efficiency of hydrogen are determined by the method by which it is generated.

Steam reforming is a high-temperature process in which steam combines with a hydrocarbon fuel to yield hydrogen and is often employed in hydrogen generation. Many hydrocarbon fuels, particularly natural gas, diesel, renewable liquid fuels, gasified coal, and gasified biomass, can be processed to make hydrogen.

Several ways for producing hydrogen are discussed below (Alternative Fuels Data Centre: Hydrogen Production and Distribution):

Natural Gas Reforming Synthesis gas is produced by reacting natural gas with high-temperature steam to produce a mixture of hydrogen, carbon monoxide, and a trace of carbon dioxide. Carbon monoxide reacts with water to make more hydrogen. This is the most affordable, efficient, and widely used approach.

Gasification

In a pressured gasifier, coal or biomass could be combined with high-temperature steam and oxygen to produce synthesis gas. This process, known as gasification, transforms the coal or biomass into gaseous components. The resultant synthesis gas contains hydrogen and carbon monoxide, which is separated using steam.

Electrolysis

It is the process by which an electric current divides water into hydrogen and oxygen. If the electricity is generated from renewable sources such as solar or wind, the producing hydrogen is indeed renewable and has various emission benefits. Sometimes it is also referred as renewable electrolysis. Power-to-hydrogen initiatives are getting popular, utilising extra renewable electricity to produce hydrogen via electrolysis when available.

Renewable Liquid Reforming

At the point of use, renewable liquid fuels like ethanol are combined with high-temperature steam to produce hydrogen.

Fermentation

Biomass is transformed to sugar-rich feed-stocks, which could be fermented to make hydrogen.

There are various alternative approaches in the development stage. For instance, high temperatures generated by solar concentrators or nuclear reactors, through a set of chemical reactions split water to generate hydrogen in the 'high-temperature water splitting' method, whereas microbes, such as green algae, consume water in the presence of sunlight and generate hydrogen as a by-product in the 'Photo-biological Water Splitting' technique. Photo-electrochemical systems, which use specialised semiconductors to create hydrogen from water in the presence of sunlight, are also used. The **Figure 2** illustrates alternative scenarios for renewable hydrogen and electricity production (Harrison, K. Renewable Electrolysis).

Mission Innovation, a large worldwide project comprising 24 countries and the European Union, was unveiled on November 30, 2015. The Mission Innovation (MI) Initiative aims to drastically accelerate global clean energy innovation by doubling the government's clean energy R&D funding over the next five years.

India is taking part in this initiative. The execution will be accomplished through transnational research and large-scale demonstration activities, as well as collaboration between the public and private sector on industry-directed achievements. As a result, the Department of Science and Technology (DST) begins research on alternative techniques of generating hydrogen. The country map in **Figure 3** shows several institutions/industries/organisations working on hydrogen manufacturing in India.

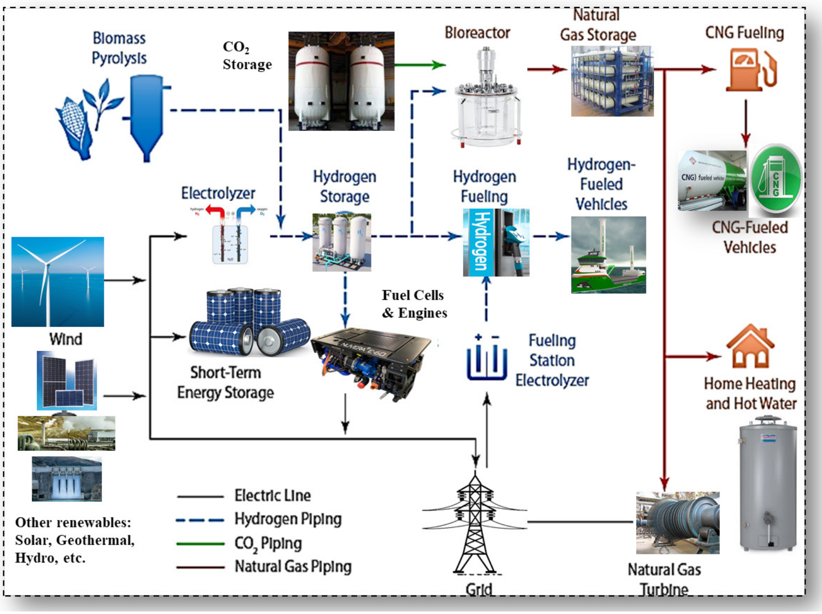

Figure 2. Renewable Hydrogen & Electricity/Hydrogen Cogeneration Strategies

In India, hydrogen is manufactured primarily in the fertiliser, petroleum refining, and petrochemical sectors, as well as a by-product in the chlor-alkali industries. Electrolysis also produces a modest amount of hydrogen for commercial applications.

The **Figure 4** depicts the cost of hydrogen produced using various ways according to the MNRE analysis. The fundamental concern for hydrogen production is to reduce the cost of manufacturing technology such that the produced hydrogen is competitive with traditional transportation fuels.

DISTRIBUTION OF HYDROGEN

There are three methods used for distributing the hydrogen viz. pipelines, high-pressure tube trailers, and Liquefied hydrogen tankers. The pipe-line is the cheapest means to deliver huge amounts of hydrogen, but its capacity is limited because pipe-lines are only built for short distances. These pipes are in close proximity to huge petroleum refineries and chemical factories. Transporting compressed hydrogen gas in high-pressure tube trailers by truck, railway, ship, or barge is expensive and limited to routes of 200 miles or fewer.

Cryogenic liquefaction is the process of cooling hydrogen to the point where it becomes a liquid. Although the liquefaction process is costly, it allows hydrogen to be carried over greater distances more effectively than high-pressure tube trailers by truck, railroad, ship, or barge. If the liquid hydrogen is not utilised at a high adequate rate, it boils off (or escapes) from its containment vessels. As a result, the rates of hydrogen delivery and consumption must be precisely coordinated.

India is aiming to harness its compressed natural gas (CNG) pipeline grid and infrastructure to cut transportation costs for the new generation of emission-free fuel—hydrogen. The Petroleum and Natural Gas Ministry of India revealed plans to blend hydrogen and compressed natural gas (CNG) in the current natural gas network for usage in transportation.

Yet, there are a number of reasons why this may not be feasible. While small amounts of hydrogen (5%-15% by volume) can be mixed with natural gas and carried through existing natural gas pipeline networks, rising blending levels endangers the reliability of designated natural gas pipes owing to the intrinsic differences between hydrogen and natural gas (Baldino et al, 2020).

STORAGE OF HYDROGEN

The key obstacle in the hydrogen pathway is hydrogen storage that is compact, effective, elastomeric, economical, and safety.

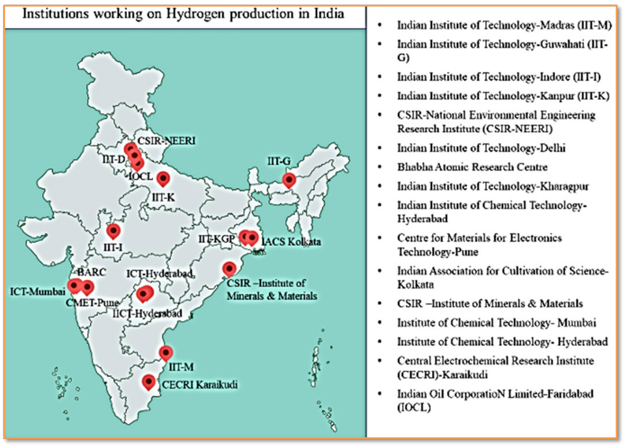

Figure 3. India country map: Various Organizations for Hydrogen Production

The needs of a hydrogen store differ between stationary and vehicle usage. For the transport industry, the weight and size should be low, refuelling should be quick, and the hydrogen storage system should have the majority of the characteristics that current fossil fuel vehicles have, such as range, cabin space, safety, cost, acceleration/deceleration, start/stop, refuelling time, durability, etc. **Figure 5** depicts the many storage choices for hydrogen, which include pressurised, liquefied, and solid states.

Because hydrogen has a low density of 0.089 kg/m^3, keeping it in gaseous form necessitates compression to high pressures. Commercially accessible Type III and Type IV tanks can hold hydrogen at 350 and 700 bar, respectively. The weight of the tank decreases as we progress from Type I to Type IV, but the expense increases. Moreover, compressing hydrogen from ambient to 700 pressures requires around 21 MJ/kg or 0.13 kWh(el)/kWhH$_2$ by means of a five-stage compressor (Rivard, Etienne et al, 2019). (kWh(el) = also kWhe)

Liquefaction of hydrogen requires significantly more energy than compression, requiring approximately 0.33 kWh(el)/kWhH$_2$. The temperature of liquid hydrogen is 20K (density is 70.8 kg/m3), hence the container layout should include super insulation to protect any heat influx into the vessel, however these are not intended to withstand high pressures. The liquified hydrogen storage suffers from boil-off losses, which occur after the pressure builds up and the vaporised hydrogen is released to maintain the tank pressure; the tank system then operates as an open system (Petitpas G et al, 2017).

Another option is cryo-compressed tanks, which are a hybrid approach that combines compressed and liquid state storage. Cryogenic temperatures (usually 70 K 200 K) and increased pressure are used to store hydrogen (typically 100 bar – 500 bar). The advantages of such tanks include better effective H$_2$ storage density and lower system size rather than spending on the energy and cost of complete hydrogen liquefaction, resulting in a longer driving range. The tank in this case is designed to accommodate both the cryogenic liquid and the internal pressure (NITI Aayog, 2018).

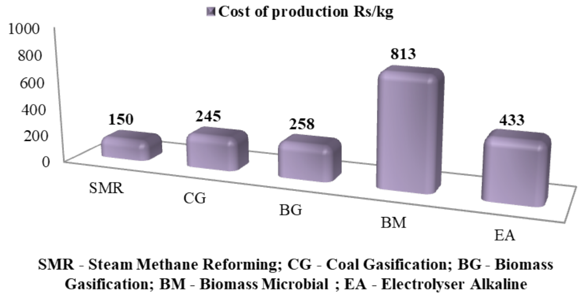

Figure 4. Cost of Producing Hydrogen

India is aiming to harness its compressed natural gas (CNG) pipeline grid and infrastructure to cut transportation costs for the new generation of emission-free fuel—hydrogen

CHALLENGES IN THE USE OF HYDROGEN FOR MARITIME APPLICATIONS

The fuel cost of hydrogen is extremely difficult to calculate since it requires three components: generation, storage, and transportation. Because of production costs, port system location, and mode of transportation, complex overall price methods can have wide variations in shipping industry. The primary goal of hydrogen production is to lower the cost of manufacturing technologies such that the hydrogen produced is affordable with traditional transportation fuels. Depending on the carbon intensity of the production process, hydrogen is classified into three types: Gray hydrogen is generated by steam reforming fossil fuels. Blue hydrogen is formed by steam reforming, but the plants are retrofitted with carbon capture, utilisation, and storage technology. Green hydrogen is developed through electrolysis, which uses electricity to divide water into hydrogen and oxygen. Green hydrogen is the only form of hydrogen with a nearly carbon-free production process because electrolysis does not emit CO_2. Electrolysis with renewable energy (solar or wind power) yields less than 5% of the CO_2 emissions produced by grey hydrogen. While gray hydrogen is now competitively priced in comparison to typical fuel sources, costing roughly $1-2/kg H$_2$, it does not provide a long-term solution for reducing GHG emissions on a large scale. Blue hydrogen is 30-80% more expensive than gray hydrogen, and green hydrogen is around four times more expensive than gray hydrogen. **While retail prices for blue and green hydrogen are expected to fall as the cost of renewable electricity and electrolysis decreases, government intervention is essential to encourage**

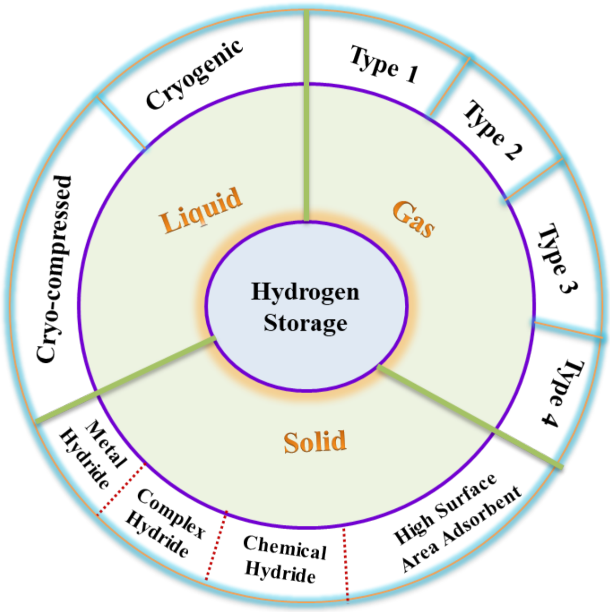

Figure 5. Stages of Hydrogen Storage

private investment in green hydrogen technology and to build the infrastructure for refuelling and hydrogen transportation to make it cost-effective. To make zero-emissions a reality, cost-competitive green hydrogen and cross-industry collaboration will be required.

On-board hydrogen storage devices are prohibitively expensive, especially when compared to traditional petroleum fuel storage systems. Low-cost materials and components, as well as low-cost, high-volume manufacturing methods, are required for hydrogen storage systems. The durability of hydrogen storage devices is insufficient. Materials and components for hydrogen storage systems with a lifetime of 1500 cycles are required.

There are numerous problems in developing an infrastructure for hydrogen distribution and delivery to thousands of future individual fuelling stations. Because hydrogen has less energy per unit volume than all other fuels, transporting, storing, and distributing it to the point of consumption costs more per gasoline gallon equivalent. The initial capital expenses of constructing a new hydrogen pipeline network are considerable, and the characteristics of hydrogen bring unique problems to pipeline materials and compressor design. However, because hydrogen can be generated from a wide range of resources, regional or even local hydrogen production can make the best use of local resources while minimising distribution issues.

Hydrogen is extremely flammable and has a wider ignition spectrum than most conventional fuels, which means that when paired with oxygen, it will burn at both low and high concentrations. However, there are precautions that can be taken to reduce this risk during storage, transit, and ignite. The deployment of green hydrogen will be dependent on the ability to provide training and standards to solve safety issues. There are no applicable rules or standards for hydrogen storage systems or interface technologies that will simplify implementation/commercialisation while also ensuring safety and public acceptance. Standardised hardware and operating procedures are necessary, as are appropriate codes and standards.

The stability of the carriers differs amongst solid-state hydrogen storage techniques. It is best to keep hydrogen carriers away from air and moisture. If not, the hydrogen is discharged from the carrier, which could be dangerous if it happens during bunkering or sailing. There is currently no bunkering infrastructure accessible for large ships, with the exception of FTS-fuels, LNG, and methanol. One of the key hurdles for hydrogen utilisation in maritime ships is the construction of new bunkering infrastructure.

Commercial demand for low-carbon hydrogen should be stimulated by tightening shipping emission rules and providing tax breaks to shipping companies that equip their ships with hydrogen fuel cells. This will assist compensate for the financial loss of cargo that may be displaced due to increased fuel volume.

CONCLUSION

Hydrogen can be generated in a number of ways. Nowadays, the most majority is derived through the reformation of fossil energy carriers, with only 4% derived via electrolysis. Only when produced using renewable energy sources can it play to its strengths in terms of both primary energy use and CO_2 emissions. Furthermore, hydrogen generation via electrolysis can improve grid stability and allow the efficient utilisation of renewable power plants through a process known as sector coupling. The myriad challenges surrounding hydrogen as an alternative fuel for ships were examined in this study. The many techniques of producing, storing, and transferring hydrogen were highlighted. The possible problem found was hydrogen storage, which varies depending on the size of the ship. Future vessels may use hydrogen as fuel if a new infrastructure is created with suitable bunkering facilities and government incentives to reduce carbon emissions.

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[This paper was presented at INMARCO (November, 2022)]

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LUBE MATTERS # 29

TRIBOLOGY OF FUEL INJECTION PUMP

Sanjiv Wazir

Introduction

The fuel injection system is the heart of the engine. The fuel injection pump (FIP) is the most vital component of the fuel injection system. It supplies diesel into the combustion chambers at high pressure and controls the amount of fuel oil needed to gain the desired power. It is timed to operate to keep the engine running smoothly. There are two main types of FIP used in the marine industry.

Types of FIP

On their large 2-Stroke engines, WinGD have replaced the earlier suction and spill valve type with the electronically controlled common piping system called the High-Pressure Common Rail system.

However, because of their simplicity, reliability, and possibility to scale up to meet demands of large engines, most 2-Stroke and 4-Stroke marine diesel engines operate with individual plunger barrel type FIP supplying the fuel to the individual cylinders through one or more fuel injector nozzles. These FIPs are variants of the mechanical reciprocating FIP referred to as a "Bosch" type pump, consisting of a barrel and a helical plunger as shown in **Figure. 1.** These are actuated by the camshaft that is gear-driven by the engine's crankshaft. This type of FIP is discussed below.

"However, because of their simplicity, reliability, and possibility to scale up to meet demands of large engines, most 2-Stroke and 4-Stroke marine diesel engines operate with individual plunger barrel type FIP supplying the fuel to the individual cylinders through one or more fuel injector nozzles"

Even in their electronically controlled engines, MAN did not change the FIP, except for changing the control system from camshaft control to a cam less system with electro–hydraulic valves.

Both FIP designs allow adjustment to fuel oil feed rate and to change the end of injection, and, with the application of VIT (Variable Injection Timing), also allows advancing or retarding the injection timing. This helps economize fuel usage under low load conditions.

FIP working conditions.

The Barrel and Plunger of the FIP forms a precisely machined pair, separated by the fuel oil. During operation, the plunger reciprocates and rotates in the barrel. The sealing of the assembly is maintained by the the tight radial clearances which are from 5 µm to 25 µm.

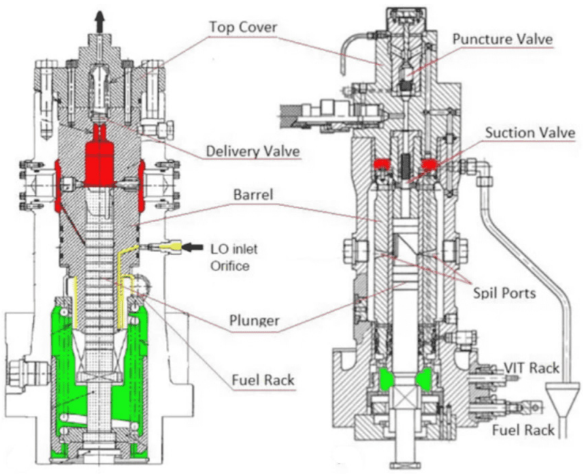


Figure. 1: "Bosch" type Fuel Injection Pump

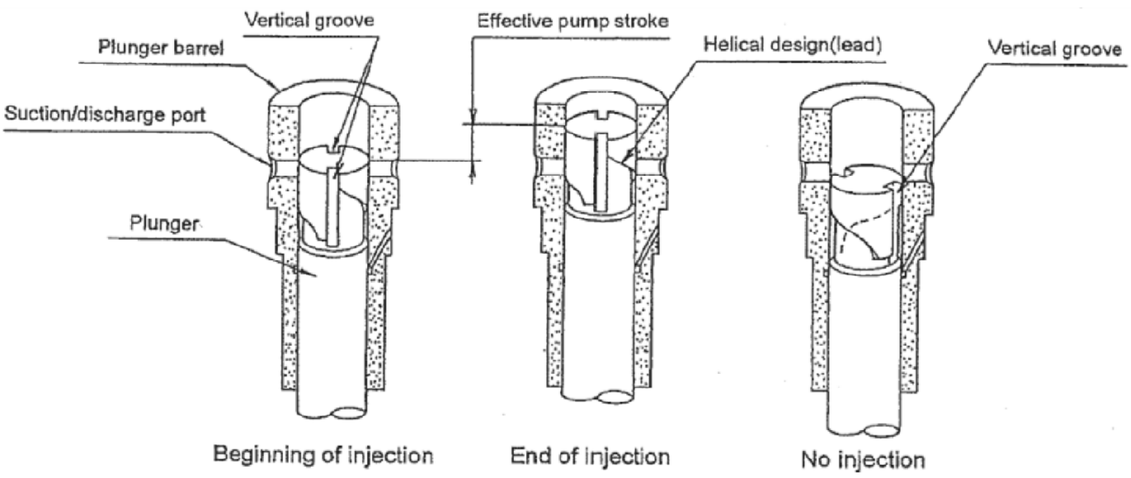


Figure. 2: FIP working principle (1)

Besides being the pumped fluid, the fuel oil in FIP functions as the lubricant, coolant, and sealant. There is a regular flow of fresh fuel to and through the FIP corresponding to feed rate. Thus, the fuel is a constant source external disturbance to the system, and its quality, temperature, impurities and viscosity can significantly impact the FIP performance and efficiency.

Common wear mechanisms in FIP

Abrasive wear in plunger-barrel

Residual fuels, whether high or low sulphur, can contain cat-fines carried over from the FCC – Fluidized Catalytic Cracking process in the refinery. These are mainly compounds of aluminum and silicon having a diameter of 5–150 µm, oval shaped, and with hardness close to that of grinding materials. Despite using various methods of cleaning the fuel oil, starting from gravitational separation in settling tanks, followed by centrifuging to remove solids contaminants and water, followed by high efficiency filtration, complete removal of impurities is not accomplished.

Even in fuels that have been efficiently centrifuged on board to bring cat-fine levels below 10 ppm (OEM limit 15 ppm), the remaining cat-fines due to their shape and size may not be trapped, even in fine filters of nominal mesh 10–30 µm and are still a risk of increased abrasive wear.

Abrasive wear due to the fuel oil containing impurities in the form of hard particles is the most common wear process in FIP.

Seizure of plunger-barrel

The refinery processes which remove sulphur from oil, also impact the fuel components, which give the fuel its lubricity. Most refiners add lubricity-enhancing additives to the fuel that requires it, to fulfil the limits in ISO 8217 (2). Too little lubricity may result in fuel pump seizures.

A low viscosity fuel oil impacts the FIP in three ways:

1) Breakdown of hydrodynamic oil film (resulting in seizures),

2) Insufficient injection pressure (resulting in difficulties during start and low-load operation), and

3) Poor acceleration due to insufficient fuel index margin (2).

Use of distillate fuels VLSFO, ULSFO with low viscosity and sulphur content close to zero, can lead to wear of injection pump as a result of changes in fuel viscosity, and can lead to seizure of plunger-barrel once the oil film thickness between plunger and barrel is reduced, or lost.

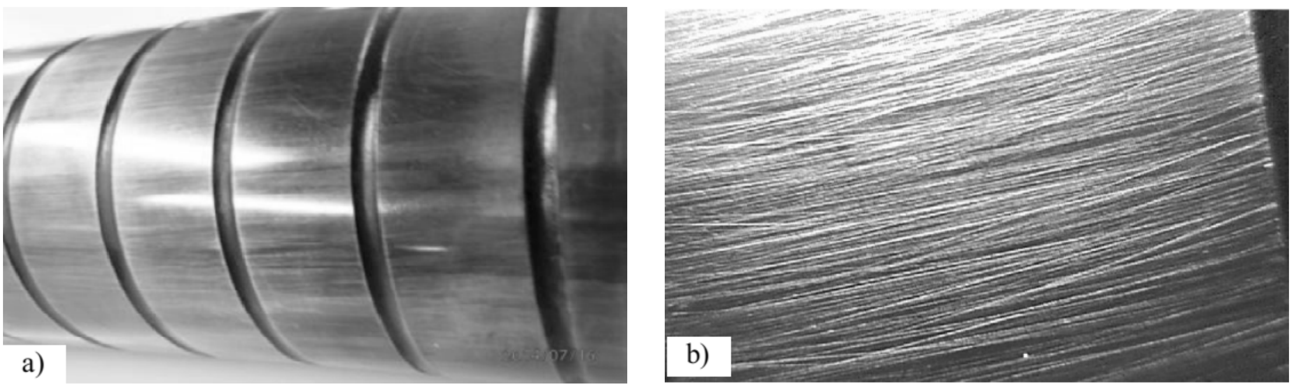


Figure. 3: (a) Abrasive wear on FIP plunger (b) Magnification x 10 (1)

> **Most refiners add lubricity-enhancing additives to the fuel that requires it, to fulfil the limits in ISO 8217 (2)**

The most common cause of jamming and seizure in FIP are the excessive changes in fuel temperature during changing of different grades of fuel, while having to go from distillate into residual fuels, and vice versa. The changeover should be conducted in a controlled manner. Minimum fuel viscosity of 2 cSt needs to be maintained, if required, by cooling. The rate of change of fuel temperature should not exceed 2°C per minute. The changeover must be conducted a low load (25% - 40% of MCR). Changeover to/from extremely high viscosity fuel e.g., RMK 700, should be managed carefully.

Particular care must be taken when changing from a low-viscosity fuel, which is cold, to a high-viscosity fuel, which is hot. When the warm fuel flows to the cold components, they will warm up, and the material will expand slightly. For example, the fuel plunger will warm up first, whereas the barrel contains more material and, therefore, its expansion will take longer time. This means that the clearance will decrease and thereby the risk of seizures increases. Changing the other way around, from warm to cold fuel, is less sensitive, as the plunger will cool down first, reducing in size and, thereby, increasing the clearance and decreasing the risk of seizures (**Figure. 5**).

Sticking of Plunger/Barrel and Fuel Rack

Sticking occurs due to heavy deposits forming on fuel racks, springs, and lower part of plunger. Lacquering can occur on plunger and barrel.

Sludge formation

Lube oil from the engine lubricating system is fed to the fuel rack to lubricate and wash down fuel deposits. It also splash-lubricates and cleans the lower part of FIP plunger and washes the spring chamber. If the oil flow gets restricted or there is a fuel leak due to wear of plunger-barrel, the lubrication and cleaning of these FIP elements may not be sufficient and may lead to deposits forming and jamming and sticking of the parts.

It may also result from decrease in fuel viscosity during engine stoppage and formation of deposits in FIP parts, especially deposition and hardening of remaining residual

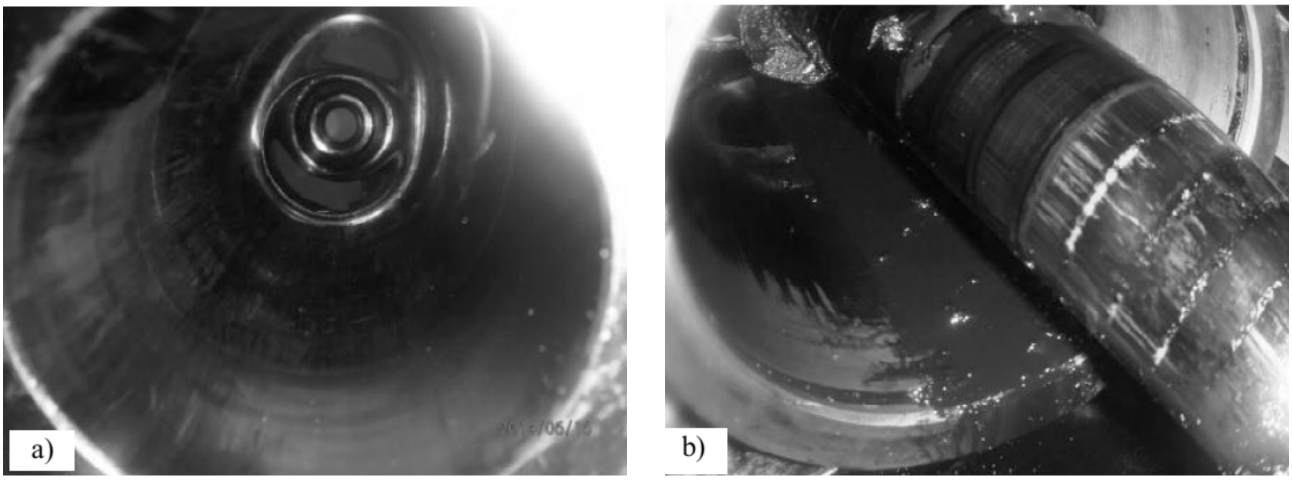


Figure. 4: FIP(a) sticking barrel, (b) sticking plunger (1)

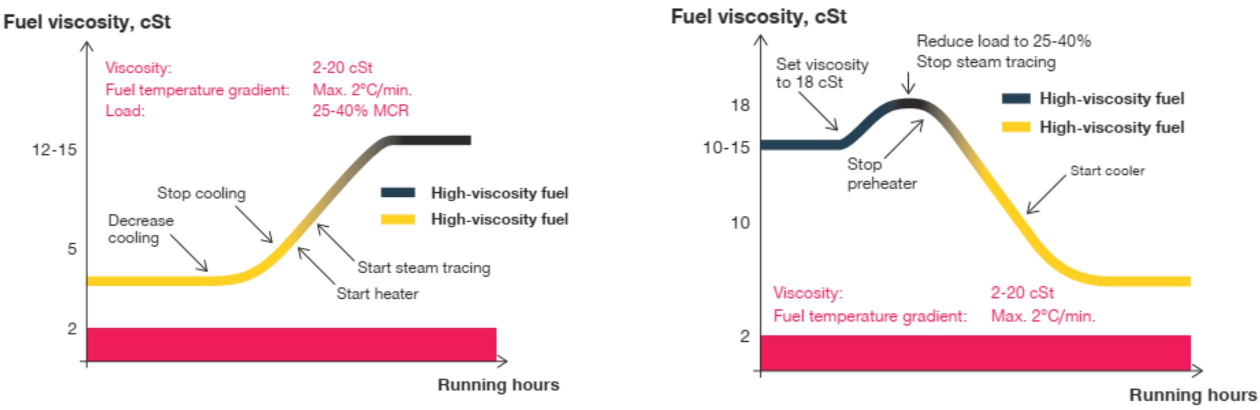
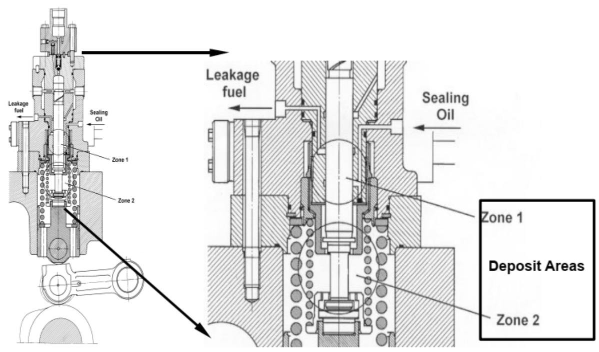


Figure. 5: Changeover from cold, low viscosity fuel to hot, high viscosity fuel and vice versa (2)

The most common cause of jamming and seizure in FIP are the excessive changes in fuel temperature during changing of different grades of fuel, while having to go from distillate into residual fuels, and vice versa

fuel components in the spring chamber and on the lower part of plunger, as shown in the images on **Figure 6. Frequent engine stop-start operations with the stops lasting some time may give enough time for the deposits to settle and consolidate on plunger and barrel (1)**.

Usually, it may be possible to reuse the stuck components after thorough cleaning with solvents and soft cloth. It may become impossible to start the engine without repairing or replacing the affected FIP.



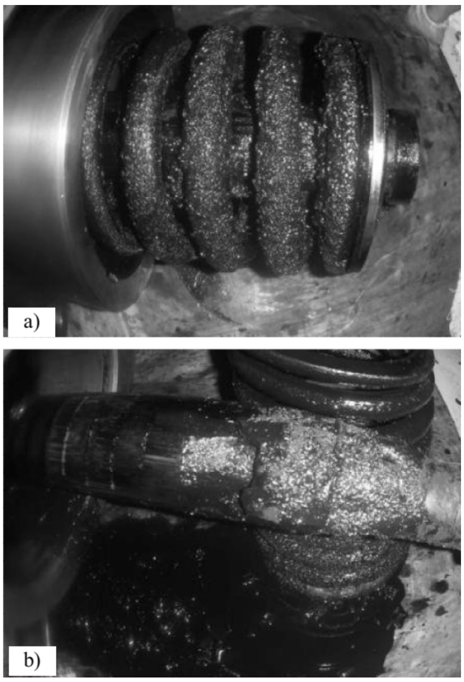


Figure. 6: (a) Solid fuel deposits covering FIP spring (b) and plunger.

Some OEMs suggest, after stopping the engine, to continue to circulate fuel and lubricant for some time (say half-hour), followed by an additional period of same duration circulate lubricants only.

Lacquering

Lacquering is attributed to incompatibility between fuel and lubricating oil, especially low BN oil.

The reciprocating motion of the plunger can cause some lube oil to be scrapped up and mix with the fuel. Capillary action can also pull up the lube. This can result in lacquer formation on the plunger/barrel surfaces and grooves **Figure. 7**. The clearance between plunger-barrel is reduced and leads to plunger sticking.

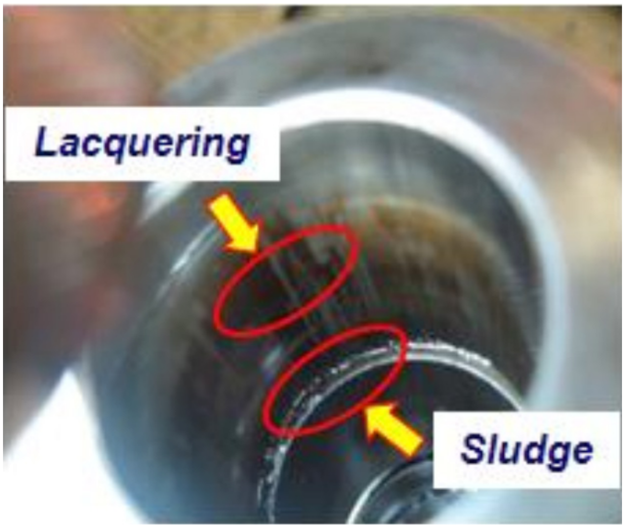


Figure. 7: Lacquering in FIP barrel (3)

Avoid sticking of fuel injection pump, an HHI (3) has suggested the following:

- Turn crankshaft using turning gear or air running.
- Change-over from high viscosity HFO to MDO/MGO before long term standstill.
- Circulating MDO/MGO and starting engine with MDO/MGO may release stuck plunger.
- Keep the drain hole or groove inside of barrel from clean of fuel sludge.
- When using extremely high viscosity HFO (500-700 cSt) increase engine fuel inlet viscosity up to 18 cSt to avoid formation of lacquering or heavy sludge at high temperature. For some engines inlet fuel viscosity up to 24 cSt is permissible.

MAN have introduced a FIP with a sealing ring inside the pump barrel that avoids mixing of fuel and lube oil, significantly reducing lacquering and all associated side-effects.

Wear of Delivery valve

The fuel compressed to a high pressure by the plunger forces the spring-loaded delivery valve to

pop up and allows the discharge of the pressurized fuel to the injection pipe. Once the effective stroke of the plunger ends, the delivery valve is brought back to its original position by the spring and works like a non-return valve to block the fuel path, thereby preventing counter flow of the fuel. When the deliver valve shuts, the volume available to the fuel in the high-pressure pipe is increased, and the pressure drops below the closing pressure of the injector nozzle. This maintains consistent injection "shot to shot" by maintaining a constant pressure in the pipeline between injections. The delivery valve also acts as a check valve to prevent cylinder gases blowing back into the pump in case a nozzle valve is stuck open.

Figure. 8: Wear of delivery valve (1)

Abrasive particles in the fuel may cause wear of the delivery valve sealing surface. If the worn discharge valve is leaking, all its above functions will be impaired, leading to delayed injection, poor combustion, pulsations in the high-pressure line and unbalanced cylinders.

Erosion/ cavitation of FIP components

Upon completion of fuel injection, the pressurized fuel oil located above the plunger flows along and below the helix edge of plunger to the spill ports (suction / discharge), and then through the orifice or deflector, it sprays / overflows into the fuel inlet chamber heating the erosion plug after each cycle of FIP. Sprayed at high velocity, the fuel oil is bounced back and reflected from it to the helix while undergoing turbulence on the plunger's working surface which induces a rapid drop in pressure causing cavitation on the plunger surface and deflector edges (**Figure. 10**).

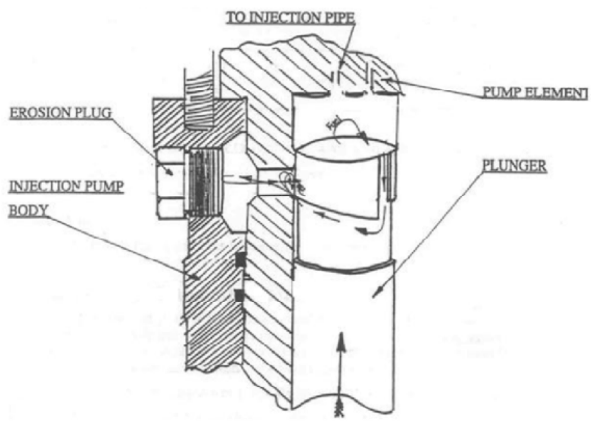


Figure. 10. Cavitation/erosion phenomena in barrel-plunger pair of FIP

This causes erosive wear just above the helix edge of the plunger's working surface (**Figure. 11**), and on the surfaces of deflector and erosion plug, which is designed to be worn by erosive wear. The deflectors are also subject to wear and may require replacement along with the erosion plug, during FIP overhaul.

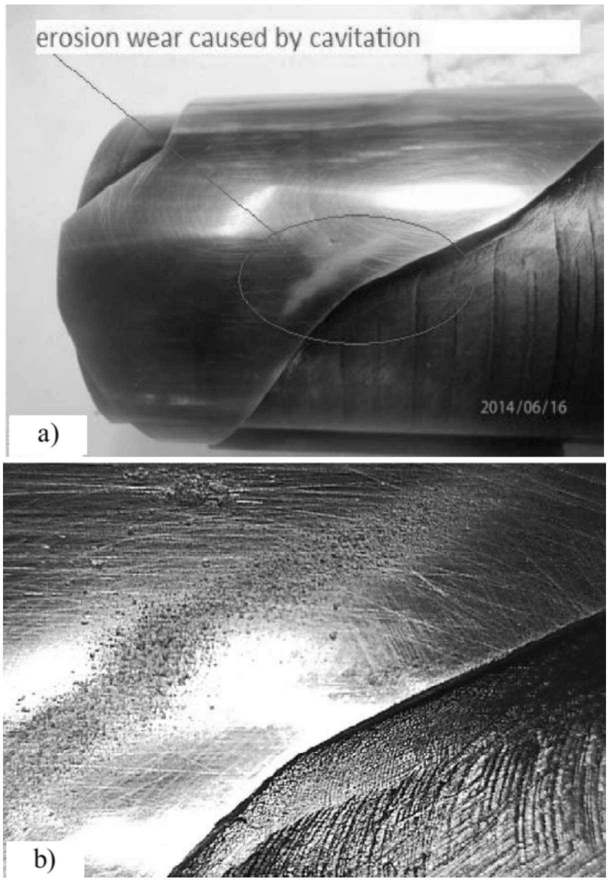


Figure. 11. (a) Erosive wear above hex edge of plunger working surface caused by cavitation, b) magnified x10

Corrosion (4)

High water content in the fuel can cause two forms of corrosion:

1. On the external surface of the pump element, if rusting begins, it indicates the fuel does not reach

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Course Fee: Rs.15000/- (per participant inclusive of Taxes)/Rs.13500/- For IME (I) Members (inclusive of Taxes) a temperature above the boiling point of water. This could be a sign that the fuel pre-treatment is inadequate.

2. Under fuel feed pressure, the boiling point of the entrained water is elevated and, although the fuel temperature may exceed 100 °C, the water is not boiled off. However, as the fuel leaks down the shank of the pump plunger (and of the nozzle needle), the pressure is reduced toward atmospheric pressure, and the entrained water flashes into steam. This results in corrosion of the plunger and barrel and produces black iron oxide on the surfaces. The initial glazed black appearance soon deteriorates to a matt black as the surface is destroyed. The fine clearance is lost, leakage is increased, and pump delivery drops.

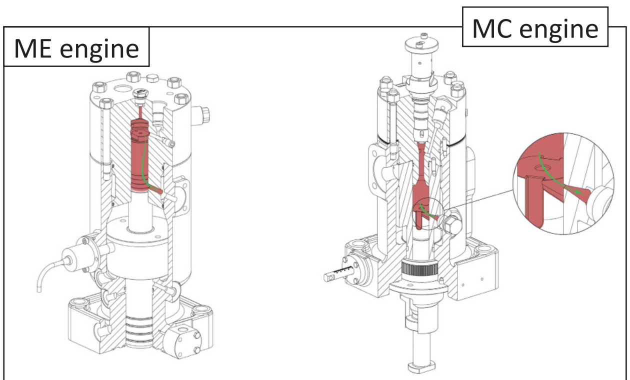
FIP pressure

The pressure developed in the fuel pumps must be sufficiently high to be able to open the fuel valves and achieve fuel injection with proper spray, and, thereby, good combustion. Worn fuel pumps increase the risk of starting difficulties because the fuel oil pump pressure needed for proper injection cannot be achieved. Older design FIPs may be more prone to this.

MAN have highlighted that the design difference in the FIP fitted on ME & the older MC engines could result in lower fuel injection pressure in MC engines at start-up especially when plunger/barrel are worn **Figure. 12 (2)**.

FIP Cracking (4)

During changeover from light to heavy fuel and vice versa, the unheated light fuel will temporarily cool the FIP and fuel system components, and the heavy fuel. The resulting increase in viscosity of the heavy fuel can increase the loading on the fuel pump significantly. If the fuel has not been sufficiently pre-heated prior to changeover, this superimposed load caused by the chilled interface between the light and heavy fuel may be enough to cause fracture in the FIP or other parts of the high-pressure fuel system.



ME engine – fuel oil pressure booster. Usually no problem with low-viscosity fuels because: 1. Plunger velocity is governed by supply pressure. 2. At start conditions it has 75-78% of full load supply pressure 3. Long leakage path	MC engine – cam driven fuel oil injection pump. Test to find the low-viscosity limit because: 1. Plunger velocity is governed by engine rpm. 2. At start conditions it has 15% of the full load engine rpm. 3. Short leakage path (green). Solution: Use unworn fuel pumps.

Figure. 12 : FIP in MAN ME and MC engines (2)

Conclusion

The "Bosch" fuel injection pump was invented in the 1920s and has continuously developed in sync with the needs of modern diesel engine. Delivering the right quantity of fuel through the fuel injector to the combustion chamber, precisely at the time of the diesel cycle when the heat generated by the high air compression will ignite it and generate power smoothly. While the main operating parts are made from hardened materials, operating conditions can impact it efficiency and durability. Ensuing its reliable operation is key to optimal running of any engine.

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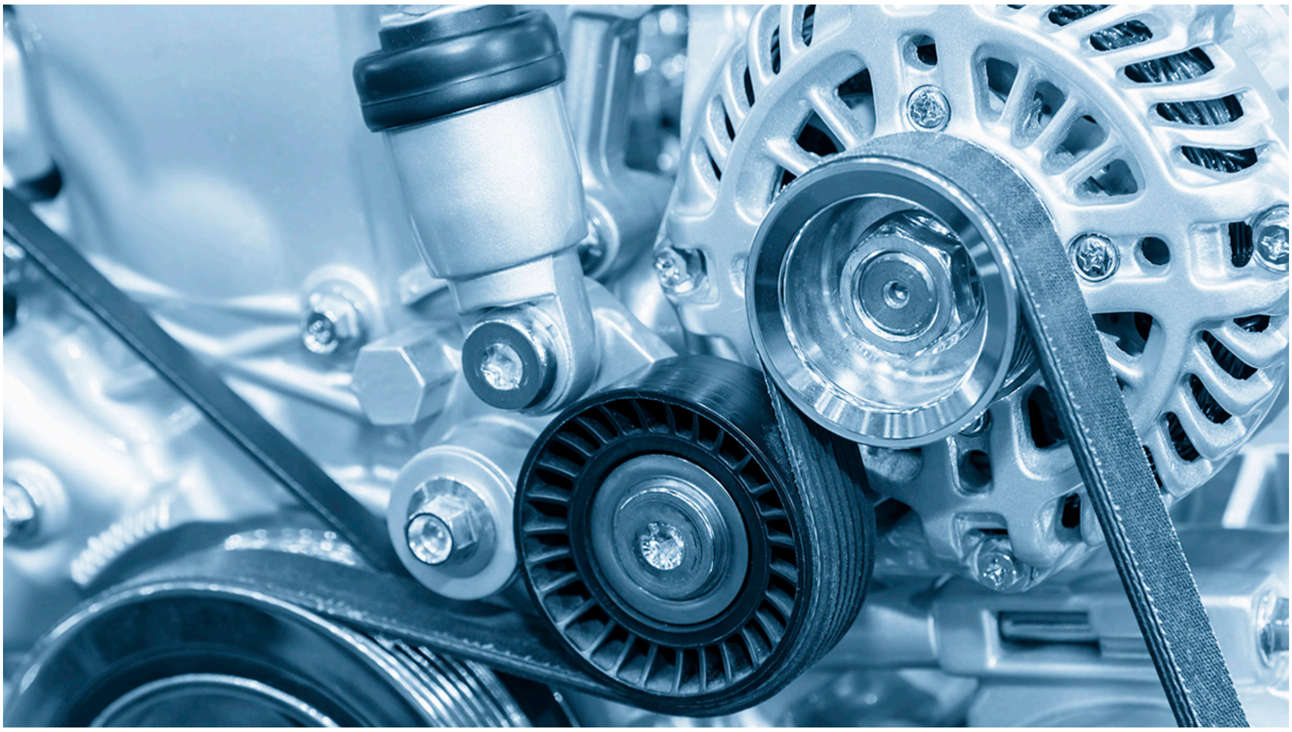
Troubleshooting of Alternators Part 1A



Elstan A. Fernandez

Abstract/Summary

This is the concluding part of the basics of troubleshooting Marine Electrical equipment, in a series of exclusive articles for MER that will attempt to highlight the various aspects of Maintenance and Troubleshooting of almost all commonly-used Electrical and Electronic Equipment onboard commercial ships. It is based on the current requirements of Marine Engineers and ETOs.

Key Points

- ✯ Reading Electrical Diagrams
- ✯ An Alternative (logical) approach to troubleshooting

Some of the key features to be determined from Blue Prints and Diagrams are:

- How should the circuit operate?
- What kind of features does the circuit have?
- What voltages should you expect at various points on the circuit?
- Where are the components physically located?
- How are the components wired together?

Introduction

Troubleshooting of Alternators will be published in two parts. Part 1, presented in this article will address the common / key methods of troubleshooting basic faults in alternators, with some guidelines on how to carryout checks while troubleshooting them.

1 Troubleshooting an Alternator

The first step of troubleshooting is to gather as much information as is possible from operating personnel and individuals present during the failure. Typical information includes:

a) How long had the unit been operating?

b) What loads were on line?

c) Did the protective equipment function or not?

d) Was there any water ingress?

e) Was the prime mover maintaining constant speed? If not, were there extended periods of under speed operation?

f) Did the prime mover experience an over-speed condition? If yes, what was the maximum speed, and how long did the unit operate at that elevated speed?

1.1 Measuring Resistance Values of Components

When carrying-out fault finding, it is necessary to measure the resistance values of components and windings, and compare them with known normal values, in order to identify a faulty winding. The normal resistances of the windings are given in the winding resistance charts, in the generator installation and maintenance handbooks, service and maintenance section.

Resistance values above 10 ohms can be measured accurately with a multimeter. Between 0.5 and 5 Ω, a multimeter has a limited accuracy, and other test methods may be adopted.

1.1.1 Resistances between 0.5 and 5 Ω

The resistance value of a winding such as a brushless main rotor will be between 0.5 and 3 ohms. A multimeter may not give an accurate-enough reading at these levels.

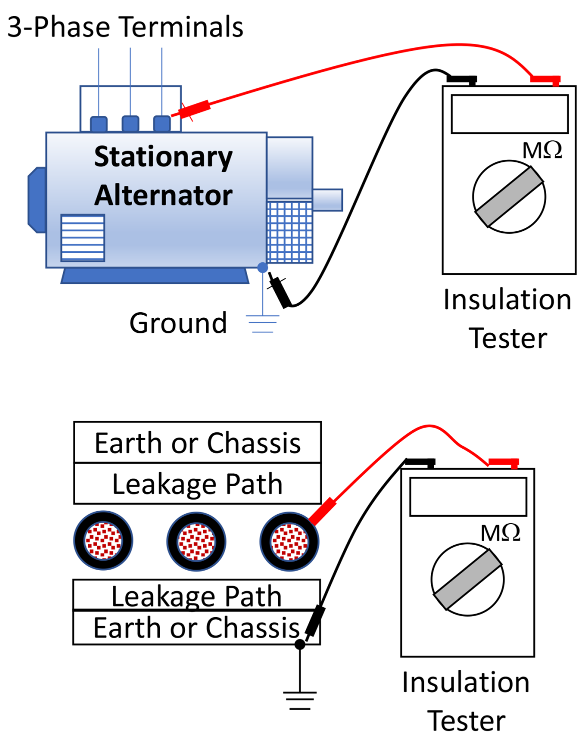


Figure 1. Insulation Resistance Measurement with respect to the Earth

If a Wheatstone Bridge Resistance Meter is not available, an accurate measurement can be obtained by means of a battery supply, using a Multimeter in series on the 10 Amps D.C. range. Most multimeters have this current range, or alternatively, a battery charging Ammeter could be used instead). Using a 6V battery, the resistance of the winding can be calculated by adopting the Ohm's law. The battery is connected to the main rotor windings, with a multimeter in the 10A scale and another multimeter set to measure the DC voltage of the battery.

The applied 6 V / I = $R_{winding}$

The resultant can be compared with the correct value given in the resistance charts, and this method can be used for any resistance greater than 0.5 Ω. Below this value the current in the circuit would drain the battery, and it is therefore impractical to use this method.

1.1.2 Very Low Resistance Values (Below 0.5Ω)

Main stators and exciter rotors are included in this category. These values can only be measured accurately with a special instrument, such as a Kelvin bridge test meter. The test leads are equipped with special spiked probes, which penetrate the surface of the contact, ensuring accurate reading. The generators main stator windings can also be tested by means of separately exciting the machine, thus partly eliminating the need to have this specialised type of instrument when fault finding in the field.

1.2 Insulation Resistance Measurement to the Earth - L V Generators 100 – 690 V AC

Note:

When conducting a high voltage test to earth, it is advisable to either disconnect or short out any electronic devices, such as the Automatic Voltage Regulator, (AVR), and Main rotor diodes. Short circuiting the terminals can be achieved with a piece of fuse wire, which must be removed immediately after the tests are completed.

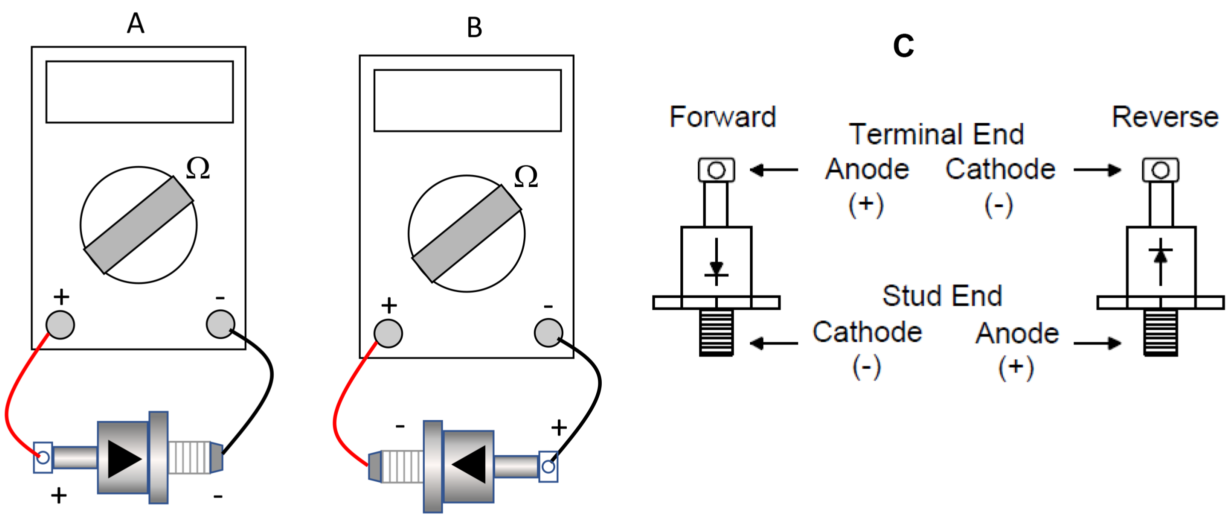


Figure 2 – Diode Testing

- ***Running the generator before removing the short circuit connection could seriously damage the generator. When Megger-testing a machine, failure to protect the voltage control unit and diodes could result in permanent damage to one or more of the electronic components.***

The resistance of the insulation between the copper conductors and the frame of the machine, (earth or ground), is measured by means of a high voltage tester, or "Megger", which applies a D.C. potential of 500 or 1000 volts across the winding's insulation.

The high voltage causes a current to 'leak' through the insulation system. This current produces an output reading on the Insulation tester ('Megger'), which is measured in Megohms (resistance to earth or ground). A normal value for a low voltage Generator winding should be higher than 1 Megohm to earth.

Generators with an output voltage of between 100V to 600V should be tested as above. If the output winding (stator) is lower than 1 Megohm to earth, the windings should be cleaned, dried, or sent to a workshop for complete refurbish.

1.3 Insulation Testing of Medium and High Voltage Generators, 1 kV or Higher

Danger!

- ***High voltage generators are capable of storing a dielectric (capacitive) charge in the main stator windings, following a high voltage insulation test.***
- ***Any testing of the main stator must be followed by a discharge to earth or ground for at least 1 minute. Do not attempt to touch the main output terminals until all residual charge has been discharged.***

The effectiveness of a particular on-site test will depend to a large extent on the machine application. In many situations, measurements of insulation resistance and polarisation index only will be appropriate. More detailed testing involving loss tangent, dielectric loss analysis, partial discharge measurement, is undertaken at intervals in order to establish the extent of deterioration of insulation condition. Other tests such as high voltage withstand tests are particularly effective for investigative work in order to identify the onset of fault conditions.

1.3.1 Polarisation Index Test (P.I.)

The P.I. test is used as a guide to the dryness, cleanliness and safety of the winding insulation system. A special motorised insulation tester is required, which can maintain a test voltage of 1 - 2.5 kV, (medium voltages), or 5kV, (high voltage), for a period of 10 minutes. Readings are taken (in Megohms) following a 1 minute and 10-minute time interval:

The P.I. index is obtained by the formula:

$$\text{P.I.} = \frac{\text{1 Minute reading}}{\text{10 Minute reading}}$$

The resultant ratio is called the P.I. index, and should be a minimum of 2 at 20°C.

A P.I. index below 1.5 suggests the windings are wet, dirty or faulty, and should be cleaned, dried, and refurbished as necessary.

Caution!

- ***Do not test any winding other than the main stator with this method.***

1.4 Testing of Diodes in a Brushless Alternator

A diode has two resistance values, forward and reverse, these can be measured with a multimeter as shown in the diagram below. An arrow printed on the diode body identifies the positive side of a diode. Remember that in the **Figures 2 A and B** for testing below, only one type of diode is shown - where the stud that is fitted on the common plate of the rotating rectifier assembly **(Figure 9),** is negative and the terminal input from the alternator is positive. The diode that has an anode stud fitted on the common plate of the rotating rectifier assembly **(Figure 9),** will have a negative terminal as shown in **Figure 3.** Both types shown in **Figure 2 C** should be tested.

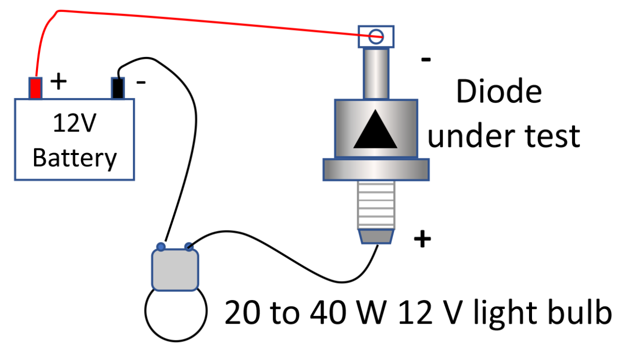


Figure 3. Diode Testing with a Lamp

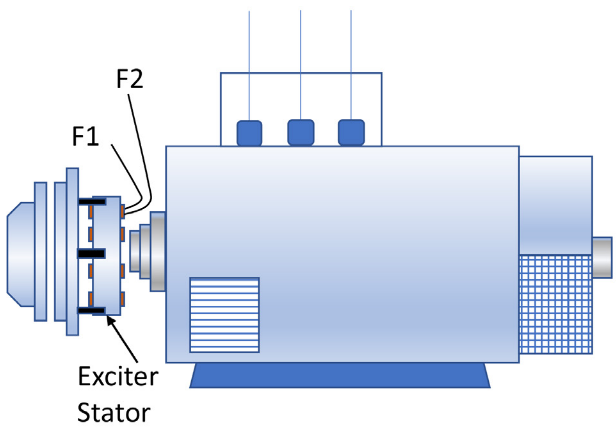


Figure 4. The First Step – The AVR is Disconnected

The forward resistance is being measured in **Figure 2 A** with the positive meter lead connected to the forward side of the diode. In **Figure 2 B**, the meter leads have been reversed, and the reverse resistance is being measured.

A digital instrument will read true electron flow; hence the resistance polarity readings will be reverse to conventional current flow.

A digital multimeter is usually capable of a semiconductor test with the selector switch set to the diode symbol. This measures true electron flow, and will indicate a forward value or reverse value. Using an analogue meter on the resistance scale, the forward resistance varies considerably, depending on the internal impedance of the multimeter and the diode type. A typical reading would be between 20 and 100 Ω.

The reverse resistance must be very much higher, usually in excess of 100 kΩ, (100,000 Ω). A faulty diode will give a reading in both forward and reverse directions (short circuit), or no reading in either direction, (open circuit).

A good diode will light the bulb in only one direction. It should not light when test leads are reversed on the diode pin and base. A faulty diode will light the bulb in both forward and reverse directions (short circuit diode), or no light in either direction, (open circuit diode). If one or more diodes are found to be faulty, always change the complete set of diodes.

1.5 Restoring Residual Magnetism / Flashing of the Field with a Battery

Residual magnetism in the generator's exciter field allows the generator to build up the voltage while starting. This magnetism is sometimes lost due to shelf time or improper operation, among other reasons. Restoring this residual magnetism is possible and is sometimes referred to as 'flashing the exciter field'. It is also possible that initially, self-excited ship service generators may need to have the fields flashed to establish the residual magnetism, which is necessary to start the exciter's induction process. To restore the small amount of residual magnetism necessary to begin a voltage build-up, connect a 12-volt battery to the exciter field while the generator is at rest.

Danger!

- ***It is essential that all instruments be regularly checked for safety, and any connection leads, probes or clips checked to ensure that they are suitable for the voltage levels being tested.***
- ***Never attempt to test a "Live" generator unless there is another competent person present who can switch off the power supply or shut down the engine in an emergency.***
- ***Never expose "Live" connections unless you have created a safe working area around you.***
- ***Make sure you have made all other persons in the immediate area fully aware of what you are doing.***

1.5.1 Preparing for the test

This is done as follows:

Remove the exciter field leads e.g., F+ / X+ / J and F- / XX- / K, from the automatic voltage regulator. Ensure that the correct two exciter leads are identified, by physically tracing them back to the exciter stator windings, fitted inside the non-drive end bracket of the Generator.

Caution!

- ***Before conducting the following tests, the insulation resistance of the main stator windings should be checked. The minimum insulation resistance to the earth for the main stator is to be at least 1.0 MΩ.***
- ***Failure to remove the field leads from the regulator during flashing procedures may destroy the automatic voltage regulator.***

1.5.2 Checking the Exciter's Stator Resistance

Measure the exciter's field resistance across the F+ / X+ / J and the F- / XX- / K ends with a multimeter. Refer to the Generator Operation and Maintenance manual onboard, for correct values. You should be able to read some value of resistance e.g., 18-30 Ω as you are measuring a continuous winding. An infinite resistance reading would indicate an open circuit in the exciter field. Also ensure that there is no grounding in the circuit.

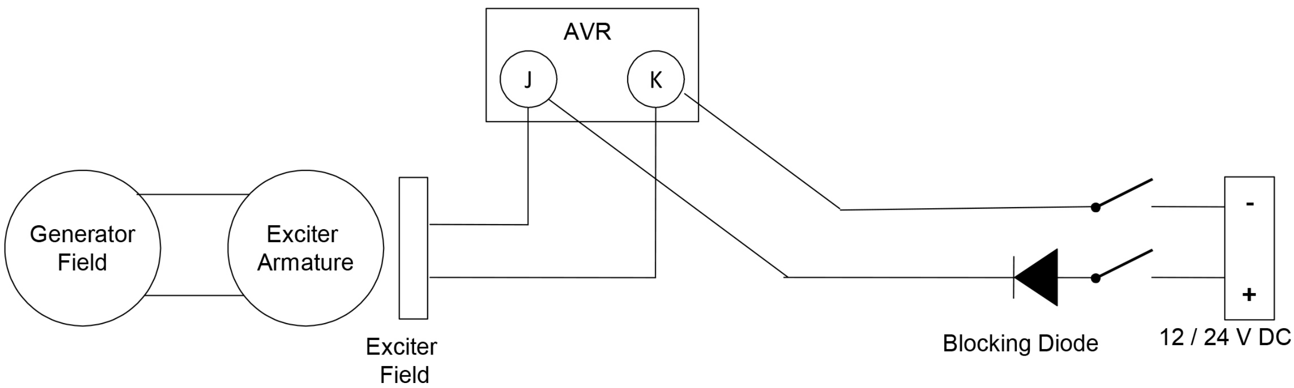


Figure 5. Flashing an Alternator with a Proper Kit

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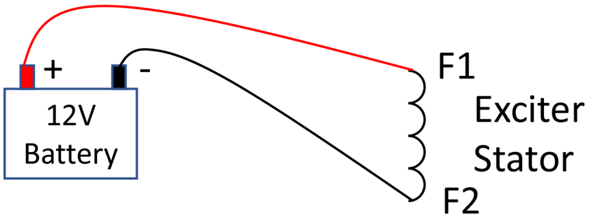


Figure 6. Connecting a 12 V Battery

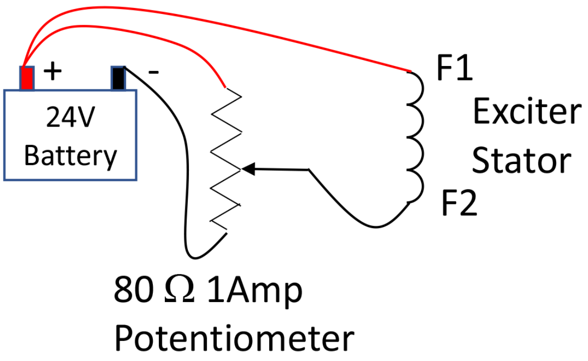


Figure 7. Connecting A Variable Source to the Field

1.5.3 Connecting the Battery

1. Connect the X+ / J / F+ or orange lead to the positive pole of the battery.
2. Connect the XX- / K / F- or black lead to the negative pole of the battery.
3. Press the pre-excitation switch if it exists, for about 5 to 10 seconds.
4. The alternative is to apply the voltage from an external battery or another DC source in series with a 10 to 20 Ω 25 W limiting resistor or a bulb to the field coil while observing polarity.

1.5.4 Run the Generator at Nominal (Normal) Speed.

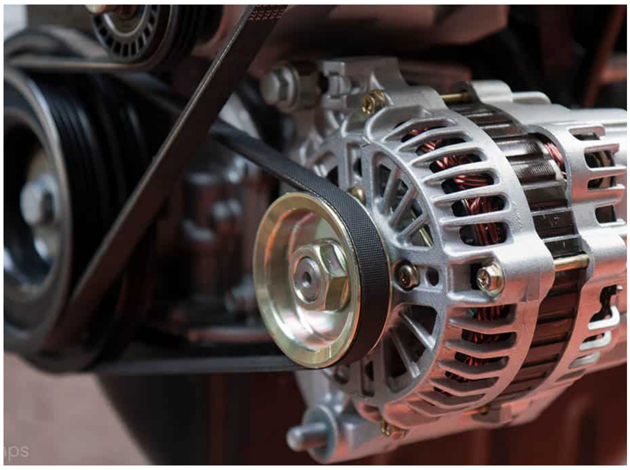
Ensure that the speed is within 4% of the nominal. The engine speed must be correct, to avoid misleading test results.

1.5.5 Excitation Voltage at No Load

It is essential that all loads are disconnected from the machine, and that the speed is correct.

Check the battery voltage after connecting to the Exciter Stator, a minimum of 12 V DC is required.

When testing with a fixed battery supply, any difference between the values below, and the actual battery voltage, will affect the test results, and should be considered. For example, if your battery voltage is 10% higher or lower than the values shown, you can expect the Generator voltage to be equally 10% higher or lower than expected.



The approximate D.C. battery voltages lie between 10 and 14 V, to produce a nominal output voltage ± 10% from the Generator at no load. This depends on the alternator, so please refer to the maker's manual.

1.5.6 Checking the Generator Output Voltage

a) Using a Multimeter, test the output voltage across the main terminals, Phase to Phase (and Phase to Neutral if it exists).

b) If the output voltage from the main stator is within 10% of the nominal, or higher than the nominal, and balanced across phases, this indicates that the main stator, the main rotor, exciter stator, exciter rotor, and main rectifier diodes, are all functioning correctly.

c) Proceed directly to 1.11 - Testing the AVR Sensing Supply (feedback)

d) If the output is unbalanced phase to phase, or more than 10% below the nominal, this indicates that a fault exists in one of the above components, and the following tests must be conducted.

1.5.7 Completing the Procedure

- Reconnect the AVR's terminals to the regulator.
- Repeat the procedure if the generator fails to build-up voltage.

Acknowledgements and References

Thanks to my dear classmates Lakshman Singh Yadav and Harbhajan Singh for co-authoring a very popular series with me, titled "Marine Electrical Maintenance and Troubleshooting", comprising of four books.

About the author

Elstan A Fernandez: 44 years in the Maritime and Energy Industries; Author / Co-author of 80 Books

Chartered Engr, FIE, MIET (UK), MLE℠ Harvard Square (USA); Joint Inventor with a Patent for Supervised BNWAS; Promising Indian of the Year in 2017

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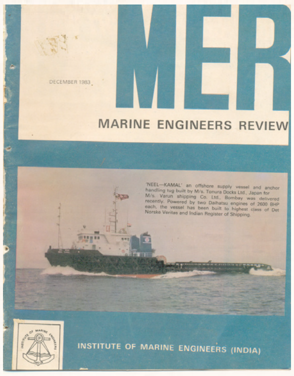
Going Astern into MER Archives



The December 1983 issue starts with an introspective poser on need for engineers to be management savvy. The Editorial pitches for a 5-year correspondence course through AIMA. [In near future, similar programmes could be available. For the sailing mariners to pursue].

This is followed by a short piece on ship financing. Disabusing the notion that banking only is responsible for a skewed understanding, shipowners' secretive plans are also posited as an accomplice. The painful effect is the oversupply. (Ship financing needs a focussed attention especially in India where it is treated similar to other sectors.

Then there is an interesting article on induction motors. The significant factor highlighted is the energy saving controller which helps in cutting down the losses. The Controller adjusts the terminal voltage, thereby the magnetising current resulting in lesser core losses. A few extracts are inserted to catch your attention and interest.

We would welcome such industry-backed articles for MER.

Staying on electrical power, another article features a discussion from the IMarE Conference on energy saving auxiliary power arrangements.

This is followed by a talk on disadvantages of Halon 1301 as a fire sighting agent. There is another absorbing analysis on performance of L60MC and K84EF engines (B&W). This would be another familiar ground for many engineers.

There is one article on underwater acoustics pertaining to offshore drilling structures. This has some contemporary value also. The longest pieces is, 'Role of a Manager' by Sharu Ragnekar. I would leave this to the readers to read and reflect. POSTBAG carries a safe-worthy read on Electro static hazards, emphasising the need for an inert ambience during tank washing. Another letter on B&W's efforts on modernising its engines will certainly recall a few technical memories of many engineers of yore.

One advertisement which caught my attention was the on IDOCATS (International Directory of Consultants and Technical Services). This could be a good publication that the Institute can pursue.

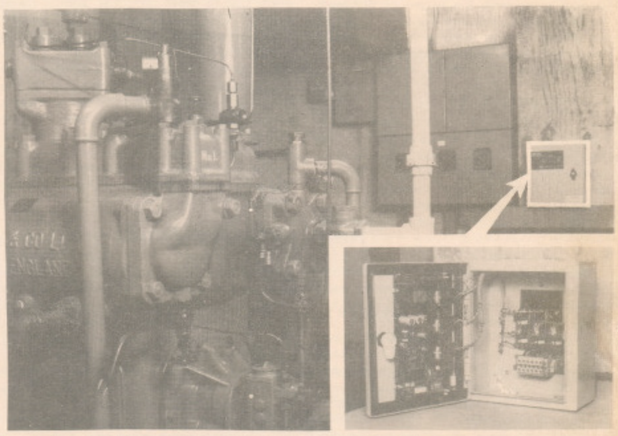


Fig 1: Energy-saving controller fitted to a standard induction motor on a reciprocating air compressor. It automatically adjusts the terminal voltage to reduce the magnetising current, and hence the core losses.

Fig 2: Typical performance curves for a 7·5 kW, 1420 rev/min induction motor.

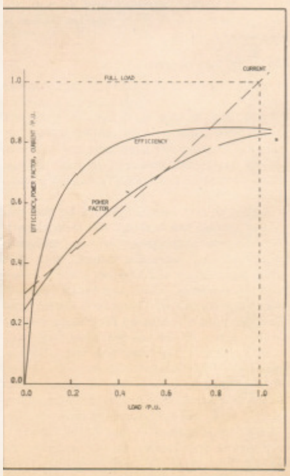
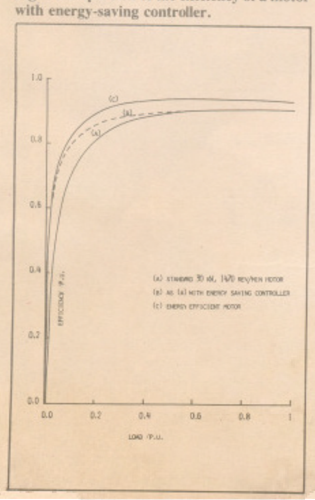


Fig 3: Comparison of the efficiency of a motor with energy-saving controller.



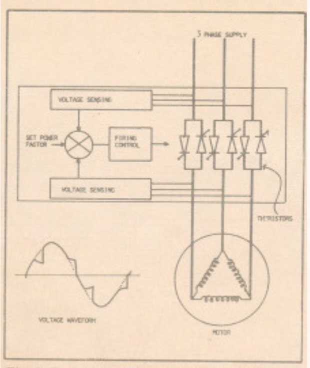
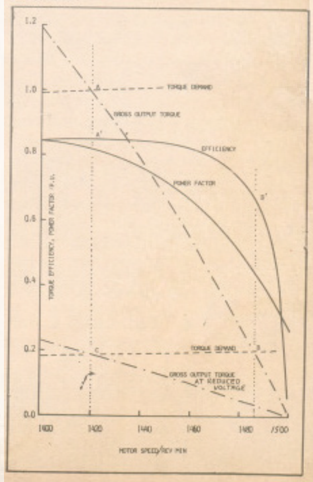


Fig 4: Energy-saving motor controller.

Fig 5: Principle of operating energy-saving controller.



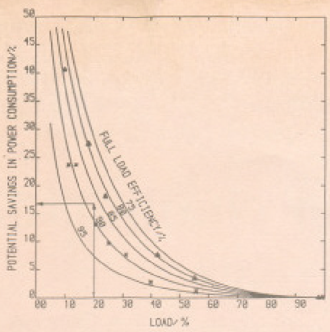


Fig 6: Potential savings in power consumption for 3-phase cage induction motors with normal consumptions at variable load.

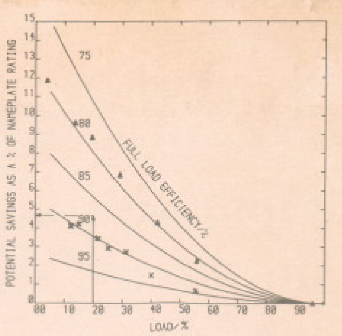


Fig 7: Potential savings in power consumption for 3-phase cage induction motors on the basis of nameplate rating.

POSTBAG

Electrostatic hazards

Sir,
The above article by two researchers of Shell Oil Co appeared in the June issue of MER.

Under a heading 'Tank Washing', which starts by referring to explosions on VLCCs and concludes by stating 'Tank washing can therefore be carried out in an inert atmosphere (less than 8% oxygen); or too lean an atmosphere, ie, one in which the hydrocarbon concentration is below the lower flammable limit; or too rich an atmosphere, ie, one in which the hydrocarbon concentration is above the upper flammable limit (at least 15% by volume)'.

This might seem a reasonable view in theory, but in practice it has led to the loss of many lives and many good ships. Incidentally, the figure of 8% provides little margin of error and IMO ask for inert gas to be supplied at 5% O_2 with a 'shut-down' point at 8%, so that if any sample from a tank shows 8% O_2, in-tank operations should cease until a figure below 8% has been established.

The VLCCs referred to were *Mactra, Marpessa* and *Kong Haakon VII*, all of which exploded in December 1969 whilst conscienciously endeavouring to wash cargo tanks in what they had every reason to believe was a 'too lean' condition! The Court of Formal Inquiry into the explosion on *Mactra*, a Shell oil tanker, concluded that it was not possible, under the practical constraints of actual operation, to guarantee that a 'too lean' condition existed in every part of these huge tanks throughout the washing operation. This is due to the inability to check the hydrocarbon content of the tank atmosphere by any realistic series of sampling checks, to the possibility of gas regeneration from pockets of oil and sludge remaining on the tank side members and the tank bottom, and to the possibility of oil or gas entering from some other space whilst washing is in progress.

Since that date many other tankers have suffered fire and explosion because personnel were under the mistaken belief that it was possible to wash tanks safely in any but the fully inerted condition. Unfortunately, the industry has done little to disabuse the officers and crews operating tankers that such is the case. In fact, to the best of my knowledge, the 'Tanker Safety Guide'—to which they subscribe—still says that any of the three methods can be used with suitable safeguards.

On Monday 3 October Capt Chadwick of the Liberian Investigation Division presented a paper to the Institute on 'Marine casualties and how to prevent them'. In the examples quoted from Liberian flag casualties in 1979–1980, there were seven cases of fire and explosion on large crude oil carriers.

Of these, 5 were not inerted, although 4 had inert gas systems fitted, whilst the fact that a VLCC was still running in 1979 without an IGS indicates that whilst owners have perforce to comply with the IMO 'SOLAS' conventions they pay little heed to IMO recommendations. In the summary of the *Mycene* casualty, which exploded whilst cleaning tanks, Capt Chadwick comments 'In early 1980 some senior tanker officers were still not convinced of the value of an IGS as a primary and absolute means of protection against an explosion in a cargo tank.

Energy Concentration, which broke her back with the release of a large quantity of crude oil, the comment is made 'As her IGS was operating properly, there was no fire or explosion'. Unfortunately, such was not the case for the non-inerted *Betelgeuse*, which broke her back, caught fire and suffered devastating explosions in Bantry Bay, when all 50 ship's crew and jetty staff perished.

Again in the case of the *Agean Captain* which suffered collision followed by fire, the fire was contained; almost certainly because the vessel was inerted. Many non-inerted tankers have not been so fortunate after a collision.

In the discussion of the paper a number of speakers stressed the necessity of operating in the fully inert condition at all times if safety was to be assured. Capt Jolivet, Chairman of the Tanker Safety Group, made a statement which, I believe, was to the effect that the group would be recommending that all in-tank operations should be stopped if the inert gas system was not operating properly or the tank not properly inerted. It is to be hoped that the 'Tanker Safety Guide' will be quickly amended to reflect this attitude, and that oil industry employees will come into line with their recommendations.

Meantime I regret that the statement made in the June issue, which will be seen by all the Institute members, gives the impression that the Institute condones these unsafe practices! I would suggest that the damage could be minimised by publishing a statement, perhaps after consultation with the authors and Capt Jolivet, correcting the statement in MER and giving the latest views of the Tanker Safety Group. Such a publication might perhaps help to prevent further explosions and loss of life due to our members following practices which are said to be safe in MER but which casualty investigations have shown to be most unsafe.

G Victory

Wallington, Surrey

'Barham' sinking

Sir,
I refer to MER September 1983 and the synopsis of 'The Complete Encyclopaedia of Battleships' by Tony Gibbons.

The statement that land-based aircraft sank HMS *Barham* is incorrect. *Barham* was sunk by several torpedoes from a U-boat at 1630 h on 25 November 1941 between Crete and Cyrenaica (Cunningham – A Sailors Odyssey, p424). Cunningham, the C in C, was in *Queen Elizabeth* and witnessed the sinking.

Lt D G Mercer, RN

Surrey

FEEDBACK

Our readers greatly appreciate reading about practical problems. Unfortunately few, if any, of our contributors seem to have any problems—at least for publication—before they have retired! Please remember that we depend entirely on you to let us publish your particular engineering problems and any solution you have found, in order that others may learn from your experience. A few hundred words are enough—Editor, MER.

Modernising older engines

Sir,
With the highly efficient propulsion machinery going into service today, you have asked: 'What can be done to the less economical diesel engines already in service?'

B&W Diesel has developed a concept for modernising uniflow scavenged two-stroke engines, which brings the specific fuel oil consumption of the converted engine in line with that of the L-MC series, corresponding to a reduction of 15%.

It has always been B&W's policy to evaluate the latest designs with a view to utilising newly-developed components and principles on engines already in service.

Up to now, such modernisation has been limited to individual components or systems and, in the last few years, with a special eye on components capable of saving fuel oil.

During the last five years in particular, vast improvements have been made in the operational economy of two-stroke engines. At the same time the service speed of the ships has, in general, been lowered. As a result, there are in today's fleet a great number of ships which, while still being fit for many years of service, are, when compared with the new ships, equipped with less economic and over-dimensioned propulsion machinery.

This has led us to the introduction of the concept aimed at modernising two-stroke uniflow engines currently in service.

F Andersen

B&W Diesel A/S
Copenhagen

Details of the conversion package are given on page 22—Editor

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

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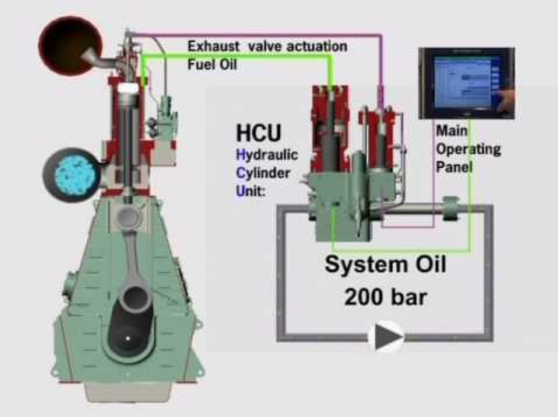

This 3 days course is designed for all Ship's Engineer Officers and Electro Technical Officers responsible for the operation of ME Engine. This course consists of technical lessons and practical instructions on the design, principles, operating procedures and maintenance activities for the safe, efficient and optimal performance of the engine system.

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- **Engine Control System (ECS)**
- **Main Operating Panel (MOP)**
- **Standard Operation**

Entry Requirement / Target Group:

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