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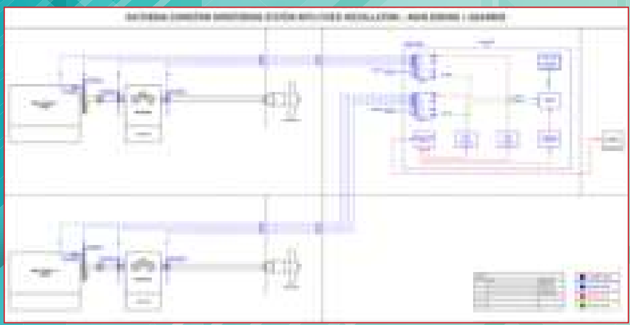

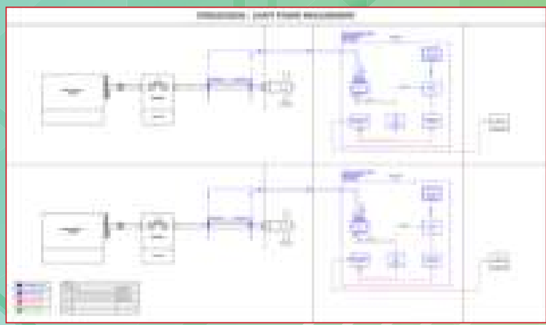

CBM: ENGINE HEALTH WATCH WITH VIBRATION SENSING

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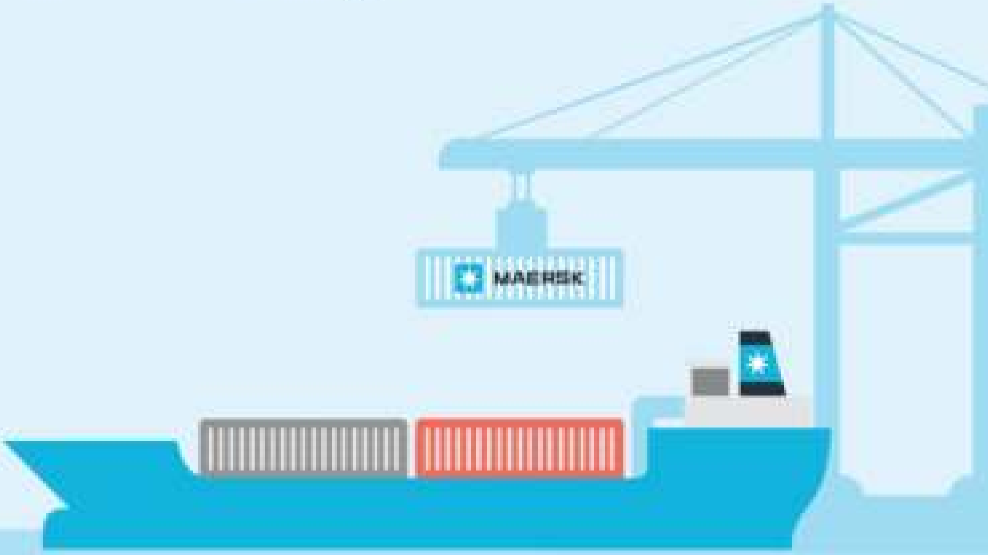

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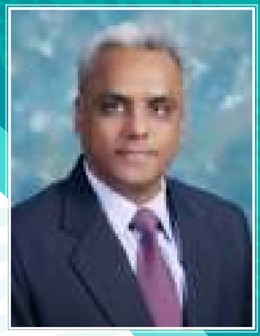

Without continual growth and progress, such words as improvement, achievement, and success have no meaning.

- Benjamin Franklin

The Year End Review of the MoPSW whizzed past with the year 2022. Some notes are worth highlighting: Coastal traffic crossed 130 MMTA; Indigenous Aircraft Carrier, Vikrant took to the waters; JNPA became a fully landlord Major Port; 3-phase Heritage Complex at Lothal got the funds push.

A bright-line separation was the Sagarmala scorecard: 802 projects/₹ 5.4 lakh crores under plans, out of which 220 projects/₹ 1.12 lakh crores have been completed. Moving on, Ro-Ro/Ro-pax, cruise terminals, coastal infra/tourism/shipping etc., will get their share for development. The Sagarmala talks bring the earlier, mid-year Report into focus, which had expressed serious concerns on the slow pace of work progress under this flagship programme. A regular reminder on this would help expedite plans.

The stats under the skill development activities in hospitality, tourism, logistics and ship breaking deserve a bold tick mark. The impetus should continue in Inland Vessels [IV] (of the Inland Waterways sector) and the Safety Training at Alang (ship breaking) Yards.

Another plus point on progress should go to the initiative of dispute resolution mechanism in the form of Conciliation & Settlement Committee. This is bound to ease many bottlenecks (some decades long ones too). The pace and power of one interesting initiative, which needs to be monitored, is that of the Gatishakti Master Plan.

While aircraft carrier, heritage complex could be the feathers, continual growth in skill development, digitisation and fillip to inland waterways are certain bets for a meaningful success. A pandemic-free, peace filled 2023 holds the keys.

In this issue...

Condition based monitoring (CBM) has become a part of all major equipment architecture. Uday Purohit and Narendra Kumar Karicheti explain a CBM system for Diesel engines. Typical torsional vibration measurement and FFT application are explained for easier understanding. The features of a Class approved system are discussed, highlighting the merits. Acyclism (linear movement of pistons resulting into rotational movement crankshaft), change in angular velocity/acceleration/position etc., get a mention but are explained in a tangential fashion. This will be a good read for the sailing engineers to understand shipboard CBM systems.

From engine monitoring, we move to material movement by drones. Prasanna Kumar and Dr. Ajanta Devi present a solution for moving supplies to ships from shore. The merit of the case is in the saving of fossil fuel usage (and hence the reduction in emissions) by the launch boats, which ferry supplies to ships in anchorages. The article discusses a survey study and highlights a few limitations such as payload and security issues. However, the article argues that the drones can carry documents and light loads. This is an interesting read in lines of 'articles on innovations' we have been hosting.

Descending from the drone, we have Subhakar Dandapat with a discourse on Coastal cum Inland Shipping (CIS). In this instance, Dandapat presents the rationale for greening the Inland Waterways Transport (IWT) sector. Undoubtedly, this is a sector where scope for development is immense. The network, support infrastructure and the cargo shift etc., are bound to create employment and opportunities. The new Act intends to give impetus to this growth. The Inland Vessel (IV) training and certification are also in the ambit of these changes. IWT sector deserves a good focus and Dandapat's informative article is worth your attention.

Under Lube Matters, Sanjiv discusses wear phenomena. Heritage Hourglass: Uma Kalbe projects navigation instruments, which were invented based on ocean going needs. Under the MER Archives, we present a few interesting extracts from Feb '83 issue. We host a reprint of a technical note on pumps for carbon capture storage applications.

While awaiting the budget and any sops for shipping, here is the February 2023 issue.

Dr Rajoo Balaji
Honorary Editor
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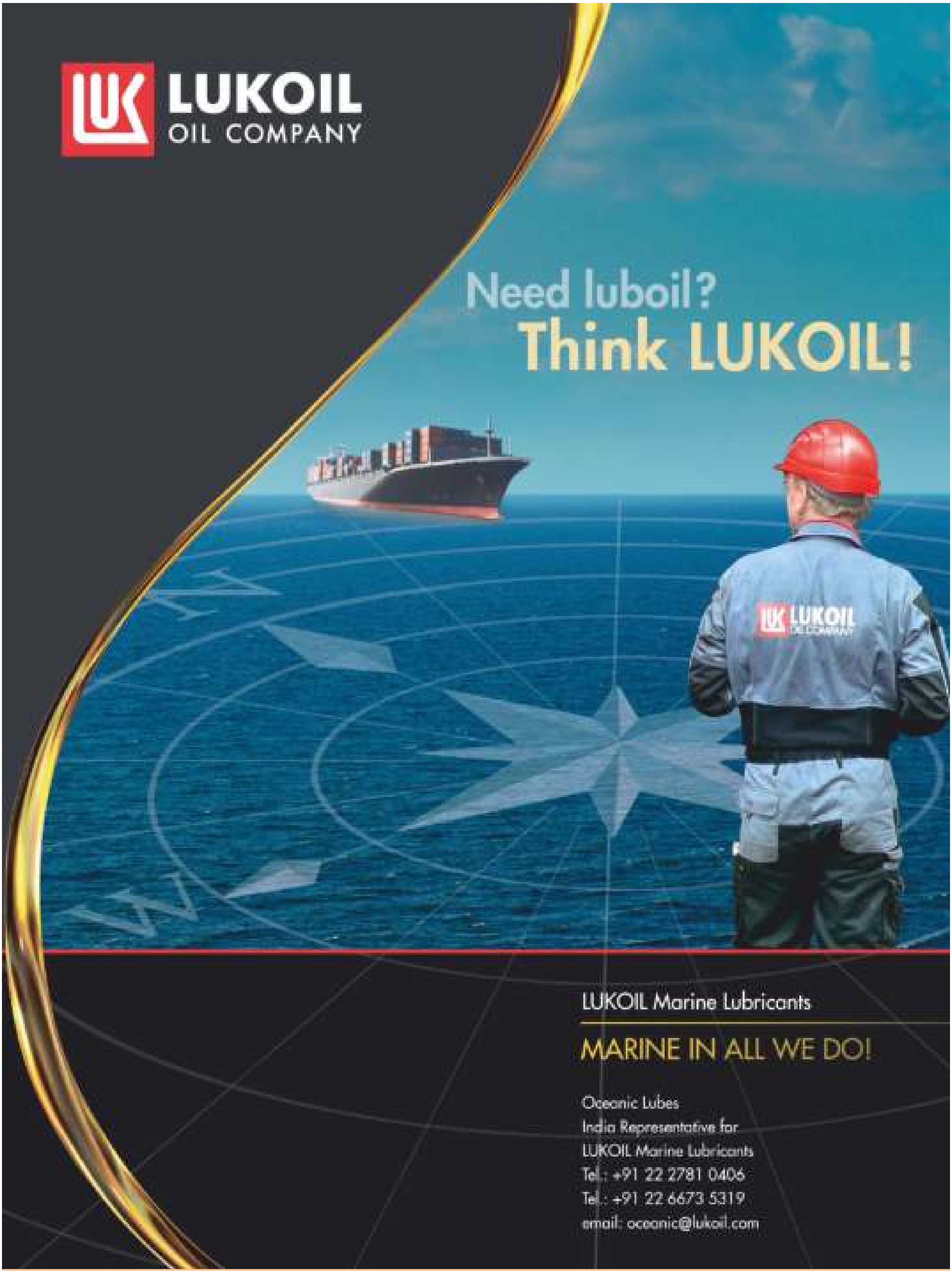
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In This Issue

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COLUMNS

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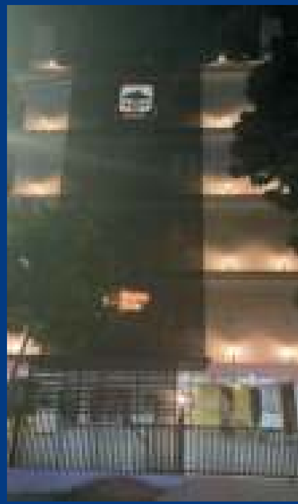
Layout, Sensor and Installed state of Vib 360 System

Cover pictures courtesy:
Uday Purohit



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ADVANCED INSIGHTS INTO THE HEALTH OF DIESEL ENGINES: IR CLASS APPROVED ENGINE CONDITION MONITORING SYSTEM, VIB 360

Uday Purohit
Karicheti Narendra Kumar

Abstract:

Condition monitoring of diesel engines through speed data. The article discusses about technology through which marine engines' fuel efficiency, mechanical health and emissions can be monitored. With everchanging engine fuels and fuel composition, dynamic effect of injection system on the crankshaft is studied through the speed sensor to monitor and improve above-mentioned.

Torsional Vibrations of the shaft can be identified from a simple speed sensor. Identification of Torsional vibration is the earliest form of identification of defects. Frequency information of speed sensors contains signature of individual faults and individual cylinder faults.

The outcomes and the salient points of the study are:

1. Speed sensor can be used to identify Torsional Vibrations.
2. Torsional Vibration of the shaft is the earliest form of vibration and defects of the engine can identified well before any other form of condition monitoring
3. Each defect or issue in the engine produces shaft vibration with a certain frequency. Identification of frequency signature is the basic principle
4. Using a camshaft sensor for the identification of TDC of Cylinder-1, Individual cylinder's Injection, compression, bearings issues can be pinpointed
5. Damper health can be identified from Simple speed sensor on flywheel
6. Fuel loss % in real time can be calculated from the acyclism of the flywheel

Keywords: Fuel Efficiency Monitoring with speed sensors, Emission monitoring with speed sensors, Mechanical health monitoring with Torsional vibrations, Damper health monitoring

1.0 Introduction/Background

This paper explains how an engine's Torsional vibrations (TV) are detected through a single non- intrusive, unpowered MPU(Magnetic Pickup Unit) and how this information from the MPU is utilised to identify and detect nascent defects. The system pinpoints issues related to compression, increased friction in bearings, Injector related faults, stresses on the crankshaft, overall mechanical health, Engine related accessories, (Pumps, etc.,) and condition of the holding down bolts. Vib360 is a powerful tool to monitor fuel efficiency of the engine, on a real time basis, which ensures that emissions have not deteriorated due to poor combustion conditions. Equations of TV and related spectrums will be explained in detail. This paper shall also explain how the system with a single peak pressure sensor mounted on any cylinder can calculate the peak pressure of all the other cylinders. The paper shall distinguish between alarm systems & condition monitoring (CM) systems. In addition, a brief about the existing CM systems and Vib360 will be provided to prove the significance of Vib360.

Impedance-Neptunus has developed a Real-time online condition monitoring product VIB360 with this technology for the benefit of the engine operators. The system is designed by considering all the challenges in the marine environment.

2.0 Text/Methodology/Results/Discussion

The Power of this technology is to change the way maintenance is done on engines, reduce cost of ownership and eliminate breakdowns completely. Currently there is no method to monitor and therefore correct the fuel consumption of engines. Operators therefore are unaware when fuel consumption starts increasing due to defective components. The 'Power Loss' indicator addresses this issue by having real time data for the operator. Engines can now be operated at peak efficiency.

Due to the absence of better technology, operators rely on engine maker's scheduled maintenance intervals. This is both expensive and unnecessary. With the presented technology, operators can now have interventions based on the actual condition of the engine.

Breakdowns are expensive. The technology enables the operator to be alerted when defects are initiated giving him sufficient time to plan corrective actions. Currently there is no mechanism for the operator to estimate 'Residual Useful Life' or RUL of the engine. By plotting long term trends the system enables the operator to estimate RUL and pinpoint components that fail prematurely.

Due to the absence of better technology, operators rely on engine maker's scheduled maintenance intervals. This is both expensive and unnecessary. With the presented technology, operators can now have interventions based on the actual condition of the engine

3.0 CURRENT PRACTISES

In marine applications, internal combustion engines are critical assets. To ensure continuous operation and optimum engine performance, it is essential to mitigate the risk of premature engine failures by an automated continuous monitoring tool.

Current practices of Engine performance monitoring are:

- **a.** Manual Peak pressure measurement
- **b.** Exhaust Temperature, Pressure and Flow measurement and monitoring.
- **c.** Linear Vibration measurement by accelerometers
- **d.** Boroscopic Inspection
- **e.** Use of ultrasound devices
- **f.** Lube analysis

Protection devices fitted on the engine prevent the engine from catastrophic failures. All these methods are not satisfactory in detecting the onset of defects in various components of the Diesel Engine. By the time the engine mounted sensors show a deviation in temperature and pressure, the fault has progressed to a stage where the component has already failed and corrective action is expensive. VIB360 is a complete product for the condition monitoring of diesel engines. Following Planned Maintenance Schedules offered by Engine manufacturers only partly mitigates the risk of breakdowns.

4.0 VALUE OF CONDITION MONITORING SYSTEMS

Figure 1 curve explains defect propagation and identification by the performance monitoring (Alarm

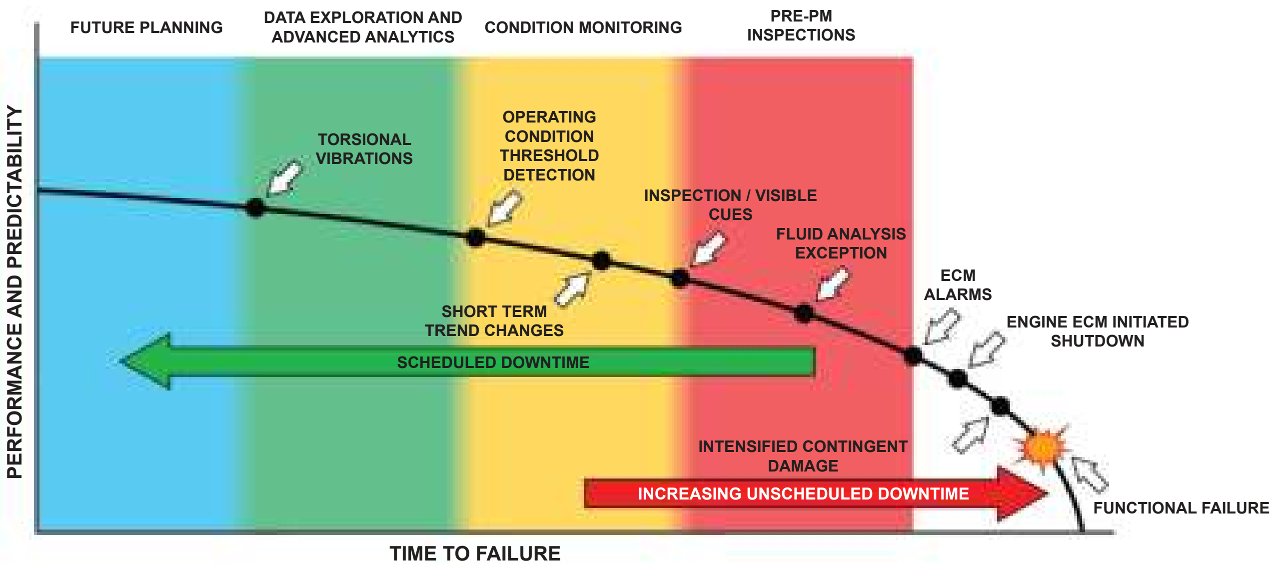

Figure 1. Defect Propagation Curve (Time to Failure)

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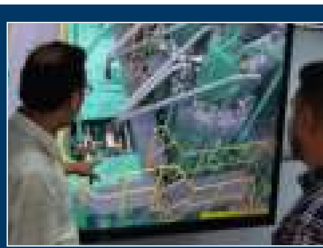

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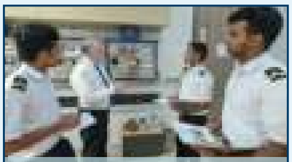
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based) and Condition Monitoring techniques. Colours in the background explain the severity of defects at every stage. Identification of defects at the green stage shall reduce the cost of repair, increase reliability and avoid catastrophic shutdowns. Importantly, identification of defects in green stage and rectification will improve the fuel savings of an engine by at least 2~5%.

- OEMs of electronic engines supply ECM Alarms and Auto Shutdown technology to avoid catastrophic failure.
- In most cases, ECM produces an alarm, the defect has already propagated to near failure (Red Zone).
- Lube analysis and thereby manual defect prediction is not accurate, is time consuming and not real-time. Prediction accuracy is dependent on the quality of sampling, lab analysis and skill of the engineer. Lube analysis is to-date majorly used to determine the overhaul/change of bearings as per OEM guidelines.
- Detection of Torsional Vibration is the only technique by which a defect can be identified in early stages and so can be called a condition monitoring technique. All the other systems that are used to measure performance and alert customers before failure do not fall in the condition monitoring basket.

Detection of Torsional Vibration is the only technique by which a defect can be identified in early stages and so can be called a condition monitoring technique

5.0. TORSIONAL VIBRATION ANALYSIS - TECHNOLOGY

5.1 TECHNOLOGY BRIEF:

This paper introduces the technology to address the challenges that engine owners and operators face today - optimum fuel efficiency whilst meeting environmental norms for emissions using different fuels, preventing unplanned shutdowns and optimising the intervals between overhauls. Identifying faults at a nascent stage not only protects the equipment but also individual components, significantly lowering ownership costs.

The patented technology uses a single non-contact, non-invasive, Magnetic Pickup unit or MPU (similar to those fitted on any engine) to measure the instantaneous speed of the crankshaft and hence the 'torsional vibration'. The voltage signal thus recorded is processed by the software embedded in the Intelligent Controller. The output is available both to the operator at the local location and to the manager at any remote location.

5.2 What are Torsional Vibrations ?

Torsional vibrations are angular vibrations of the shaft within each rotation. These are induced by (bad) condition of the engine or varying load. Structurally sensitive frequencies from the mounts may amplify and transfer these phenomena to the engine leading to stability issues. The level of torsional vibration is influenced by a number of parameters, such as material properties, operating conditions (such as temperature, load, RPM, etc.). **Despite tremendous progress in Engine design by OEMs, overall system complexity still necessitates accurate qualification and quantification of these torsional vibrations in real-time to diagnose the mechanical and thermal health.**

5.3 Equations of Torsional Vibration

Angular displacement $\alpha(t)$ in [rad] or [°]

Angular velocity $\frac{d\alpha(t)}{dt}$ in [rad/s] or [°/s] or [RPM]

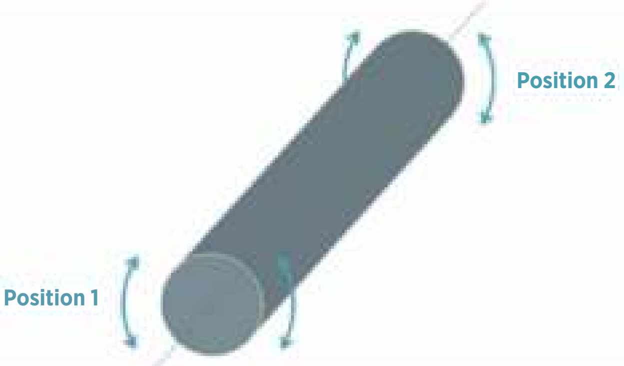


Figure 2. Shaft Rotation

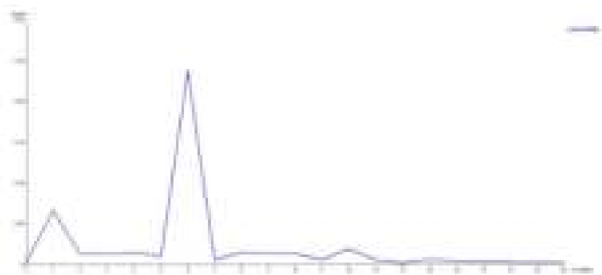


Figure 3. Harmonics of Volvo Perfect Engine

Figure 4. FFT spectra of a 6 cylinder 4-stroke engine with defect

Angular Acceleration $\frac{d^2\alpha(t)}{dt^2}$ in [rad/s2] or [°/s2]

While R = radius of the shaft and Jz [m4] = torsion constant or the polar moment of inertia), then $J_z = \frac{\pi \cdot R^4}{2}$

Twist-angle(T) method is based on the measurement of the relative-angle deformation between two separate locations on the shaft.

$$T = \frac{GJ_z\Delta\alpha}{L}$$

Twist angle and twist RPM : The twist RPM is the difference in RPM between the two extremities of a shaft. This difference in RPM between the two locations, the so-called twist, is a measure for torsional vibration on the shaft.

Vib360 utilises Instantaneous Angular Speed (IAS) and Twist Angle to identify the health of engines as depicted in **Figure 2**. Vib360 doesn't need amplitude of the speed signal, it uses only its frequency. Two main paths of engine diagnosis are frequency domain analysis and time domain analysis

5.4 Frequency Domain

The Fast Fourier transform (FFT) is used to transform a signal from the time domain into the frequency domain allowing to break up the signal into its frequency components and its spectrum. Engine problems generate torsional vibration at specific frequencies, this information can be used to diagnose the cause of abnormal torsional vibration by using the FFT spectra. If an engine has an issue with the gas forces, the torsional vibration is periodic throughout an engine cycle, thereby limiting the frequencies of interest in the frequency domain which appear as peaks in the FFT spectra.

Torsional vibrations are angular vibrations of the shaft within each rotation. These are induced by (bad) condition of the engine or varying load

If a 6-Cylinder 4-stroke engine is working in almost perfect condition, the firing frequency is the dominant peak in the FFT spectra **(Figure 3)**. But, if it is not working properly due to gas forces, a peak appears at the 0.5x order in the FFT spectra. 0.5x is the lowest order for a 4-stroke engine whereas 1x is the lowest order for a 2-stroke engine. For 4-stroke engines, half order frequency refers to the frequency at which a full engine cycle repeats, which is equal to half an engine's speed (RPM). Half order frequency is present in all piston engine torsional vibration signatures due to some degree of variation in the firing process from cylinder to cylinder. However, frequency analysis is only one aspect of interpreting the information contained in a torsional vibration signal. Not all engine problems can be derived from the information of an FFT spectra. For example, to detect bearing defects the FFT has its limitations but can be identified by a method used in the time domain.

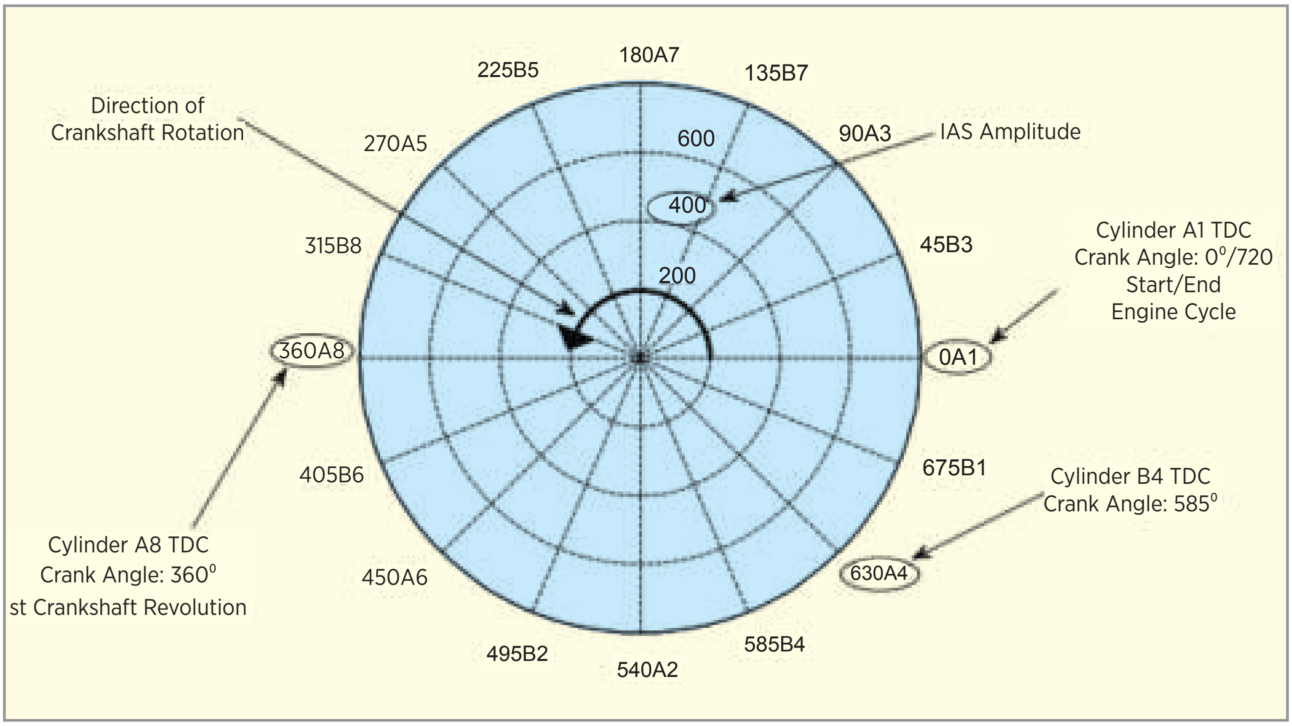


Figure 5. Envelope of a 16 Cylinder Diesel Engine created by VIB360

Figure 3 presents the FFT spectra of a Volvo engine without any defect showing its major harmonic at 6th ½ order, thus 3rd order. Without any defect the major harmonic contains the greatest energy in the spectra. But as soon as a misfiring of cylinder 6 happens the FFT spectra changes as shown in **Figure 4**.

Figure 4 represents defects in the 6th cylinder of the engine. The dominant peak is at ½ cycle which indicates issues in combustion of cylinder 6.

5.5 Time Domain

Conversion of real signal of MPU to analytical signal is performed through Hilbert Transform. Hilbert Transform generates the envelope of a signal and removes the rapid oscillations data that will not be useful for analysis.

Figure 5 envelope analysis combined with torsional vibration is to eliminate disturbances and emphasise the fault. At an early stage of a defect, the chance of detecting the defect using FFT is low. Signal envelope analysis provides an effective extraction method for signals having a low Signal to Noise Ratio (SNR). The Hilbert transform of a signal *s(t)* is defined by an integral form:

$$H[s(t)] = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{s(\tau)}{t-\tau} d\tau \qquad (1)$$

The Hilbert transform keeps all the amplitudes of the spectral components unchanged but the phases are shifted by . Thus, Hilbert transform is the convolution integral:

$$H[s(t)] = s(t) * \frac{1}{\pi t} \qquad (2)$$

The imaginary part of the analytical signal is the Hilbert transform of the real part, written as

$$S(t) = s(t) + iH[s(t)] \qquad (3)$$

Normally the spectrum of a signal having a low SNR usually contains less diagnostic information. Whereas the envelope signal contains the required information about faults which affect the torsional vibration [2],[3]. The magnitude of the Hilbert transform is the instantaneous angular velocity, which can be used to calculate acceleration and displacement. Using these three values with the statistical moments, e.g. Skewness and Kurtosis, mechanical defects of the engine can be derived. The Skewness which is the third moment characterises the degree of asymmetry of a distribution around its mean and describes the shape of distribution curves.

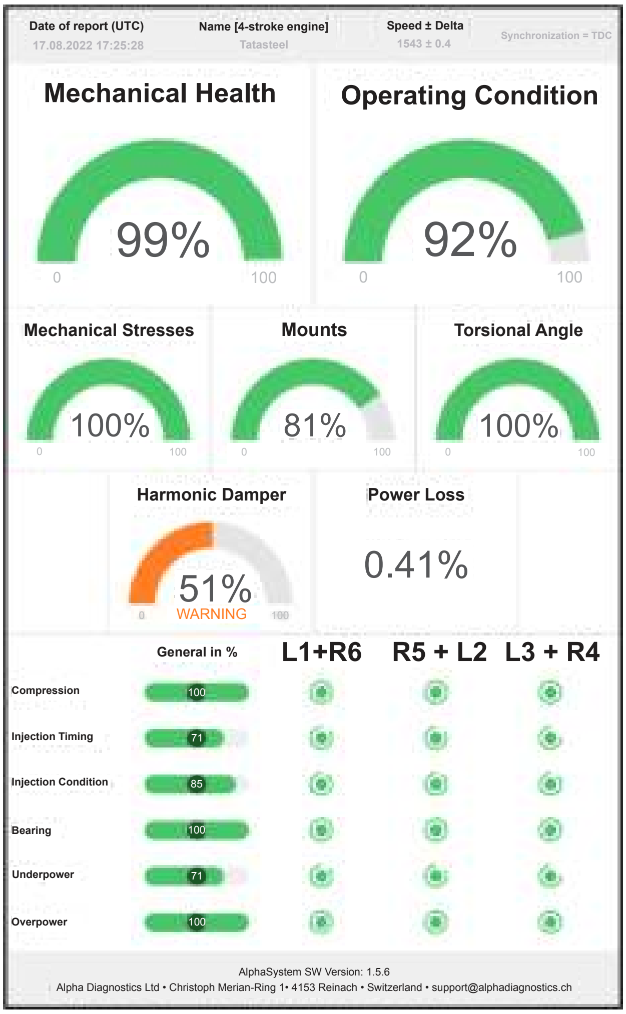


Figure 7. Health Report of Vib360

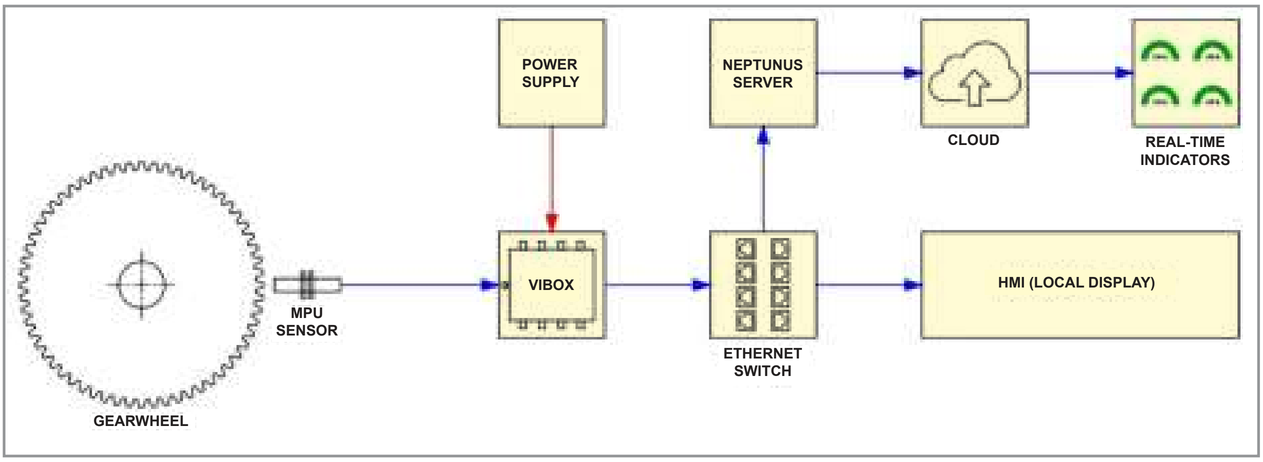


Figure 6. General arrangement of the Vib360 system

$$Skewness = \frac{1}{N-1}\sum_{i=1}^{N} \left(x_i - \underline{x}\right)^3 \qquad (4)$$

Kurtosis is a measure of peakedness and is a good indicator of signal impulsiveness in the context of fault detection for rotating devices. It is the ratio of the fourth moment to the square of the second moment which is known as variance.

$$Kurtosis = \frac{(N-1)\sum_{i=1}^{N} \left(x_i - \underline{x}\right)^4}{\sum_{i=1}^{N} \left(x_i - \underline{x}\right)^2} \qquad (5)$$

Kurtosis allows us to define the impulsive character of a signal. If for example, the acceleration has a Gaussian distribution, the kurtosis value is around 3 while, in the presence of impulsive phenomena e.g. bearing defect, the distribution of the data does not have Gaussian shape and its Kurtosis value is higher than three(3) [4]. But if the value is above 13, it can be said that this is not due to an impulsive phenomenon of the moving part but from some external system.

5.6 Torsional Orders Vs Torsional Resonances

- Torsional orders are forced responses induced by the cyclic excitation of the rotating source. A Fourier analysis of this irregular torque/RPM at a certain moment will show the different harmonics and the relative importance at that moment, thus related to the operating condition at that moment. The waterfall or colour map of a combustion engine provides a global overview of the torsional-frequency behaviour, and the dominant-torsional orders.
- Torsional resonances, which are related to the structural properties of the system, are independent of the operating condition. When excited, they very often amplify the torsional vibration phenomena, so it is important to identify and quantify them. As torsional excitation under operating conditions is mainly limited to the harmonics of the forcing torque, torsional resonance levels can be small compared to the orders. A good measurement-dynamic range will be important to avoid the torsional resonances being masked by the orders.

Engine condition monitoring - Dashboard Indicators

Sr no.	Indicator	Explanation
1	Mechanical Health	• Indicates minor and major mechanical problems in the moving parts, which indicates impending damage. • Calculated from the wear/friction and crankshaft bearings indicators.
2	Operating Condition	• Indicates efficiency of the engine with regards to fuel consumption. • Calculated from injection timing, condition & compression indicators. • If the status of this indicator becomes significantly worse, the engine is running inefficiently. However, it can still be kept in operation without concern of damage to the engine as long as the mechanical condition indicator is normal. The consequences of allowing the engine to continue running under this condition are only higher operational costs and higher fuel consumption.
3	Power Loss	• Overall indication of engine imbalance, expressed as a percentage, due to non-optimal thermal health (refer to indicators) and the inertia resistance of the rotating and moving parts.
4	Mechanical Stress	• The presence of unexpected stress pulses in the crankshaft twist, measured in each operating cycle. An indicator of mechanical fatigue • Potential problem : Crankshaft is dynamically deformed and becomes misaligned due to material expansion, high load or high rotational speed. All components connected to the crankshaft are exposed to undesired forces. coupling clearance or alignment.
5	Mounts	• Overall movement of the engine(excessive chassis vibrations, foundation, ageing and weak supports)
6	Torsional Angle	• The dynamic twist in the crankshaft is measured in each operating cycle. • Problem : The engine may be heavily loaded. The engine may be running irregularly during idling, which may be a fuel saving setting of the engine control system. The torsional vibration damper may not have a significant effect at current RPM. Failure of torsional vibration damper. Problem in engine mounting and/ or engine alignment
7	Harmonic damper	• Overall indication of the torsional vibration damper effectiveness at current rotational speed
8	Over/Under power	• The power contribution of indicated cylinders deviated from the other cylinders.

- Often the twist angle or the twist RPM is analysed, since they remove most of the torsional orders and more clearly highlight the torsional resonances.

6.0 Measurement, Processing and Analysis

- Magnetic Pickup sensor records voltage information with torsional vibration data in it.
- The data is processed in the local embedded box (Edge Computing) with VIB360 patented software.
- The analysed signal can be locally viewed on any HMI without the use of any external software and internet. Data stored in the embedded box is for offline trend analysis.
- Vib360 distinguishes the torsional orders from the torsional resonances.

The Fast Fourier transform (FFT) is used to transform a signal from the time domain into the frequency domain allowing to break up the signal into its frequency components and its spectrum

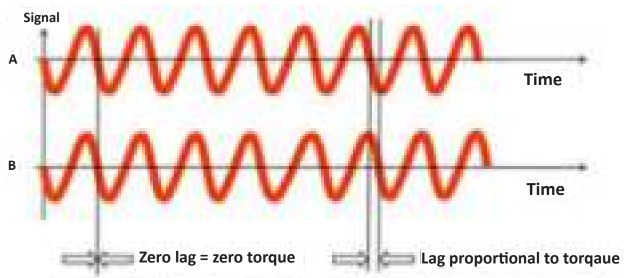


Figure 8. Measurement of Torque from Speed sensors

6.1 Analysis output available to customer:

The Intelligent Controller edge computes data and gives the following output:

(i) Injection equipment condition and injection timing cylinder wise

(ii) Compression condition of each cylinder

(iii) Status of bearings of each cylinder

(iv) Overall power loss as a % in the engine

(v) Peak pressures of all individual units using a single sensor on any one unit.

(v) Overall mechanical health of the engine

(vi) Overall combustion efficiency

(vII) State of the vibration damper

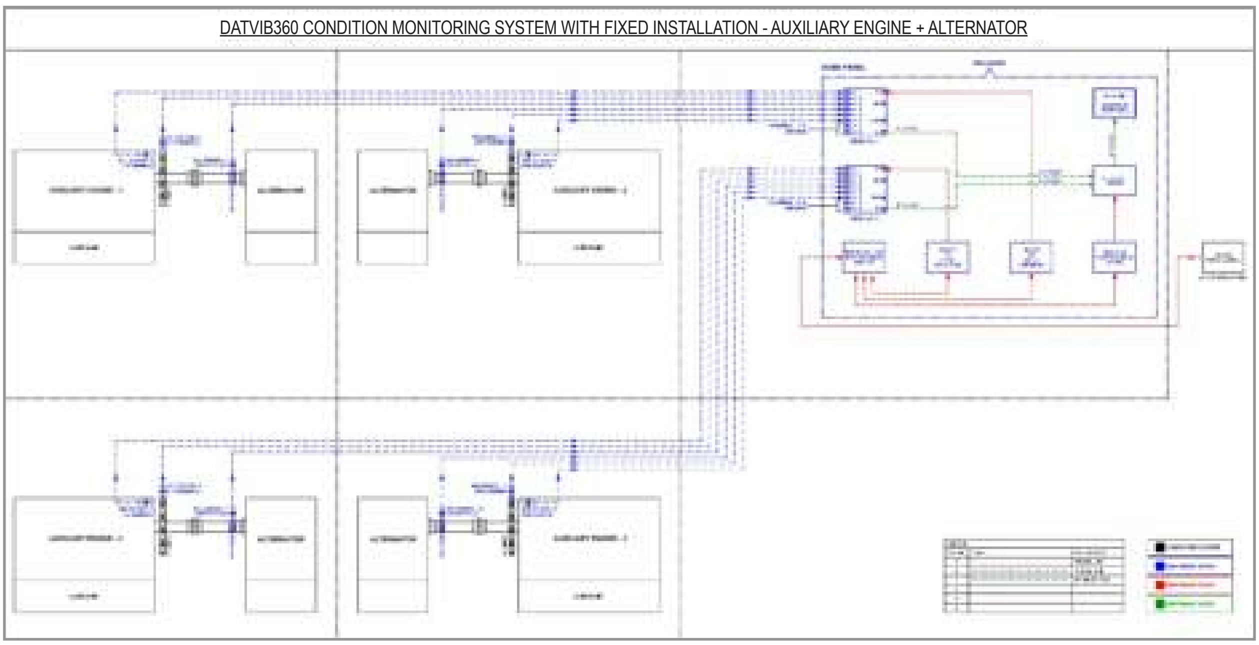
(vii) Integrity of the foundation and holding down bolts

(viii) Stress and twist on the crankshaft resulting from unbalanced forces

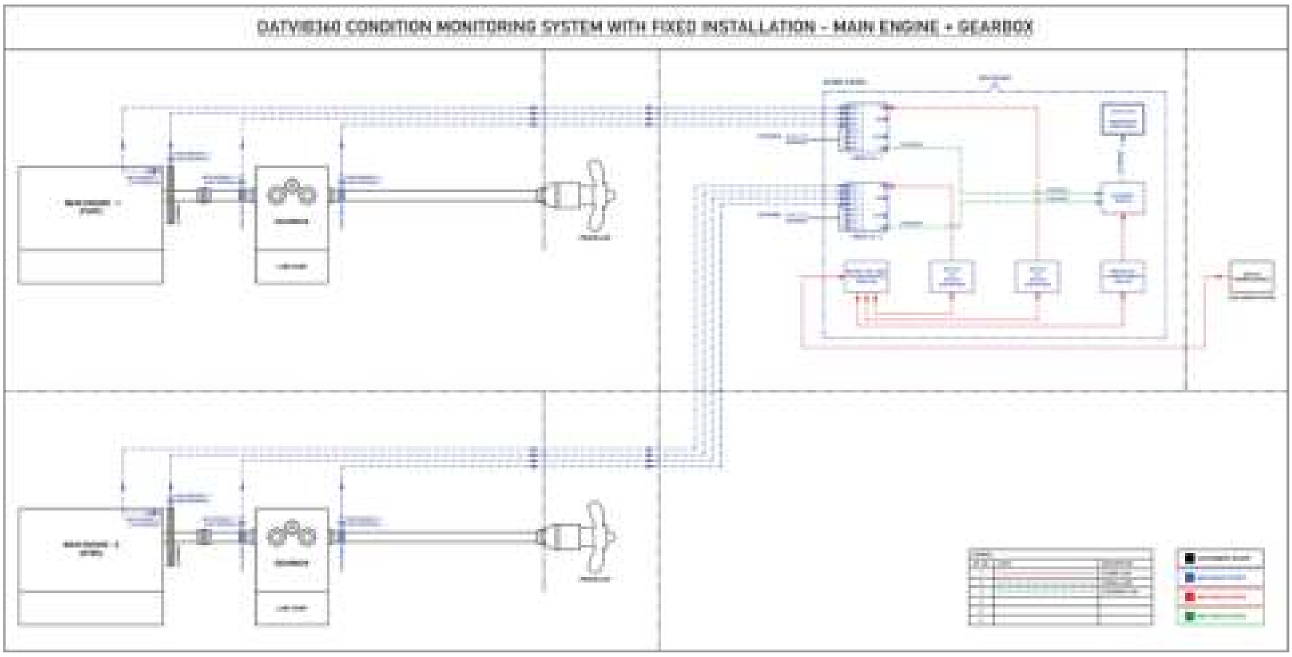
This data serves to inform the performance of the engine and thus its fuel efficiency in real time.

7.0 IR Class Certification

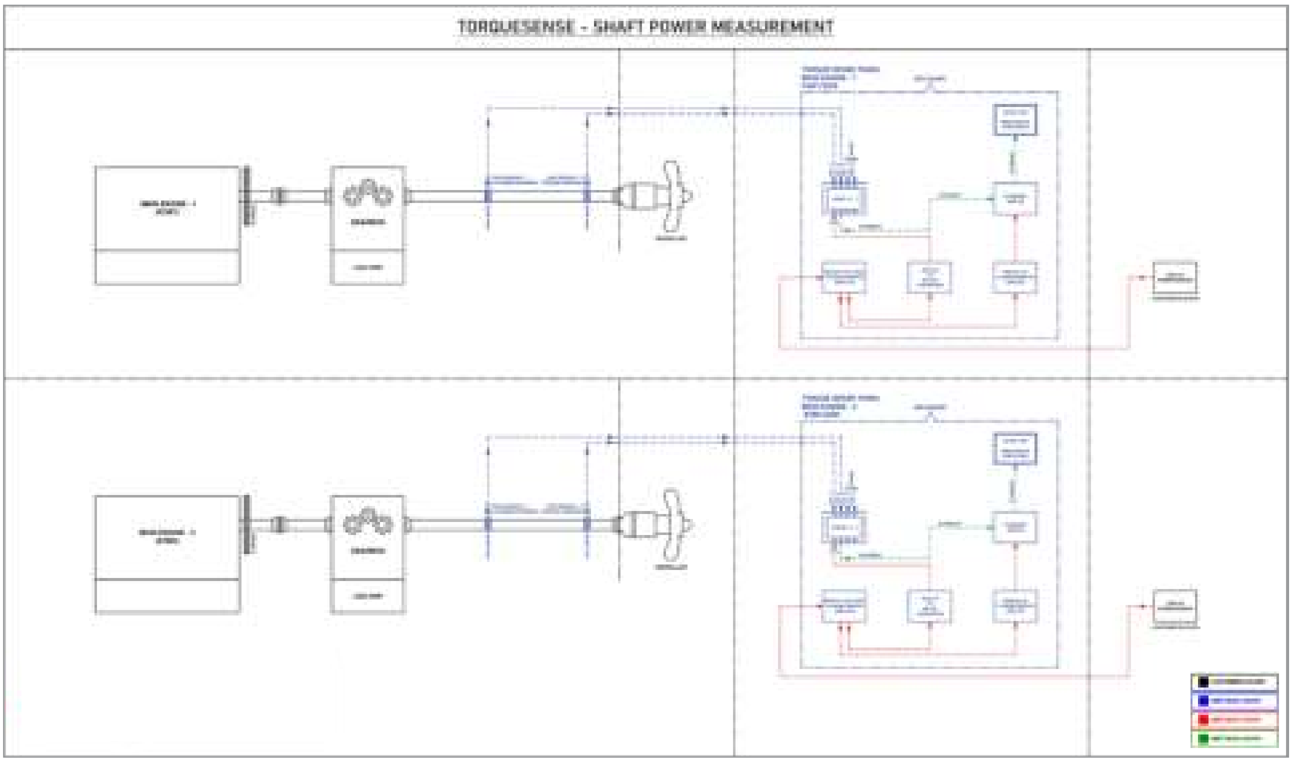
VIB360 product - Torsional Vibration Condition Monitoring by Impedance is the only approved condition monitoring system by IR Class. After 6 months of continuous monitoring and surveys, IR approved the condition monitoring system for use on engines. Advantages of the certification for marine fraternity are listed in the concluding section.



9a: AE & Alternator



9b: ME & Gearbox



9c: Shaft power measurements

Figure 9. Image Representation of Shipboard Installations

8. Torque Measurement without Strain Gauges

Strain gauges are commonly used across the globe for the identification of torque on the propulsion system. Life of strain gauges is low. With time, the accuracy of the gauges reduces and needs replacement and frequent calibration. With this problem statement in mind, Impedance designed a Torque measurement system for ships on the principle of Twist angle.

The twist generated on the shaft is proportional to the Torque and is $\theta = \frac{2L(2\varepsilon)}{D} = \frac{32LT}{\pi G D^4}$

Hardware Required : 2 RPM sensors and Hardware for measurement and local analysis

Capacity upto which technology works : Tested till 120 MW

Hardware life : 15 years

Calibration : Not needed

Accuracy of Torque output : 99%

Cost of the system = ⅓ of the strain gauge based system

The system can be operated completely without the need of internet connection. Data analysis and trending for years can be completely stored inside the system itself. In the presence of the internet, data can be transferred to the internet for visualisation by the ship office. **Figure 9** shows a shipboard layout.

Conclusion

a. Ship owners can change the notation of Engine from PM (Periodic Maintenance) to CM (Condition monitoring). The overhauls or actions on the engines can be scheduled based on the condition and not on the running hours. Thus MTBO can be extended safely.

b. Identification of health of individual cylinders can help save fuel to a very significant extent and decrease OPEX.

c. Identification of mechanical health and trend will provide information well in advance about the time of overhaul. Planning can be effective.

d. Catastrophic failures can be completely eliminated by rectifying faults at early warning of system.

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About the Author

Uday Purohit is a Marine Engineer by profession and a first generation entrepreneur. He is alumni of DMET, Kolkata. He is inspired by people, new technologies, challenges, new business ideas and his main area of interest is in the design of engineering systems. He is the Founder and Managing Director of Neptunus Power Plant Services Pvt Ltd. Uday is also the Immediate Past President of the Institute of Marine Engineers (India) and was the Hon.Editor of the MER. He is an avid reader, keen golfer and is widely travelled.

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AIR DRONE AS AN ALTERNATIVE TO SUPPLY BOATS IN SEA PORTS

R.Prasanna Kumar
Dr. V Ajantha Devi

The maritime mode of cargo transfer is an age-old practice of trade between different countries. The efficient turnaround of ships' arrivals to departure depends upon various parameters, including the availability of berths and weather conditions. The vessels stay in the port area at anchorage locations because of non-supportive weather or lack of berths. Due to the nature of cargo loaded on the vessel, the designated anchorage areas are located away from each other for different types of ships. On the seaport requirements, almost in all locations, large vessels' supply needs are fulfilled by conventional supply boats. These supply boats transit between the shore and ships. As we know, the boats use conventional IC engines for their propulsion, and it is not a variable that depends upon the cargo capacity. The efficiency of this mode of transport is poor. Added to the above, the emissions due to diesel fuel used for this purpose affect the environment in the sea ports.

On the other hand, with today's technological advancements and widespread acceptance in the industry, cargo transfer for short distances is done with drones on land. Applying this new invention in the maritime industry, in few ports, air drone transfer is used for small consignment sizes. The main advantage of using drones for supply is that it eliminates the need for humans to travel on water. When we do the close-up view of this technology, the benefit of the energy saving has not been a huge difference from conventional supply boat methods. The path and the distance travelled by drone in the air and supply boat in the water are different, and this is the main contributor to the efficient operation of these vehicles. The objective of this paper is to demonstrate a hybrid method of drone and supply boat use in small distances and for small-sized consignment transfers between shore and ship.

Keywords: Air Drone, Remote operation, cargo transfer, supply boat, Energy efficiency

1. INTRODUCTION

Several logistics companies, e-commerce retailers, tech companies, and startups have all conducted extensive research into the ability of drones [1] to make autonomous vehicles deliveries. There has been numerous drone - based delivery prototypes and operational modes investigated, some of which have not yet been used. Drones are likely to be less expensive and consume fewer energy per unit of distance travelled than boats since they are much smaller than launch boats and because drone - based delivery technology have evolved dramatically. Furthermore, given that the bulk of delivery drones run on electricity, which may be generated using more environmentally friendly energy sources., they might emit less greenhouse gas per unit of energy than traditional diesel boats. Drones may not be cost-effective or environmentally friendly due to their limited cargo capacity, the need for additional depots or charging stations to increase their short flight ranges, the labour required to operate them. Additionally, a number of studies have found that there are substantial questions regarding their effects on the environment [2–5].

Deliveries from the shore to the ship have been a significant component of the shipping industry ever since it began. Every day around the world, spare parts, medical supplies, and money are just a few examples that are transported to ships [6]. Deliveries have historically been made by launch boats for ships that do not frequent ports and involve a number of expenses, including manpower and fuel costs as well as preparation and travel time, customs clearance, transfer from launch boat to vessel [7, 8].

> **Deliveries have historically been made by launch boats for ships that do not frequent ports and involve a number of expenses, including manpower and fuel costs as well as preparation and travel time, customs clearance, transfer from launch boat to vessel**

Unmanned aerial vehicles (UAVs), also known as drones, have begun to enter the shipping industry as a more effective and environmentally friendly alternative due to the high demand for shore-to-ship deliveries around the world and strict environmental regulations [9]. Many industries are turning to UAVs because of their accessibility, speed, and low operating costs compared to more conventional methods of transportation that require labour, according to the consulting firm [10].

Using a UAV certified for explosive environments, the shipping company Maersk claimed to have made the first delivery by UAV to a ship at sea in 2016. [11]. A project called Skyways, a partnership between the aerospace company Airbus and the ship agency Wilhelmsen, is one of the most recent and pertinent ones that the company has been working on since then to further investigate shore-to-ship solutions [12]. Singapore hosted the first commercial UAV delivery trial in the world, where supplies were delivered to a ship in port over the course of ten minutes [13].

While some studies indicate that, if used carefully, drone-based delivery could lower greenhouse gas (GHG) emissions and energy consumption [14, 15], others indicate that, in many situations, drones used for parcel delivery actually use as much energy as launch boats do [16 – 18].

2. REVIEW OF LITERATURE

Since its discovery, society has always depended on shipping for transportation by water, and it is now a key component of the global economy [19]. 90 percent of global trade is now carried out by shipping, which is also the most economical mode of transportation. Today, launch boats are one of the traditional ways to move cargo from the land to the ship [7]. These deliveries can be challenging and pricey, frequently costing $1,000 USD or more on average [11].

2.1. Cost, Greenhouse Gases Emissions and Energy Consumption

Drone use for last-mile delivery costs and environmental impacts are also investigated. The most widely utilised functional units of analysis are a single delivery and a unit distance travelled. However, there are few available data on the lifespan emissions of drones [14, 18]. Studies carried out in various countries employ different databases. [20] uses data from Thailand and several nations, including the US, China, and Canada, to assess the environmental effects of drone delivery. [16] suggests a comprehensive energy consumption model for the drone delivery process. It also considers the environment in which it is functioning (wind). The energy usage of diesel boats operating out of the same depot and providing services to the same clients is then compared to that of drones. Because drone delivery consumes more energy than launch boat delivery, the results demonstrate that transitioning to a drone delivery system is not energy-efficiently advantageous.

2.2. Ship Categories

Different commercially used vessels come in a variety of sizes and shapes that are tailored to fit the intended cargo (International Chamber of Shipping). According to [21], the mission of a ship establishes the specific specifications and elements, such as the kind of cargo to be transported, the required speed, the operational range, or the distance to be covered. Additionally, it lists various ship types, including tankers, container ships, roll-on/roll-offs, passenger ships, and dry bulk. There are designated helicopter operations areas on each of these ship types, which can vary in size and location [22]. Given that the procedures will be similar to those for helicopters, these locations will probably be used for UAV shore-to-ship deliveries [23].

2.3. Areas of Marine Application

Inspections and surveys are one of the marine industry's many current uses for UAV technology, according to

Figure 1. Traditional Delivery by launch boat

Figure 2. Provides an example of a drones

the classification society DNV GL. These are primarily carried out in cargo holds, ballast and cargo tanks on ships, as well as in the structural elements of offshore installations. UAVs have been used in this area, according to some justifications, which include shorter preparation times and increased safety thanks to unmanned inspections. Compared to traditional surveys, this approach allows for high-resolution documentation and can be finished faster and with less expense. Monitoring of ships' sulphur emissions inside Emission Control Areas (ECA) is another use [24]. These ECA areas were created to reduce emissions of SOx and particulate matter, which is typically done by limiting the amount of sulphur in the fuel oils used onboard (International Maritime Organization).

> **Singapore hosted the first commercial UAV delivery trial in the world, where supplies were delivered to a ship in port over the course of ten minutes**

The Danish Maritime Authority (2019) claims that specially made UAVs can help enforce these sulphur limits more effectively. The operator will receive information on the sulphur content of the air by means of special sensors that examine the air's composition as they pass over a ship in motion [25].

Shore-to-ship deliveries are a third application for UAV technology [23]. In addition to having the largest ship agency network in the world, Wilhelmsen has extensive experience arranging daily deliveries of cash, essential spare parts, and medical supplies to shipmasters around the globe [23]. Deliveries made by UAV rather than traditional launch boats would cost 90 percent less to make, pose fewer risks of injury, and have a smaller environmental impact.

3. DELIVERY METHODOLOGY

3.1. Conventional Delivery Strategy

The European Ship Suppliers' Organization claims that shipping is changing due to the need for faster cargo handling, imports, and exports, which has resulted in more frequent port calls but less time spent in port. Higher demands on suppliers and deliveries are the result of this. Nowadays, some ships only conduct ship-to-ship transactions, leaving the ship with no choice but to have supplies delivered while at anchor.

According to [7], the operation of launch boats was most frequently utilised for shore-to-ship deliveries as shown in the **Figure 1**, and this process is as follows: The beginning of the delivery process involves receiving a customer inquiry, which is followed by an order confirmation. The customer is informed as the order is later prepared for delivery. The price for direct delivery to the vessel is given to the customer who requested it. The client must concur on the price before the process can move forward. Transportation plans are made, and the ship agent's contact information is obtained. When the agent is contacted, the delivery can be scheduled in accordance with anticipated arrival time and loading window availability.

Before any staff are allowed onboard the ship to finish the delivery, operations like anchoring may take some time, and immigration clearance must be completed. When the coordination process is complete, the agent plans the collection of the goods, and the transporter plans the movement of the goods from their warehouse to the loading port. After customs clearance, these items are loaded onto a launch boat. Upon arrival, the launch boat coordinates the delivery with the responsible Officer onboard after informing the vessel of the incoming cargo. The responsible officer signs and stamps the delivery order before returning with the launch boat and transporter after the goods have been transferred to the vessel. Sending the invoice to the client is the process's last step. Every day around the world, smaller launch boats are typically used to deliver supplies or cargo to ships at sea. The source cites Marius Johansen, Vice President,

Drone design	Delivery Operations	Environment
Drone weight	Payload weight	Air density
Number of rotors	Size of payload	Gravity
Size of rotors	Empty return	Wind conditions
Size of drone body	Fleet size and mix	Weather (rain, snow, etc.)
Battery weight	Single-/multi-stop drone trip	Ambient temperature
Battery energy capacity	Delivery mode (landing, tether, parachute)	Regulations
Size of battery	Area of service region	
Power transfer efficiency		
Maximum speed and payload		
Lift-to-drag ratio		
Delivery mechanism		
Avionics		

Figure 3. Impacting factors of Drone

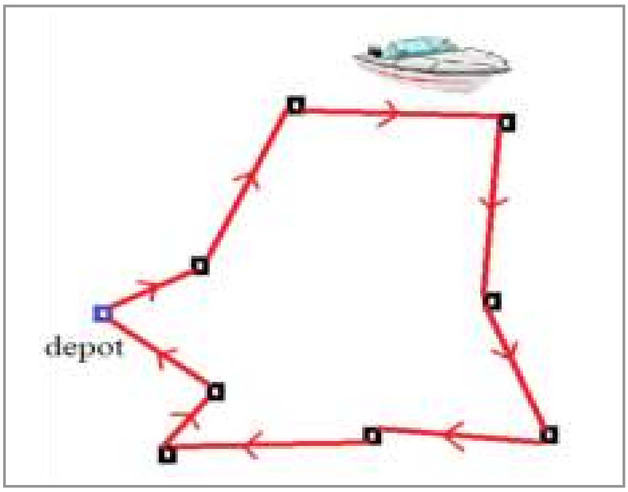

Figure 4. Shows conventional Launch boat delivery where it travels on a multi stop route delivering packages to various ships

Commercial at Wilhelmsen Ships Service (2017) [13] as saying that regardless of the size or number of packages, the average cost for these types of deliveries is around $1500 USD. The cost will always be the same because this type of transportation always needs a crew for the boat, including labour and fuel. Supply delivery to a ship can frequently be very expensive [30].

The Danish Maritime Authority (2019) claims that specially made UAVs can help enforce these sulphur limits more effectively

3.2. Unmanned Aerial Vehicles (UAV)

A simulation module was developed in a study by [28] to show how a UAV can land onto a ship safely in a predetermined location as in **Figure 2**. The area here was constructed like a helipad platform. There were two distinct phases to the process. The drone had to find the ship in the first phase, which was accomplished by placing four red LED lamps around the helipad in a square configuration. It was possible to manoeuvre in the direction of the red lamps above and hover over the helipad with the aid of a mounted camera. The second stage of the process began when the UAV was hovering above the helipad, and it was finished by using the bottom camera to further centre and position itself over the helipad. An ultrasonic altimeter was used in conjunction with the four lamps as compensation for the movement of a ship in motion. According to Wang & Bai, this allowed for good accuracy and a safe, autonomous landing on the helipad.

Maersk claimed to be the first company to use a drone to deliver supplies from a barge to a vessel in 2016. [11]. Another advancement was made in 2018 by Wilhelmsen Ships Service and Airbus, who set up stations to pilot consumables printed using 3D printers, documents, water test kits, and spare parts to vessels at anchor from Singapore Port's marina south pier [29].

3.3. Validity, Generalisability, and Dependability

In general, data for the background material was compiled from a variety of sources. The technical aspects and constraints of the field received a lot of attention. The degree to which they were analogous and the date of publication were used to determine whether or not the document was regarded as pertinent to the research questions. Because of the respondents' selection and the background data, which was deemed to be highly pertinent to the research, this study is thought to have a high level of credibility. Previous experiments and activities in the area were conducted on ships at anchor in cities like Singapore [13]. By examining reviews and publications in scientific journals, it was possible to assess the validity of the information gathered.

Due to limited lifting capacities and the fact that most respondents are aware that deliveries frequently consist of multiple pallets, it was generally agreed that UAV deliveries could complement but not entirely replace shore-to-ship launches by launch boats. In order to avoid delays, some of the respondents believed that a **UAV might be useful for transporting important documents and spare parts in narrow passages or areas where ships are passing close to the shore**. The authors initially did not think about this kind of implementation, but after studying the literature and conducting interviews, they realised how important it is.

This study's main findings, which compare UAV deliveries to launch boats, include potential cost savings, quicker delivery times, risk reduction, and less negative environmental impact as shown in the **Figure 3**. None of these advantages came as a surprise given that UAVs are powered by electricity, unmanned, and transported in air. The lifting capacity presented one of the biggest obstacles to UAV deliveries. In our interviews, the majority of participants said that a UAV's capacity was insufficient for shore-to-ship deliveries. When they made their own reflections based on personal experience, the authors thought this was reasonable. Even though the respondents

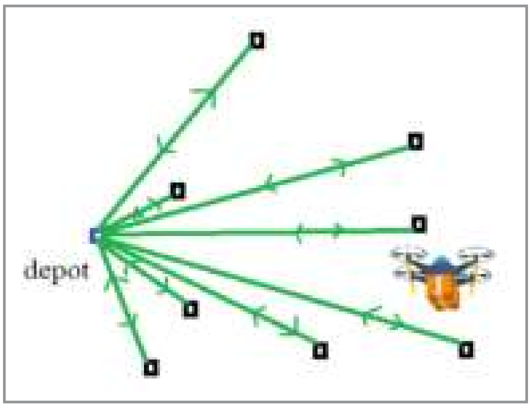

Figure 5. Provides an example of a delivery by drones to a portion of these customers. [Drone stops are indicated by the black square (deliveries).]

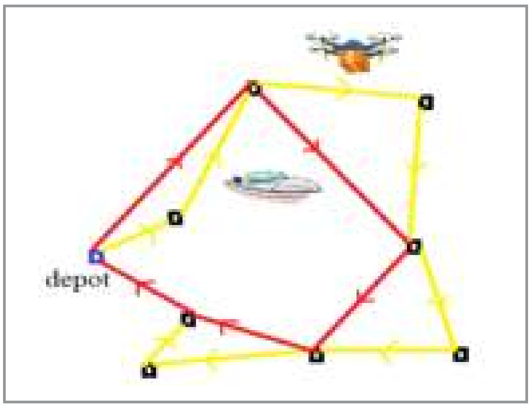

Figure 6. A hybrid Boat-drone delivery system is depicted, in which the launch boat and the drone alternate making deliveries as they pass through the service area.

received adequate information about technology that was already in use, some responses revealed ignorance of it. The predetermined belief that UAVs couldn't lift enough weight, despite the presentation of heavy-duty UAVs capable of lifting 200 kg, is a prime example of this.

Who would be responsible in the event that the UAV or cargo was lost was another issue that worried the respondents. The literature review contained no information on this matter, making it impossible to provide an answer. The respondents' perceptions of the delivery method in general may have been impacted by this.

Since the majority of respondents operate and conduct business with tanker vessels, the majority of the responses were predicated on the assumption that UAVs used for ship deliveries were classified for explosive atmospheres. This has already been classified, and it was assumed that this was necessary in order to discuss more questions with the target group.

Due to limited lifting capacities and the fact that most respondents are aware that deliveries frequently consist of multiple pallets, it was generally agreed that UAV deliveries could complement but not entirely replace shore-to-ship launches by launch boats

The study's findings revealed no particular relationship between the respondents' attitudes toward UAV deliveries and the types of ships they operated. Although when contacting some of the tanker-operating companies for an analysis, the results sometimes included references to laws governing the use of electrical equipment in potentially explosive environments. This demonstrated the significance of classification in potentially explosive environments as well as the general ignorance of UAV development at the time. This led us to wonder if, rather than the precise classifications, modern technology might be the obstacle to implementation. This is further supported by the fact that the shipping sector is frequently described as conservative and traditional.

3.4. Security and Privacy Issues With Drones

The usage of drones provided advantages on both a professional and a private level. But there are several issues with drone systems in terms of security, safety, and privacy [31]. At the highest national level, drone-related privacy and security concerns should be addressed. A very tight policy should also be in place to limit the ability of drones to photograph and video people and property without authorisation. In terms of security and threat analysis, drone assisted networks are different from traditional wireless networks like Mobile Ad-hoc Networks (MANETs) and Wireless Sensor Networks (WSNs) [32]. This is understandable given that it consumes less power and transmits less data compared to a network that makes use of drones to support public safety.

Additionally, compared to WSNs and MANETs, the drone's coverage area is substantially larger. As a result, the main security difficulties stem from the resource and delay limitations of UAVs. Drone use for physical and cyberattacks by bad parties puts society at risk by breaching citizens' privacy and jeopardising public safety. In reality, drones are being abused and misused for possible attacks in a number of technical and practical ways. This requires conducting critical activities based on offensive reconnaissance and surveillance intended to follow specific individuals and certain properties, both of which present dangers to personal privacy [33].

On the other hand, it's critical to prevent the use of drones over restricted areas because doing so results in privacy violations due to careless behaviour and the footage may be used for scamming and/or blackmail. Both material loss and damage and human casualties and deaths would result from this. The majority of studies contrast the speed of drone delivery with that of launch boat delivery. According to results [34, 35], using drones in addition to boat can reduce total delivery time, but the amount of the reduction depends on the speed of the drones compared to the launch boat. [34] make the assumption that the drone is faster than the launch boat by a factor of and demonstrate theoretically that adding a drone to a boat reduces total service time.

3.5. Hybrid Model – Proposed Model

The conventional launch boat model of supply makes the distance travelled by the boat greater and the effect on the environment due to the carbonaceous fuel emissions also higher. Refer to **Figure 4**, when the IC engine is in low power mode when slow-speeding close to the destination, the system's efficiency is lower. When too many stops are added, the overall efficiency of the trip is low.

If a drone-only model is introduced for the same supply as described in **Figure 5**, due to the limitation of the payload in drones, each ship needs to be visited separately. This makes the number of drone flights high. Even though the energy requirement of drone transit is small, because of the higher counts of travel, the overall energy requirement is equal to the launch boat model of the supply.

A hybrid model will be developed using the benefits of both modes of transport. When comparing **Figure 4** and **Figure 6**, the total distance travelled by the boat on the hybrid model is reduced, and the energy requirement as a part of boat travel is reduced. Added to this, the reduced number of stoppages in this model will lower the time required for part-load operation and increase overall efficiency too.

In the drone part of the shipment, the number of drone movements is reduced and the total distance travelled is also reduced, which lowers the energy consumption on this part too. Overall energy requirement on this hybrid model of the supply system efficiently reduced.

4. CONCLUSION

In conclusion, there is little research on the economic and environmental benefits of drone delivery. While the majority of those research focus on drone-only deliveries, fewer studies look at the launch boat and drone delivery approach, which is another crucial way to employ drones. Few research examines a hybrid delivery model that best integrates drone and sea-drone delivery. Research findings on the energy and emissions efficiency of drone delivery are likewise inconclusive, in part because little is known about drone energy consumption and the wide range of drone energy consumption models and rates. The authors were able to respond to the research questions and derive conclusions from the findings through literature reviews and interviews. UAV shore-to-ship deliveries to ships at sea could supplement rather than completely replace current launch boat deliveries.

When compared to traditional launch boat deliveries, UAV deliveries have a number of advantages for shipping companies, including lower costs, faster delivery times, a smaller impact on the environment, and lower injury risks. The industry's cautious attitude toward new technology, regulations, classifications of explosive atmospheres, and the limited lifting capacity of UAVs were found to be the main obstacles to the implementation of UAV deliveries in shipping.

About the Author

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GREEN INITIATIVE FOR INLAND SHIPPING - THE ISSUES AND CHALLENGES

Subhakar Dandapat

Abstract

The article reviews the status of the existing inland fleet with a brief introduction to the present status of inland shipping, India's third surface transport mode. To suggest transforming this third and alternate mode into sustainable and economically viable, the article also critically reviews the initiatives taken to green the sector along with the required logistics, regulatory framework, promotional measures, policies, and incentives. The article highlights the issues and challenges in successfully implementing greening projects and schemes. An attempt is also made to suggest mitigation measures for reducing emissions from inland shipping, which would assist India in achieving its targeted goal of carbon neutrality by 2070 and a green economy.

Keywords: Carbon neutrality; Carbon footprint; Carbon Credits; Zero emission; GHG factors; fuel efficiency; energy-efficient design; pollutants; modal share; modal shift.

Introduction;

Inland Water Transport (IWT) or Inland Shipping, recognised as the third and alternative mode of transport within the surface transportation system, remains one of the most environmentally friendly, with the lowest emissions per ton-km transported all over the globe, besides its other characteristics of being fuel and energy efficient, and thus the cheapest mode of transport. There are several policies and plans with increased investment, promotional measures, and financial incentives with the objective of the revival of IWT and its development to achieve at least 6% transport share, down from the present percentage of 2% (NITI Ayog @75) of the total transportation system. Its importance has been further enhanced compared with other modes of transport, be it road, rail, or aviation, concerning its emission of CO2 and other components of GHG (greenhouse gas). The renewed interest among the planners, financial bosses, and administrators of the developed and developing countries for the revival of the mode and further development to increase its modal share in the total transportation system, along with a concerted effort to green the mode wherever feasible, to assist in the action of reducing global warming and maintaining the sustainable fight against climate change in line with the target fixed by COP-15 (Conference Of the Parties) at Paris and subsequent COP-26 and COP-27 held recently based on the United Nations Framework Convention on Climate Change.

The recent Energy Conservation (Amendment) Bill-2022 of India, passed by the Lok Sabha, has a mandatory provision on the use of alternate & renewable fuel for vessels and boats besides road vehicles. It not only reduces the FE (foreign exchange) on the import of fossil fuel but also reduces the emissions to achieve the target of reducing emissions of 30% by 2030 to the 2005 standard and zero by 2070.

India's contribution to CO2 emissions from inland shipping, with a modal share of only 2% of the transportation system, is presently minuscule in comparison to the European Union, which accounts for 14% of the modal share, having an emission share of only 1.86% of those, falling behind the shipping sector (9.26%), the road sector (72%), and the rail sector (1.67%). With the envisaged increase in the share of transportation from IWT in India, there may be an increased share of emissions. Therefore, it is crucial to review the current status of the greening of IWT mode in the nation, the issues, challenges, and the necessary policies and regulatory framework similar to road mode to ensure a clean, emission-free, and energy-efficient method of transport achieving carbon neutrality.

> **The state governments of Goa, Kerala, Maharashtra, and Gujarat have displayed similar interest in developing and modernising the passenger movement on the inland waterways**

Present Status of IWT & its Fleet

There is a total length of 20,250 km of national waterways (The National Waterways Act-2016, March 26, 2016), covering 111 no. of NWs in the country. The IWAI (Inland Waterways Authority of India), a statutory and apex body under the MOPS&W (Ministry of Port, Shipping and Waterways), is mandated for developing, maintaining, and managing these NWs besides promoting IWT (Inland Water Transport). Through the 29 no NWs, as reported to be either fully or partially navigable, the total cargo traffic per annum is 108.79 MMT (2021-22) and projected for 200 & 400 MMTPA by 2029-30 and 2049-50, respectively, with the development of 50 NWs. Besides, the EXIM cargo traffic of approx.5.40 MMT per annum is presently transported through IBP (Indo-Bangladesh Protocol) routes to and from Bangladesh under existing PIWT &T (Protocol on Inland Water Trade and Transit) between India and Bangladesh, which is poised for growth. The effort of enhanced cross-border connectivity to neighbouring countries such as Bhutan, Nepal and Myanmar through the trade and transit treaty for the use of Indian & Bangladesh waterways, and KMM&T (Kaladan Multi-Modal Transport & Transit) project, the EXIM traffic, and the transit cargo traffic to NER (North Eastern Region) has the potential for augmentation substantially.

With the decreasing trend in passenger movement during the last few decades due to rail and road infrastructure development and connectivity over the waterways, the present traffic has regained approximately 200 million passengers (2021-22). There is ample potential for increased RO-RO pax and modern ferry services to reduce congestion. Besides the river cruise movement, the change in the urban planning for developing the waterway connectivity and transportation in the metropolitan cities wherever this opportunity exists for tourist and entertainment vessels. Therefore, there have been World Bank-funded projects in Assam and West Bengal for developing and modernising ferry services and institutional strengthening and capacity development of the ferry and cruise sector. Under the JMVP (Jal Marg Vikash Project)-II phase, the World Bank-funded project to augment the capacity of NW-1(National waterways No-1 on the Ganga-Bhagirathi-Hooghly River system) has been the thrust for increased community services and passenger movements. The state governments of Goa, Kerala, Maharashtra, and Gujarat have displayed similar interest in developing and modernising the passenger movement on the inland waterways. And these enhanced activities may facilitate the growth of passenger traffic in the country.

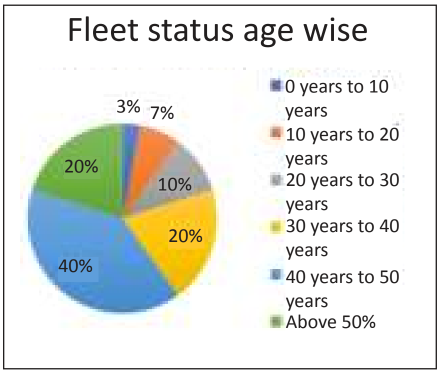
Coastal cum Inland Shipping

The integration of river transportation with coastal shipping, termed coastal cum inland shipping (CIS), commenced in the country formally only a decade ago with the notification of the rules and regulations of river-sea vessels of four types, depending on their area of operation. The lighterage operation from the mother vessels or the transhipper stationed at Sand head or Kanika sand in the Bay of Bengal to the nearest ports at Kolkata, Haldia, and the inland ports/terminals on NW-1 and other waterways by inland & river-sea vessels as the project already tried out for movement of coal to NTPC Farakka during 2013-2017 may get revival providing a boost in this type of operation in future along with similar operation in the west coast.

The Director General of Shipping (DG Shipping), through a notification in 2018, has created a separate traffic corridor within five nautical miles in the coastal water from the baseline, namely the Inshore Maritime Traffic corridor/Zone, to facilitate the movement of the inland vessels. The operation, however, is allowed only during the fair season and fair-weather conditions by the certified inland vessels as per guidelines of DG Shipping for safe operation. This type of operation enthused interest and thus has increased the coastal cum inland shipping on the coast of the Arabian Bay. The issues & challenges for safe operation on the eastern coast may likely be sorted out shortly with appropriate measures, with enhanced inland shipping integrated with coastal shipping.

Traditional boats (country boats/crafts)

The operation of the traditional boats (country crafts) in the unorganised sector for cargo and passengers, semi-mechanised or manual, by the marginal and vulnerable groups of society also contributes immensely to the IWT sector. The recently notified Inland Vessels Act of 2021, replacing the century-old Inland Vessels Act of 1917, provides the uniform regulatory framework for traditional boats for their sustainable development and contribution to IWT. There are also various schemes and plans by the state governments through the World Bank and GBS (Govt Budgetary Support) for the mechanisation of these boats to bring them into the fold of the inland vessel category for their registration under the provisions of the Inland Vessels Act of 2021 and to increase efficiency and safety in operation.



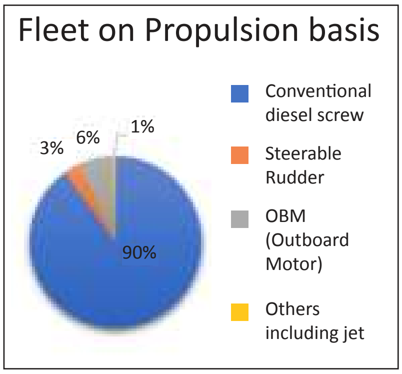


Figure 1 Fleet status age wise on Nw-1, 2,16 & 97, Fig-2: Fleet on propulsion basis

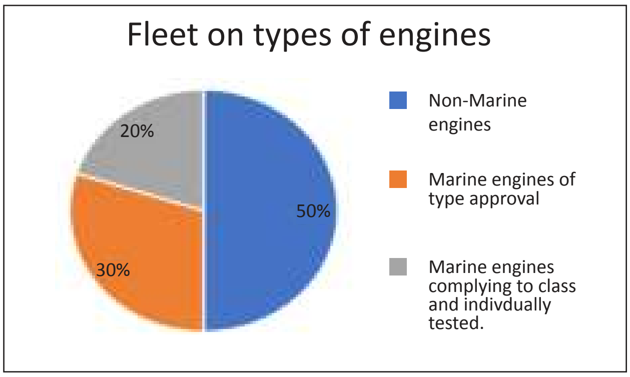


Figure 3 Fleets on type of engines

Fleet strength and its Characteristics

The total number of registered self-propelled vessels for the movement of freight and passengers in the IWT sector is approximately 8,000 in the organised sector and over 55,000 traditional boats (country boats) in the unorganised sector, with semi-mechanised and non-mechanised. There are also over 2000 ancillary and utility vessels besides the non-propelled barges.

From the recent study carried out on the characteristics of the inland fleets operating on NW-1 (the Ganga River system), NW-2 (the Brahmaputra River system), NW-97 (the Sundarbans), and NW-16 (the Barak River system)) in the NER(North Eastern Region), Eastern and Northern parts of the country for their greening through USAID (United States Agency for International Development) funding under CBIC (Cross Border Infrastructure Connectivity) program, the status of the fleet on propulsion, propulsion types, and fuel types used for propulsion is as in the **Figures 1 to 3**.

Environment Performance of Inland Shipping Energy Efficiency

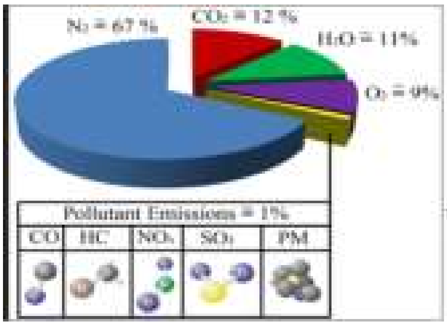
In developing countries like India and Bangladesh, the energy efficiency performance of inland vessels has been lower than in developed countries, mainly because of the use of **older engine technologies, obsolete vessel designs, the age of the fleet, the size and characteristics of the vessels and the conditions of the waterways, besides the use of non-marine propulsion engines and sub-standard fossil fuel**. The deployment of small and traditional boats has an impact on emissions as well as energy efficiency. Therefore, the improvement of the energy efficiency of the IW fleet may thus have a significant effect on its contribution to an improved climate and change its competitive cost position towards other modes.

> **The operation of the traditional boats (country crafts) in the unorganised sector for cargo and passengers, semi-mechanised or manual, by the marginal and vulnerable groups of society also contributes immensely to the IWT sector**

Fuel, Fuel Efficiency & Emissions

Fossil fuel used for the inland fleet is mainly non-marine diesel fuel with a 35-degree Celsius flash point, marine grade diesel fuel with a 65-degree Celsius flash point, and occasionally kerosine and petrol for OBM. These are the dominant fuels for this sector.

The exhaust gas from inland vessels usually comprises GHG (Greenhouse Gas) and pollutant gas with several components, as in **Figure 4**. The greenhouse gases (GHG) do not have any direct toxic effects. They are, therefore, covered within the climate change cost category with special measures and regulatory framework for their reduction. (**Contribution, *2013, p.57 to 69***). Pollutant gases, however, are harmful to air quality and human health and do not affect the climate directly. Considering the IWT as one of the surface modes of transport, there is justification for adopting the



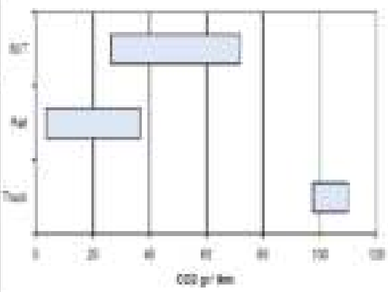


Figure 4 Components of exhaust gases from diesel engines & Figure 5 Comparison of CO2 of IWT with rail (electric) and road mode

It has been established that the development or infrastructural cost of the waterways and transport services is comparably less than the rail and road modes globally

appropriate technical solutions for the new and existing engines in stages to reduce emissions, particularly the harmful pollutants from the Indian inland fleet.

The emissions from inland vessels are exceptionally high because of poor fuel efficiency. Thus, significant variations in emissions exist between countries. The intensity of fleet modernisation, logistics efficiency, and well-developed co-modality services also dramatically influences the actual environmental performance of inland shipping.

The average CO2 emissions of the inland waterways fleet among the different countries (Ecorys Report, 2015) vary from 25 gr/ton-km to 70 gr/ton-km **(Figure 5).** The total CO2 emissions from IWT in the EU (European Union) are 1.86% **(*(Source: Climate Change 2014: Mitigation of Climate Change by Intergovernmental Panel on Climate Change.),*** with a modal share of 14% of the entire transportation system. It may not be significant in India compared to the EU, having a modal share of 2%.

The specific GHG factor for different types and sizes of vessels under operation in the European waterways is in **Table I.** However, there is no such information and data for the fleet in the country in the absence of any studies and inventories on the emissions, performance of the propulsion systems, etc. The USA has achieved the GHG factor of 11.4 gm/t-km for the pusher tugs with a flotilla of a maximum of 45 standard barges. The inland fleet of China has also achieved remarkable improvement on this front.

Liquid bulk ves22.92 The strategy of achieving zero emission levels for the Transport sector

India had the target of achieving zero-emission based on 2005 levels by 2050 as per the initial goal fixed by COP-15 (Conference Of the Parties) based on the United Nations Framework Convention on Climate Change. The government revised it after the COP-26 in 2021 at Glasgow to accomplish the same by 2070, which the Hon'ble PM reaffirmed during his 75th-year independence speech at Lal Killa, New Delhi, on August 15, 2022. There are strategies for the road and rail sectors to achieve the above target using alternate fuel, electrification, improved efficiency, modal shift, innovative technology etc. **(Climate Action Tracker on Decarbonizing the Indian Transport Sector-Dec 2020)**. Significant policies and regulatory frameworks to reduce emissions have also been formulated since 2000. There seems to be yet a strategy and target prepared for the IWT sector. However, all these strategies adopted for other modes of transport could easily apply to the IWT sector.

Justification for the greening of the Inland fleet, the initiative and achievement

The greening of the IWT sector is basically about using clean fuel for the fleet and adopting various other measures above to enhance energy and fuel efficiency and, thereby, reduce emissions and make the operation economical. In the absence of comprehensive studies and publications of data with the inventories for the mode, similar to the rail and road modes, it is an attempt to substantiate the justification based on the data and information of European waterways and other advanced

Table I. Specific GHG emission factors for different types of vessels in Europe

A. General cargo, dry, and liquid bulk carriers/vessels	GHG emission Factor (in g/t.km)
Motor vessels < 80 m	29.5
Motor vessels 85 – 86 m	20.7
Motor vessels 87 – 100m	18.4
Motor vessels 110 m	18.4
Motor vessel 135 m	19.0
Coupled convoys (163-185m)	17.0
Pushed convoy- push tugs + 2 barges	17.3
Pushed convoy- push tugs + 4/5 barges	9.7
Pushed convoy- push tugs + 6 barges	7.4
B. Container vessels	
Container vessels 110 m	25.5
Container vessels 135 m	19.8
Container vessels- coupled convoy	19.7

Source: Report on GHG factors for IWT by M/s STC- NESTRA -Published by GLEC (Global Logistic & Emission Council).

countries. It has been established that the development or infrastructural cost of the waterways and transport services is comparably less than the rail and road modes globally. Similarly, the external cost for IWT is less than the other two modes. While comparing infrastructural and external costs of rail, road, and inland waterway transportation, it is evident that IWT has an advantage over the other modes besides the GHG emission. Thus, the IWT has the justification for its greening on priority for ensuring an emission-free and cost-effective third mode and an alternative mode of transport in the country.

Suitability of the available green tools

The various options available for decarbonising inland shipping, its application, and achieving the desired level of results may depend on the: -

- Ease of use of technology and efficiency.
- The availability of green fuel and the required logistics near the waterways, including charging facilities, battery packs, swapping facilities, etc.
- The availability of propulsion machinery and engines adaptable for the different fuel types and Indian environment.
- The availability of suitable conversion tools for retrofitting the existing fleet.
- And, finally, affordability, i.e., the economy.

Worldwide, the application of any particular alternate fuel type and associated technology is yet to be established as the perfect solution. Hence, the constant effort to achieve the same is already in progress with the required studies and R & D. However, some of the different solutions available in the international arena may apply to different market segments and vessel types in India in the present context, as below.

- Electric propulsion with batteries for cross- and short/ distance longitudinal passenger ferries on rivers, canals, and creeks.
- Solar-powered propulsion for traditional (country boats) and other small vessels.
- CNG & LPG for smaller boats for a short-distance voyage
- LNG propulsion of either hybrid or single for cargo operation on the long distance and heavy duty
- Hydrogen fuel cell electric propulsion, initially for ferry services and subsequently for cargo fleets.
- Hybrid propulsion with blended bio-fuel and fossil fuel with suitable retrofitting of the propulsion system
- Methane and Ethane based on the availability of indigenous engines, the bunkering facilities and relevant safety issues.
- For greening the traditional (country) boats, it would be essential to mechanise the boats with road and non-road engines BS-VI compliant without marinisation, making this sub-sector economic.

Initiatives on greening and its status

Some initiatives towards the greening of the inland fleet in a sporadic manner have been observed, mainly through new construction with solar and battery-based electric propulsion or the hybrid mode of electric and fossil fuel propulsion, mainly for passenger and ferry vessels. Upgradation of the existing fleet through retrofitting with suitable conversion is only for the traditional tourist and passenger boats on NW-1 at Varanasi, with CNG as the alternate fuel since 2021. These eco-friendly boats receive the fuel from an innovative bunkering facility through a floating CNG filling station, termed the world's first jetty, developed by IIT Kanpur with the unique features of a self-adjusting type floating jetty (SAFJ) and installed at Khidkiya ghat on the river Ganga. The station ensures a consistent and safe CNG pipeline connection to all the dispensers with controlled risk factors, even in peak flood season. The greening of the vessels, however, with the use of the alternative fuels of the international benchmark (i.e., LNG, biofuel, methanol, and ethanol) in the IWT sector is yet to commence.

Some of the successful projects, mainly in Kerala and a few other states, for new construction with greening technology, are: -

- The use of solar energy-based batteries for electrical propulsion for tourist and ferry boats was pioneered by Kochi-based M/s Navalt Solar & Electric Boats Pvt Ltd in 2009. The MV Aditya, the 100-pax capacity ferry, designed and built in 2017 for the Kerala State Water Transport Department, is the first commercially viable vessel powered by solar energy in India and the world, being the recipient of several awards, including Gustave Trouve for excellent performance. And technology has increased phenomenally, spreading to other parts of India. Since its operation in 2017, the ferry has been instrumental in saving 165 thousand litres of diesel, 420 tonnes of CO2, and other GHG components, as shown on the website: https://navaltboats.com/aditya-solar-electric-ferry.
- M/s CSL (Cochin Shipyard Ltd) has designed and constructed the ferry boats for Kochi Metro Ltd., with a hybrid propulsion system for electric propulsion with imported LTO (Lithium Titanium Oxide) marine batteries with a charging system through inboard Genset facilities and conventional screw diesel propulsion. The CSL has a total of 34 nos. of such orders. These boats also have excellent performance in reducing the carbon footprint, as seen on the website of Kochi Metro: https://kochimetro.

org/water-transport. With the project's success, there is a plan to extend similar types of water metro services to the cities on the waterways.

- M/s CSL is designing and constructing the country's first hydrogen-fuelled cell electric (DC power) ferry vessel. The propulsion system is on low-temperature proton exchange membrane technology (LT-PEM) with technology partner M/s KPIT Technology Ltd and India Register of Shipping, the national classification society, with the target of trial and delivery in March 2023. On construction will be deployed at Varanasi on NW-1(the National Waterways, the Ganges).
- M/s Matprop Technical Services Ltd, a Kochi-based firm, has recently submitted a proposal to SWTD (State Water Transport Department), Kerala, to construct and supply a hydrogen fuel cell-powered ferry of 100 pax capacity for operation on the canals and other waterways. The technology has been developed jointly with M/s Nedstac, the Netherlands, with the technology transfer for construction indigenously. The supply of green Hydrogen used as fuel will be ensured indigenously at a cheaper rate, making the operation smooth, effective, and economical.
- M/s GRSE (Garden Reach Shipbuilders and Engineers) Ltd, Kolkata, has been awarded to design and construct two ferry vessels recently by the government of West Bengal with solar-based electric propulsion and liquid-cooled energy storage solution/technology.
- The state has also placed the contract for solar boat development for operation in the Sundarbans area with the electrical department of IIT Kharagpur.
- Assam IWT Development Society has floated an RFP seeking the EOI for greening its ferry services under World Bank funding.

> **The greening initiatives for inland shipping are mainly by the government authorities on a pilot project basis with external funding and GBS (Government Budgetary Support). The initiatives by the private players are a handful and in few pockets**

The greening initiatives for inland shipping are mainly by the government authorities on a pilot project basis with external funding and GBS (Government Budgetary Support). The initiatives by the private players are a handful and in few pockets. With the assistance of the USAID (United State Agency for International Development), a project for developing the energy efficient standard designs with the latest greening technology for dry and wet bulk carriers and container vessels besides the RO-RO pax along with the development of the business and bankable project involving the shippers and IWT operators has been planned. The construction of the green vessels with the latest greening technology from the developed standard designs is also in the planning stages with the financial assistance of USAID and/or the World Bank for deployment on NW-1, 2, and IBP (Indo-Bangladesh Protocol Routes).

International trends and its applicability in India

Several options are available and accordingly tried out for greening of Inland shipping in different countries to achieve the target of reducing emissions. The greening tools are suitable for new vessels and existing fleets with retrofitting and upgradation These are broadly under two main groups **(M/s STC Nestra & Emission from IWT-Emilia Kuciba)**. The same is on: -

A. **Direct method of reducing the emission** from the Inland fleet with the alternate fuel and emission reduction technology. These are further under three sub-groups such as: **-**

I. **Use of alternative fuels other than fossil fuels of international benchmark**

- LNG (Liquified Natural Gas)
- CNG (Compressed Natural Gas)
- PNG (Pressurized natural gas)
- GTL (Gas to liquid) products mainly from diesel with old engines without retrofitting.
- Methane
- Ethane
- Bio-Fuel blended with diesel or petrol of
- Ethanol
- Methanol
- Green Hydrogen fuel cell
- Synthetic Fuel (E-Fuel)

II. **Adoption of different technologies for air pollutant emission reduction of existing & new engines for propulsion and auxiliary purposes.**

- Alternative technology as the measure for decarbonisation.
- After Treatment of the exhaust gas through different methods, mainly for the propulsion plants of the existing fleet. These are:
- PMF (Particulate matter Filters) for the reduction of pollutant emissions
- SCR (Selective Catalytic Reduction) to reduce NOX
- DPF (Diesel Particle Filters) to reduce particulate emission

- New Engine Concepts and Optimization (development of new marine engines conforming to the requirement for the fuel types and emission standards towards the pollutants similar to road sector engines)

III. **Energy consumption reduction by**

- Energy Efficient Navigation
- Energy Efficient Ship Design & Construction
- Hybrid/Diesel -Electric propulsion
- Hybrid Electric Propulsion

Electric propulsion can either be solar-powered or battered-operated.

B. Indirect methods of reducing emission

These indirect methods are: -

i. New logistic concepts:

- The modal shift of the cargo,
- RIS (River Information Services) as supporting tools for transport management or E-navigation
- Digitisation of the sector

ii. New cargo flows

- Containerised cargo
- Increase Inland navigation with more waterways
- Cold/food chain cargo flow
- City logistics where inland navigation exists

iii. New Vessels concepts

- Efficient use of small waterways by small vessels (traditional boats in the case of India)
- Optimal cargo load
- Automation of navigation
- Barge train/flotilla

Of these options, efforts for greening inland shipping in India through alternate fuel and adopting hybrid propulsion have been made. The action of upgrading the existing fleets is unsatisfactory. Regarding reducing emissions through indirect methods besides achieving efficiency in the operation, IWAI, however, has the project of installing the RIS (River Information Services) on NW-1 in phases to introduce VTMS (Vessel Traffic Management Services), leading to E-Navigation in future. There are also plans for a similar facility along with DGPS and; the preparation of electronic charts to facilitate ECDIS navigation on NW-2 (the Brahmaputra River system) and other waterways. Under the World Bank-funded project, namely JMVP (Jal Marg Vikash Project), presently under execution on NW-1, IWAI has developed energy-efficient and standard inland vessel designs for 14 types through DST (Development Centre for Ship Technology & Transport System), Duisburg, Germany (available on IWAI website: www.iwai.nic.in). The action to digitise inland shipping has commenced recently with the creation of the portal for cargo & the infrastructures, hydrographic survey activities, chart preparation, etc.

Strategies and micro-level planning in achieving the zero-emission target

It is an attempt as a case study to illustrate the level of the strategic plan, the micro-level road map developed in the Netherlands to achieve the zero-emission level from well to tank and finally tank to wheel for inland shipping by 2050 (**Figure 5)** for making awareness. The strategy adopted from 2019 onwards is to have propulsion begin

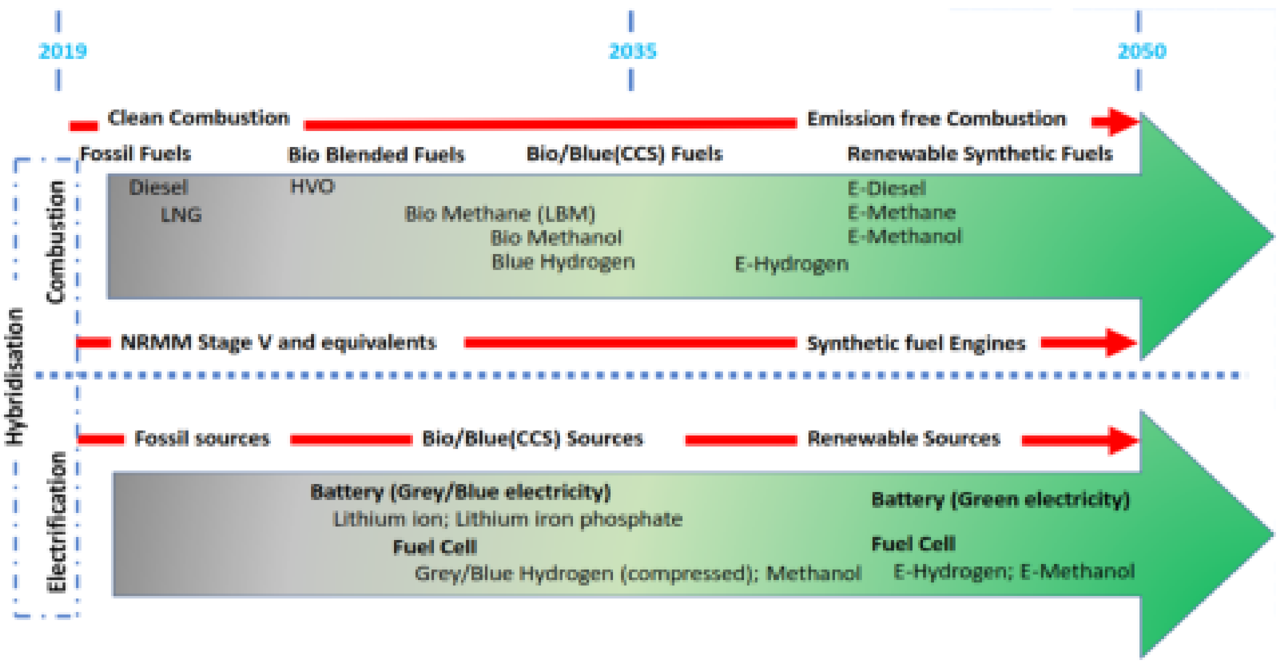


Figure 5 Strategy and micro-level planning identifying the fuels to be used in a different period to achieve carbon neutrality in Inland shipping by 2050 in the Netherlands. ***Source: Presentation of EICB (Expertise and Innovation centre Barging), Netherlands***

The greening efforts and initiatives in a few pockets of the country are primarily with the financial support of the government on a pilot project basis and a few with external funding from the World Bank, only for passenger services

with the hybridisation of fossil fuel and electricity and proceed individually with clean energy to bio-blended fuel-bio/blue (CCS) fuels and, toward the end, the use of synthetic fuels (E-Diesel, E-Methane & E-Methanol) to achieve carbon neutrality by 2050**.** The electric propulsion commenced with batteries (grey/blue electricity) and fuel cells of grey and blue Hydrogen originating from fossil sources. In the final stage, renewable sources with batteries for green electricity and fuel cells from E-Hydrogen and E-methanol will achieve the zero-level emissions targeted by 2050.

Further, to achieve the carbon neutrality target, the integrated energy strategy for developing a clean corridor on the waterways conceptualised by the Netherlands (**Figure 6**) by ensuring better logistic supply and facilities for sustainable electric propulsion affordable manner could be adopted in India from the below.

- Exchangeable energy containers with charged batteries
- Open access charging infrastructure
- Pay-for-use payment system
- Bunkering facilities for hydrogen fuel and fuel cells on the waterways

Issues, challenges and recommendations

The success of greening in India may confront the following critical issues and challenges. Some of these for finding the appropriate solutions and mitigation measures are:-.

Market readiness and business case

The IWT mode has not yet been economical because of the obvious reasons and factors such as the non-availability of a potential market segment exclusively for IWT, the fleets of economical and optimum designs, the reliable and economic inland waterways and navigation systems with all the associated infrastructures, and the policy and promotional measures for incentivising and promoting IWT. Therefore, the IWT operation is mainly confined to the few private operators of small firms, consortiums, and individuals without the support of the potential shippers, as in the case of rail and road modes. Of course, there may be some exceptions in a few pockets, such as Mumbai creeks, Gujrat and Goa. The preliminary market survey in

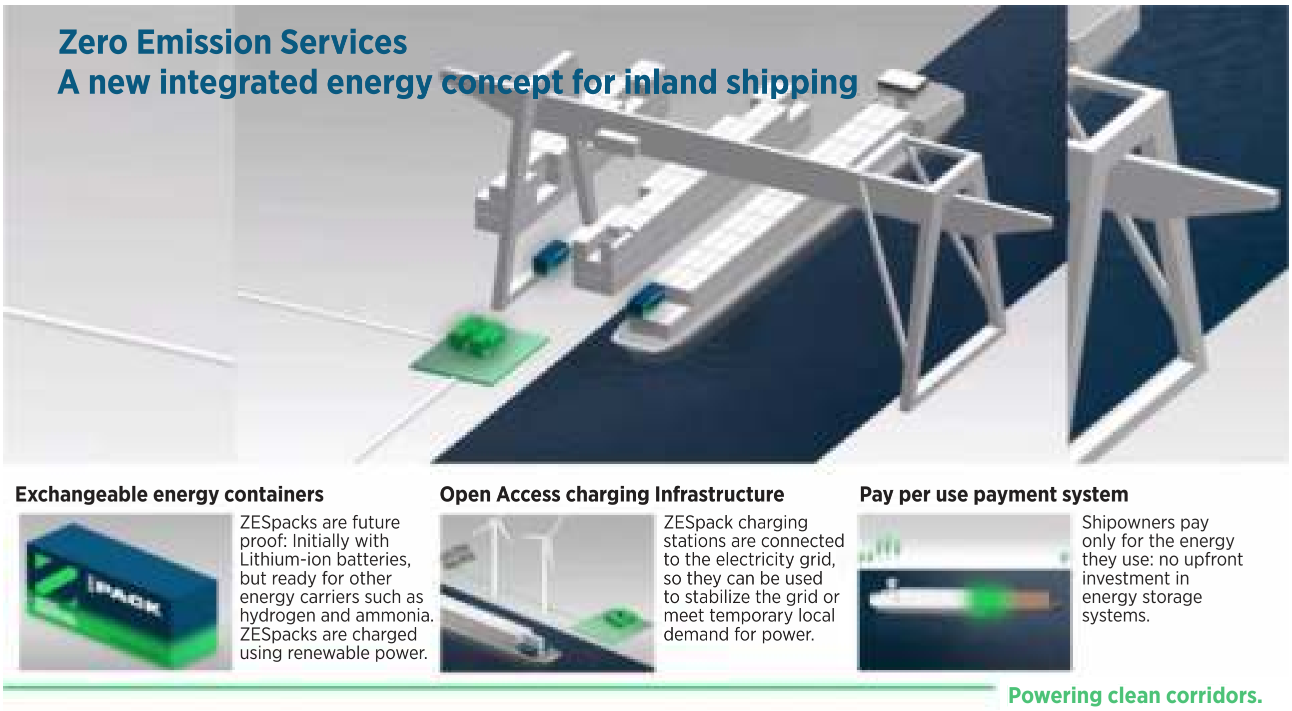


Figure 6 Integrated energy concept for exchangeable battery containers, battery charging stations, etc.
Source: M/s Zero Emission Services, Netherlands.

some parts of the country reveals that the IWT market has yet to be ready for this green transition to have viable business cases, mainly because of the initial high capital investment. The greening efforts and initiatives in a few pockets of the country are primarily with the financial support of the government on a pilot project basis and a few with external funding from the World Bank, only for passenger services. No projects for the cargo vessels are yet to be planned and executed in the private sector. Therefore, governmental support may be essential for building confidential measures toward market readiness.

Awareness

Considering the ignorance of the long-term benefits of greening the fleets, the non-visibility of any government policies and schemes towards subsidies or incentives, the absence of publicity and awareness programs, and most importantly, the lack of awareness of environmental protection and sensitivity among the operators, (particularly in the unorganised sector for country crafts and traditional boats managed by the marginalised and vulnerable sections of society), it is imperative to take appropriate steps on an urgent basis by the central and state IWT authorities.

Logistic & bunkering facilities

The country has made a rapid stride in the production of various alternative fuels and energy such as solar, wind, and biofuels and has recently made an effort to be the potential producer of green Hydrogen by improving the logistics and bunkering facilities for the primary modes of transport, i.e., road and rail, besides various other industrial sectors. The same facilities for the IWT sector do not exist; hence, it is essential, even in inaccessible operational areas.

Policy and Regulatory framework

The Energy Conservancy (Amendment) Bill-2022, passed by the lower house (Lok Sabha) of the parliament on August 22, is a landmark regulatory framework for the greening of road and water transport with the mandatory provision on the use of alternate fuel (other than) fossil fuel for the vessels and boats. The various policies, i.e., Bio-Fuel Policy-2018 and its amendment in 2022, the Green Hydrogen Mission -2020 followed by the Green Hydrogen policy-2022 in February 2022, and the proposed battery swapping bill for EV, etc., are a few concerted efforts of the government to realise the goal of decarbonisation. Because of the development of the above policies, the framing of the necessary rules and regulations and further amendments with the inclusion of suitable provisions in the Inland Vessels Act 2021 and the draft Inland Vessels Rule-2022, notified on March 22, has been imperative. The emphasis on the use of alternate fuels, fuel efficiency, the emission standards for GHG and pollutant gas harmful to human health, and the adoption of the Energy Efficiency Design Index (EEDI), Energy efficiency for the existing vessels (EEEXI) similar to the IMO (International Maritime Organisation) guidelines for ocean-going fleets, will be necessary. The phasing out of ageing, obsolete, and inefficient fleets is also a priority issue.

Development of machinery and conversion kits indigenously

The manufacturing and supply of the new engines and upgradation of the existing engines for propulsion and auxiliary purposes for different green fuels in compliance with the emission standards of national and international regulations, including those for pollutant exhausts, has assumed importance with appropriate R & D, indigenously cutting down the cost and ensuring better servicing and maintenance. The market for engines for the inland fleet in the country is limited. Therefore, manufacturing and supplying the machines at the desired standard level or upgradation of the existing ones in stages similar to the EU for maintaining the economy in the sector will be critical. Developing suitable conversion kits for the conventional engines of traditional boats and small inland vessels, with a power of less than 300 HP, marine quality batteries, etc., may be another vital area. For instance, with imported marine engines, maintenance-free marine batteries, etc., greening a few ships might not guarantee sustainable growth of the industry unless they are locally adapted to suit the environment and economic status, making them accessible and affordable.

Financial viability and incentives

The preliminary survey conducted to launch the greening project of USAID reveals that operators are reluctant to invest in the upgradation of the existing fleet and adding the new fleet with the latest green technology. The interaction with the operators reveals that suitable fiscal measures and incentives, besides the policy and regulations on the greening of the IWT sector, are the only solutions at this juncture. Therefore, the revival of the Inland Vessels Building Subsidy scheme discontinued in 2010 may be necessary with additional features of extending the provision for the existing fleets for upgradation with suitable greening tools, besides for the new construction with energy efficient design and latest green technology. Support during the operation is also advocated for the initial few years as the freight subsidy and passenger counts or subsidy in the alternate fuel. The greening of the traditional (country) boat sector for new construction and the upgradation of the propulsion system of the existing ones should also be given priority.

Institutional strengthening and skill development

The capacity development and strengthening of the institutions responsible for the IWT sector, i.e., IWAI, the State Maritime Boards, IWT Directorates, and other departments responsible for IWT, will be essential for the proper implementation of regulatory and policy frameworks, fiscal measures & incentives, and better logistic and bunkering facilities for green fuel, etc. Developing the skills of the crew and operators with a suitable training program is an essential factor for the success of the greening effort.

R & D, and creation of a database on emission inventory etc

Similar to the road and rail mode transport, IWT mode is way behind on the R & D with the required documentation and inventory with the database for the various aspects, including the greening of the sector. Data & documentation on the performance efficiency of the existing fleet & futuristic fleet after the development of the optimum & economical design, the energy efficiency parameters, the GHG factors for vessel types, fuel efficiency, and fuel share, fuel types used etc., are essential. With accurate data, inventory and information, it may be easier to formulate suitable policies, regulatory framework, measures for incentivisation etc., effectively and accordingly monitor with a well-developed strategy and road map. Therefore, it is paramount that this needs to be taken up thoughtfully for a database portal similar to E-Amrit launched in November 2021 for EVs without much loss of time for achieving the target of zero-level emission.

Marinisation of the road & non-road engines and allowing for installation on traditional (country) boats & other small inland vessels

The European Union has made the mandatory installation of engines for propulsion and auxiliary purposes on the inland and coastal fleets of different engine capacities, as in **Table II,** with minimum emission standards under regulations for Non-Road Mobile Machinery (NRMM), developed recently under stage-V from 2019-20 (European Union Emission standard---2019-20). This standard focuses mainly on the drastic reduction of air pollutants from inland & coastal shipping. It applies to vessels of different power capacities, starting from 19 KW to 300 kW and above.

In India, the emission norms for marine diesel engines of 130 KW (175 BHP) and above for the inland fleets are as

Table III. Emission limits of the pollutant exhausts for road and non-road engines of BS-VI compliant

Exhaust gases	Petrol Engines	Diesel Engines
CO (Mg/Km)	1000	500
HC (Mg/Km)	100	170
NOx (Mg/Km)	60	80
PM	4.5	4.5

Source: Transport policy network & ARIA (Automotive Research Associations of India) manual on emission standard.

per the provisions of the draft Inland Vessels (Prevention and Containment of Pollution) Rules, 2022, notified on February 25, 2022, under the provisions of the Inland Vessels Act, 2021. The draft rule specifies only SO2 for the fossil fuels and NO2 for the propulsion engines installed. While the maximum limit of SO2 will be 0.5% m/m, the limits for the emission of nitrogen oxides (calculated as the total weighted emission of NO2) will be as below, where n = rated engine speed (crankshaft revolutions per minute):

1. 14.4 g/kWh when n is less than 130 rpm;
2. 44 n (-0.23) g/kWh when n is 130 or more but less than 2,000 rpm;
3. 7.7 g/kWh when n is 2,000 rpm or more.

OR Equivalent Bharat Stage standards".

The draft I. V. Rule on the Prevention and Containment of Pollution is silent on the standard emission limit for pollutant exhausts. There are also no norms for GHG either for inland vessels with propulsion engines less than 130 KW (175 HP). The rule, however, has the riders that the state authorities may reduce the emission limit depending on the ecologically sensitive areas of operation.

Inland shipping being one of the surface transport modes, there is ample justification, similar to that in advanced countries, for prescribing the emission standards for pollutant exhaust emanating from the machinery installed for propulsion and auxiliary purposes. Therefore, it is essential to amend the draft Inland Vessels Rules, 2022, to deal with the pollutants being detrimental to human health with the appropriate

Table II. European Union Emission limits for pollutant exhausts of the engines installed on the inland vessels for propulsion and auxiliary purposes under regulations for NRMM stage-V

Category	Net Power	Date	CO	HC[a]	NOx	PM	PN
	kW		g/kW/h				1/kW/h
IWP/IWA-v/c-1	19 ≤ P < 75	2019	5.00	4.70[b]		0.30	-
IWP/IWA-v/c-2	75 ≤ P < 130	2019	5.00	5.40[b]		0.14	-
IWP/IWA-v/c-3	130 ≤ P < 300	2019	3.50	1.00	2.10	0.10	-
IWP/IWA-v/c-4	P ≥ 300	2020	3.50	0.19	1.80	0.015	1x10[12]

[a] A = 6.00 for gas enginers
[b] HC + NOx

Source: European Union Emission standards for the engines used for NRMM specific to Inland Shipping for propulsion and auxiliary

Table iV. Emission standards for the pollutant exhausts of heavy-duty vehicles engines of BS-VI complaints

Test types	CO	HC	CH4	NOX	PM	PN
	gm/kWh					kwh
WHSC (CI)	1.5	0.13		1.40	0.01	8.10x10^{11}
WHSC (CI)	1.5	0.16		1.46	0.01	6.0x10^{11}
WHSC (PI)	4.0	0.16	0.50	1.46	0.10	6.0x10^{11}

Source: Transport Policy Network & ARIA (Automotive Research Associations of India) manual on the emission standard

measures for their manufacturing and supply and through the upgradation of the existing engines. It may be a reasonable step to allow the road and non-road engines of BS-VI compliant (**Table III**) with or without marinisation for installation on traditional boats and small crafts with an engine power of less than 300 kW for mechanising and greening on an immediate time frame and an economical manner. Alternatively, as in **Table IV,** the viability of installing heavy-duty engines that comply with BS-VI standard limits for all the pollutant exhausts, including GHG, may be assessed to meet the requirements for propulsion and auxiliary purposes depending on the area of operation, up to a specific power limit after marinisation or without.

Conclusion

India has evolved several strategies and action plans to achieve the carbon neutrality target in the transportation sector by 2070 with the complete elimination of the emission on the well-to-tank and, finally, tank to wheel concept. There are also the required policies and regulatory framework with vigorous and concerted efforts, except for IWT mode, to use alternate and clean fuels to improve energy efficiency and reduce emissions. Though IWT has a negligible modal share in total transportation, it has ample potential to increase its share because of the latest National Logistic Policy with the thrust for increased multi-modal transport and connectivity. It has also been reflected in the strategies worked out for achieving carbon neutrality for road and rail modes for the modal shift of cargo. Hence, there is a high potential that the shipments meant for the modal shift will get diverted to IWT for emissions reduction, which already enjoys recognition as the cheapest, energy-efficient, and environment-friendly mode of transport.

Further, the governments have renewed interest in the revival of the IWT sector to cater to the demand for increased traffic because of the expected modal shift. Hence, it is imperative that this mode also needs attention and a strategic plan and road map for achieving carbon neutrality. Accordingly, as mentioned, all the issues, challenges, suggestions, and way forward deserve well for the attention of the concerned authorities.

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About the Author

Subhakar Dandapat, with a graduation degree in Naval Architecture and post graduate in Ship Production Technology, commenced his career at Hindustan Shipyard Ltd., a Government of India enterprise, Visakhapatnam, and was the Inland Water Transport Directorate & Development Advisor (Shipbuilding & Ship repair) in the Ministry of Shipping, and finally joined Inland Waterways Authority of India (IWAI). After serving IWAI in various capacities and responsibilities, Mr Dandapat superannuated in 2016 as Chief Engineer (Project & Marine). As the post-retirement assignment, Mr Dandapat has been associated with M/s. Adani Port & SEZ Pvt Ltd., and its consultancy firm M/s. Howe Engineering Project (India) Pvt Ltd. Currently, he is engaged as a 'Local Technical Expert for India' to the USAID (United States Agency for International Development) sponsored project on 'Upgrading and Greening of Inland vessels Fleet' of Bangladesh and India, besides giving consultancy services through M/s. Cuts International for the World Bank assignment on assessing the inland vessels requirement for cross-border trade in BBIN (Bangladesh, Bhutan, India and Nepal) corridors.

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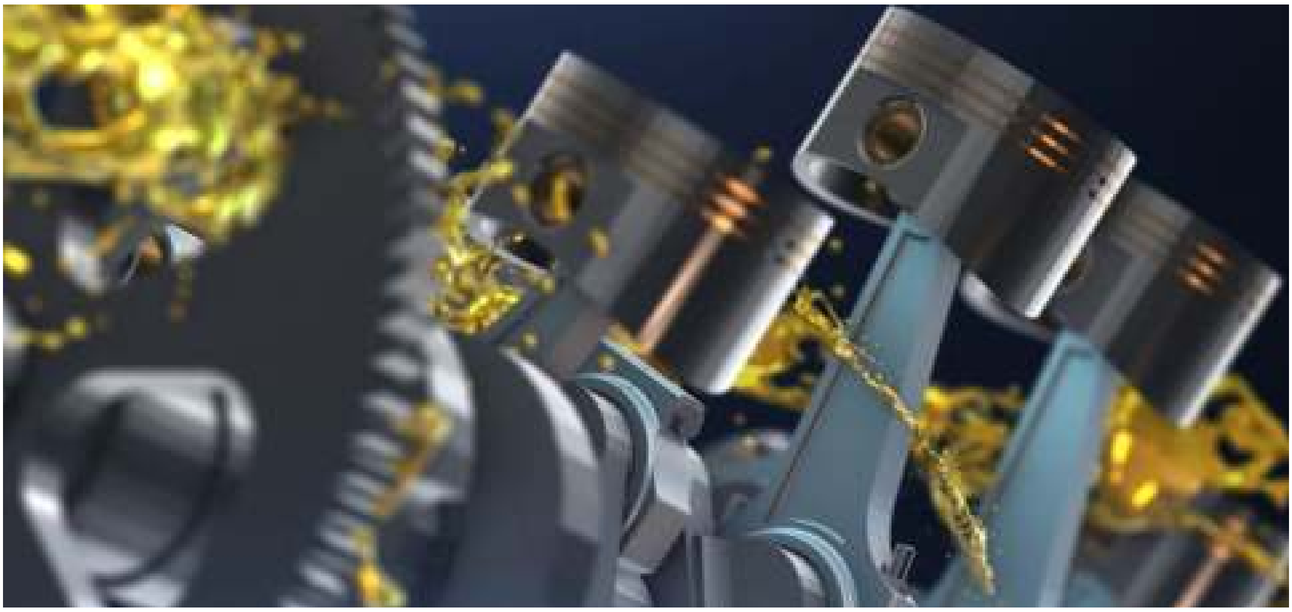
LUBE MATTERS # 20

WEAR (PART I)



Sanjiv Wazir

Introduction

Wear can be broadly described as the physical loss of material from a surface, displacement of material within a surface, or transfer of material from one surface to another. Wear is not a material property; it is a response of the surface to the local tribosystem. It occurs when a base body and a counter-body come into contact i.e. when the lubricant film becomes too thin, or lubricant is absent. Wear rates depend on contact conditions, such as the counter-body materials, surface films, substrate structure, contact pressure, sliding velocity, contact shape, stiffness, environment, and the lubricant. 'Rolling wear', 'sliding wear', 'fretting wear' and 'impact wear' are terms used to describe the type of motion which results in wear (1).

Wear Mechanisms and Modes

Mechanical wear', 'chemical wear' and 'thermal wear' are broad terms used to describe wear mechanisms.

Mechanical Wear

Mechanical wear is wear governed mainly by the processes of deformation and fracturing. Deformation has a substantial role in the wear of ductile materials and Fracturing has a major role in the wear of brittle materials. Common modes of mechanical wear are described below

Abrasive Wear

Abrasive wear refers to the removal or displacement of material caused by hard particles or rough surfaces on one body causing micro-cutting or ploughing on the counter-body. Abrasive wear is a major cause of loss of component/equipment life.

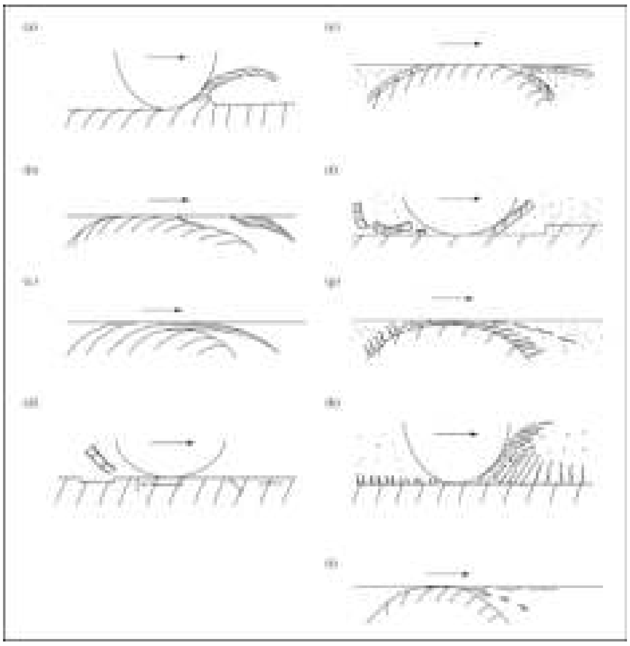


Figure 1: Schematic of main wear modes (1)
(a) Abrasive wear by micro-cutting of a ductile surface; (b) Adhesive wear by adhesion, shear & transfer; (c) Flow wear by accumulated plastic shear flow; (d) Fatigue wear by crack initiation & propagation; (e) Corrosive wear by accumulated plastic shear of soft tribofilm; (f) Corrosive wear by delamination of a brittle tribofilm; (h) corrosive wear by shaving of soft tribofilm; and (i) melt wear by local melting and transfer or scuffing

Besides the micro-cutting mechanism by the sharpest grits or hard asperities **Figure 2 (a)**, many other indirect mechanisms are involved in abrasion. The particles or grits may remove material by fracture **Figure 2 (b)**, grain

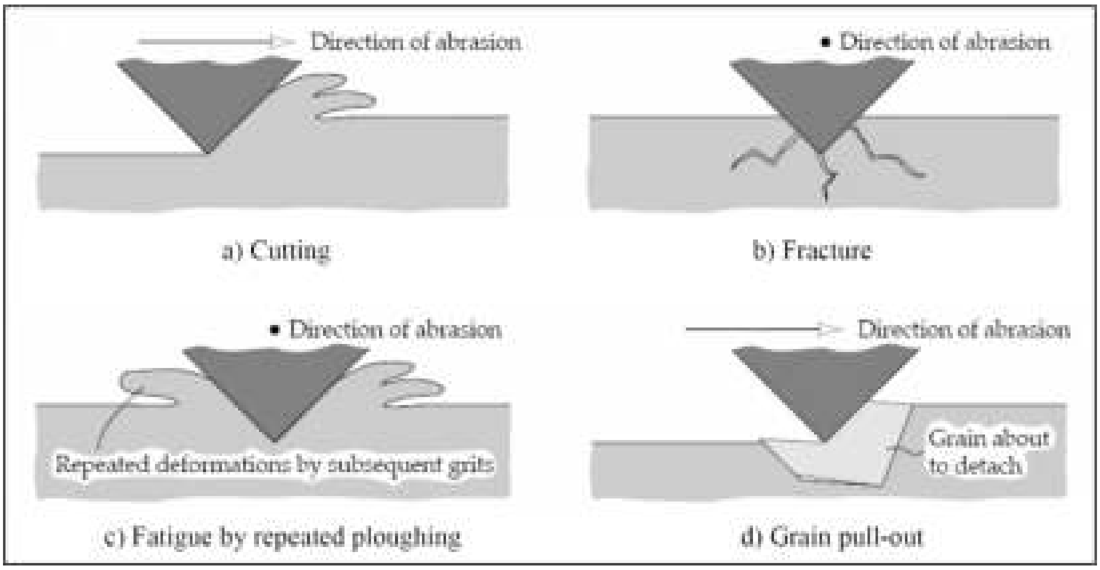


Figure 2 Mechanisms of Abrasive wear: (a) Cutting; (b) Fracture; (c) Fatigue; (d) Grain pull-out (2)

pull-out, **Figure 2 (c)**, or fatigue caused by repeated deformations, **Figure 2 (d)**.

The manner of interaction between the two bodies determines the nature of abrasive wear. In two-body abrasive wear e.g., action of sandpaper on a surface, hard asperities or rigidly held grits pass over the counter-body like a cutting tool. In three-body abrasive wear the grits are not rigidly held and are free to roll or slide over the surfaces as illustrated in **Figure 3**.

Two-body abrasive wear corresponds closely to the "cutting tool" model of material removal and wear can be very rapid. Three-body abrasive wear can be much slower. Material is removed more gradually by successive contact with grits. The relative sizes of grit particles & lubricant film thickness is also an important parameter in rate of wear by this mechanism.

Typical components subject to abrasive wear include hydraulic machinery, journal bearings, pistons/rings/liners.

Adhesive Wear

Adhesive wear occurs when surface asperities come into contact (usually sliding) under load. If sufficient heat is generated, bonding or micro-welding of the two contacting asperities can occur. The bonded section may be work hardened and shear may occur not at the asperity junction, but within the body of the material, thus allowing transfer of material from one surface to another or break away of material as a separate particle. The freshly exposed surfaces are more reactive than the original surfaces and must be passivated by additives to avoid accelerated wear.

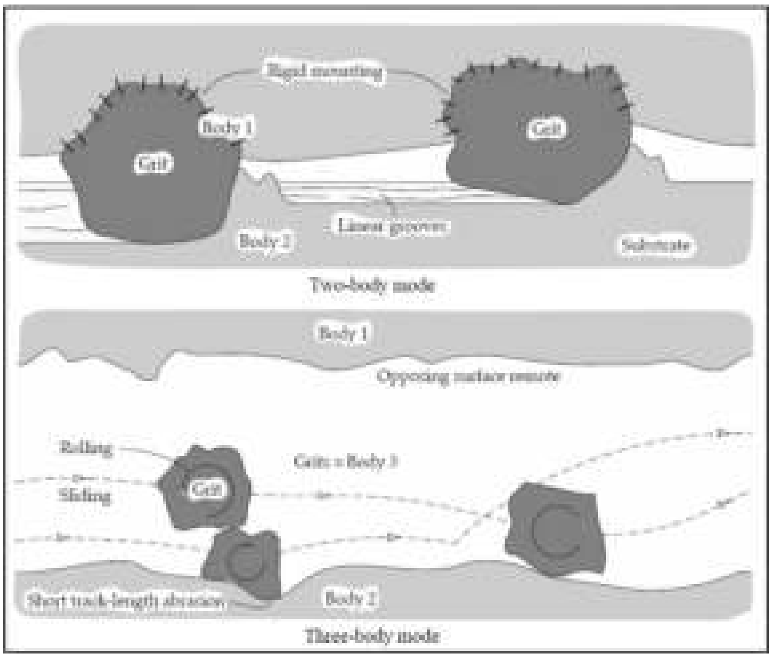


Figure 3 Two-body and Three-body abrasive wear (3)

The severity of adhesive wear is proportional to the load applied and the distance covered during contact.

Polishing is a form of mild adhesive wear when surface asperities undergo adhesive wear until a very fine "polished" surface results. Weld tears are not visible to the naked eye at this stage.

Wear is not a material property; it is a response of the surface to the local tribosystem.

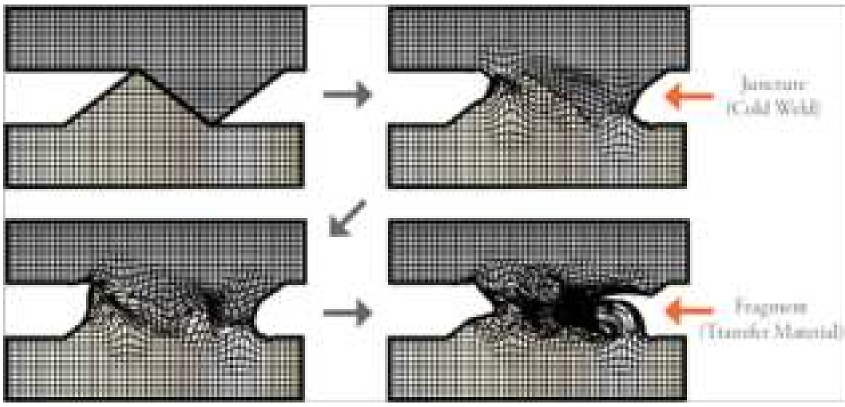


Figure 4 Adhesive Wear Mechanism (3)

Fatigue is weakening of a material caused by cyclic loading that results in progressive, brittle and localized structural damage.

Running-in is an expression used to describe the initial, higher wear rate in lubricated contacts. This is caused by the successive wear of surface asperities (left by machining processes) and results in better conformity of the smooth worn surfaces.

Moderate adhesive wear causes bluing of the surface due to thermal nature of the wear. Weld tears become noticeable and often lead to metal "pull off" resulting in a "Scuffed" surface.

Severe adhesive wear results in metal "pull-off" becoming excessive and it accumulates as it moves along the surface, which takes the appearance of being "Smeared". This leads to more pronounced cracking, scuffing, torn surfaces, and macro-pitting.

Adhesive wear affects components such as cylinders, pistons, gears, rolling element bearings.

Many wear processes start off as adhesive wear but since it often leads to formation of abrasive particles there is possibility of transition from adhesive to abrasive wear.

Conditions that can initiate or aggravate adhesive wear are

- extreme loading,
- elevated temperatures,
- acceleration or deceleration in the load zone,
- and excessive moisture present in the load zone (3).

Adhesive wear can be minimised by

- Using material pairs that do not bond easily
- Improving formation of low shear strength additive films on the surfaces
- Increasing oil film thickness

Fatigue Wear

Fatigue is weakening of a material caused by cyclic loading that results in progressive, brittle and localized structural damage. Fatigue wear, is the cracking and subsequent pitting of surfaces subjected to alternating stresses during rolling contact or the stresses from combined rolling and sliding (**Figure 5**).

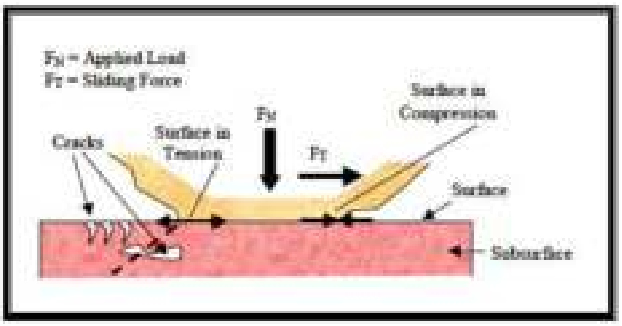


Figure 5 Fatigue

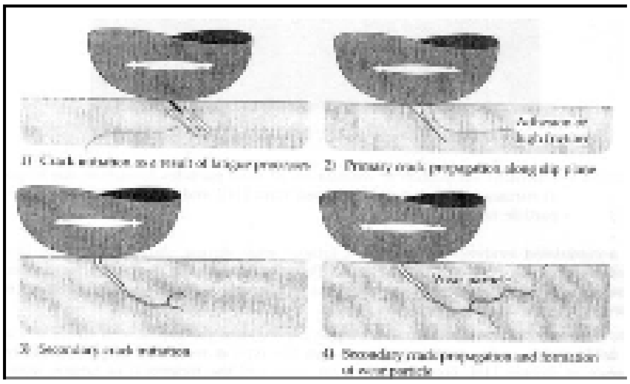


Figure 6 Crack Initiation in sliding contact (5)

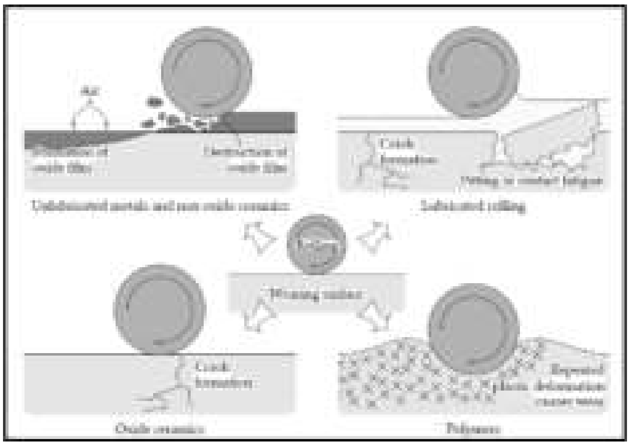


Figure 7 Crack Initiation in rolling contact (5)

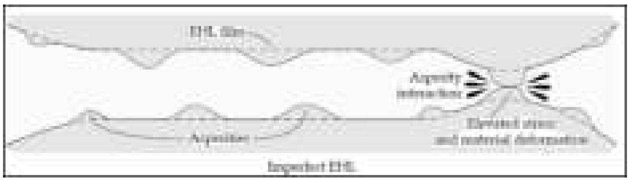


Figure 8 Contact fatigue due to surface roughness (5)

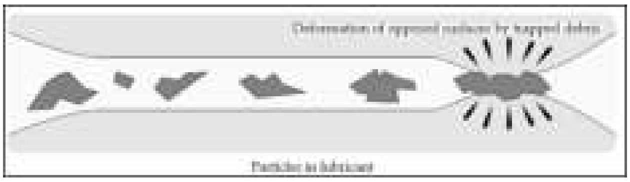


Figure 9 Contact fatigue due to entrained particles (5)

Repeated loading and unloading may induce the cause development of surface or subsurface cracks. After a critical number of cycles, the surface may break up with the formation of large fragments, leaving large pits in the surface.

Once a crack is initiated, each loading cycle will grow the crack a small amount, even if the alternating or cyclic stresses are of an intensity considerably below the normal strength of the material.

Typical components affected by fatigue are rolling element bearings, gears, journal bearings.

Other mechanical wear modes, chemical and thermal wear modes shall be covered in future articles in this series.

To be concluded.

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SELECTING THE BEST PUMP FOR CCS APPLICATIONS

[THIS ARTICLE IS A REPRINT WITH PERMISSION FROM DESMI.]

Pumps play an important role in Carbon Capture and Storage (CCS), and selecting the most effective pump is the key to achieving low operating costs, cut CO_2 emissions, and limit the global temperature increase.

For nearly three decades, the UN has brought together almost every country on earth for global climate summits. The final text of the latest summit, the COP27 in Sharm El-Sheikh, Egypt, includes a provision to boost low-emissions energy. In practice, this means that many different technologies must be used to help cut emissions – including Carbon Capture and Storage (CCS) systems[1].

What is the potential of CCS?

The International Energy Association (IEA) has provided an excellent overview of the potential of capturing, storing, and utilizing carbon dioxide[2]. It estimates that 45 Mt/year is currently being captured and that this must increase to about 1300 Mt/year in 2030 to meet a net zero emission scenario (NZE). Around 35 facilities are already in operation, and over 200 new facilities are planned to be in operation by 2030. However, this corresponds "only" to 220 Mt/year of CO_2 being captured, so facilities for at least an additional 1000 Mt/year will be required soon to meet the NZE target.

Today, most facilities are installed to capture CO_2 emitted from natural gas and hydrogen processing plants. Somewhat ironically, the captured CO_2 is mainly used for enhanced oil recovery (EOR). However, as oil production must decrease in the future, most of the new planned facilities are aimed for power plants and the cement and steel industries, as these sectors are impossible to electrify completely due to the nature of their raw materials. Furthermore, the captured CO_2 should not be used for EOR but stored permanently underground.

How does the CO_2 scrubbing process work?

Capturing the CO_2 in a scrubber or absorption tower is the most common and well-known method for Carbon Capture. As shown in **Figure 1**, a liquid mixture of water and an organic amine is circulated between an absorber and desorber unit.

The inlet flue gas is brought in direct contact with the liquid in the absorption or scrubber tower. The scrubber is usually a packed-bed type and typically 20-40 meters in total height (only the height of the bed is indicated on the figure). A relatively high tower is required if the

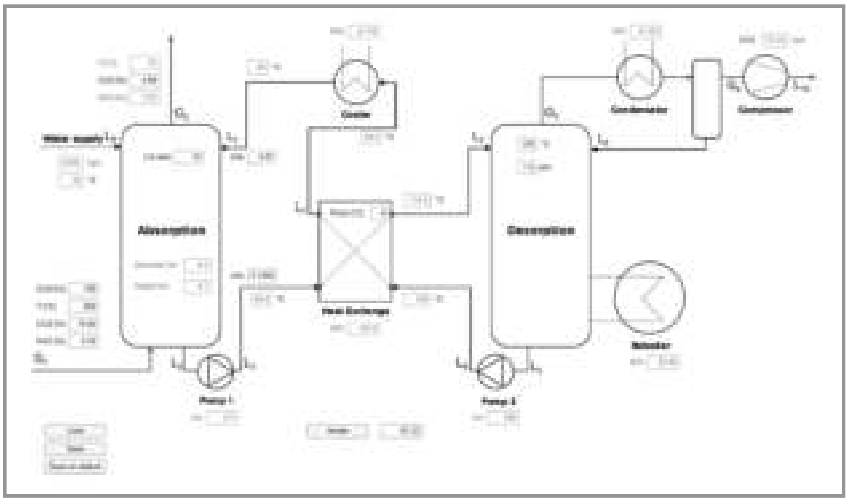

Figure 1: Amine scrubbing process for Carbon Capture. Simulation results for cleaning a flue gas with a 10% (mol/mol) MEA solution.

concentration of CO_2 is low in the flue gas or if high removal efficiencies are required.

The lean amine is fed into the top of the scrubber and is enriched with the CO_2 by flowing downwards in counter-current with the flue gas. A first pump is used to force the solution through a plate heat exchanger and to the desorption or stripping tower. The CO_2 is released in pure form by heating the liquid in the reboiler section. A second pump is used to force the liquid through the hot side of the plate heat exchanger and back to the absorption tower again. An additional cooler is often required to reduce the evaporation of water in the absorption tower.

Calculating pump operating expenses

The simulation results shown on **Figure 1** are based on many preliminary assumptions which must be further validated and adjusted as more experience with the process is gained. However, it is interesting to try to relate the calculated pump power to the amount of CO_2 captured, as we can thus arrive at an initial estimate of the operating expenses.

As can be seen, 1061 kW of electrical power (496 kW + 565 kW) is used by the two pumps for catching

20 kg/s of pure CO_2. This is equivalent to 52 kJ/kg of CO_2 or 14 kWh/ton of CO_2. If we assume an electricity cost of €0.15/kWh, the operating expense for the two pumps will be €2.1/ton of CO_2.

As CCS plants become more widespread and operate with increased capacity, selecting the most appropriate pump(s) for a certain scrubber installation is not a trivial task; particularly considering that 2 or 3 pumps are often installed in parallel to provide some redundancy in the scrubber system. At a CCS plant capable of processing 5 Mt/year, for example, annual operating expenses with the pumps used in the example above would be €2.1 million. At this scale, even small power consumption reductions make a significant difference to the operating economy. Selecting pumps that are sized correctly and operate at or near their best efficiency point (BEP) is an effective way of achieving these cost reductions.

Tips for sizing and selecting pumps

We often see that too much safety margin is added in the design phase so that for most of the time, the pump will run too far from its BEP (the blue line on the Q-H plot in **Figure 2**). In the worst cases, the pump may even run outside our recommended operating area, which is between 70 and 120% of its BEP (the area between the green dotted lines on the Q-H plot).

It is usually better to add a safety margin in the frequency converter so the pump can run at higher RPM in extreme cases where max flow and head might be required. This will save both CAPEX and OPEX as smaller pumps can be installed, and as it will be easier to operate them at their best efficiency point. The pumps will also run with fewer vibrations and generate less heat, meaning that there will be less excess energy that could cause damage.

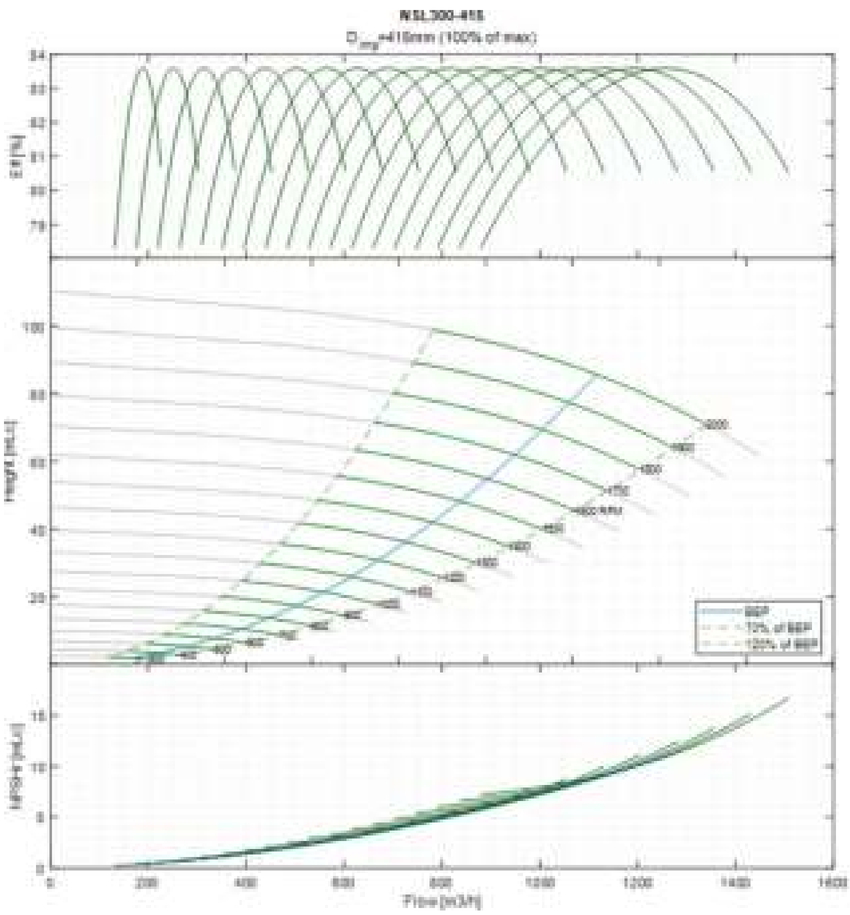

Figure 2: Performance of the DESMI NSL300-415 (example).

A low NPSHr value is often required. For the rich amine (pump 1 in **Figure 1**), the solution is almost saturated with CO_2 and therefore has a relatively high vapour pressure. For the lean amine (pump 2 in figure 1), the solution will only contain little CO_2, but the temperature will be higher and therefore will also cause a relatively high vapour pressure.

Full range of pumps and selection tools

DESMI has developed more than 60 centrifugal pumps of different sizes in the ESL, NSL and DSL series for the scrubbing industry. They are generally designed for low NPSHr values.

Most of the ESL, NSL, and DSL pumps are available in high-grade stainless steel or super duplex steel (SAF2507), which we will usually recommend for a MEA solution based on the latest scientific findings[3,4]. In addition, we recommend equipping our pumps with a Dual Cartex seal due to the toxicity of the MEA[5]. The sealing system can also be connected to an external barrier fluid to ensure that the gaskets will not exceed their max limit temperatures.

For projects that use a less toxic solution of water and potassium carbonate instead of an amine (for example the Swedish BECCS @ STHLM project), cheaper pump materials and our standard balanced sealing system can be used; the potassium will act as a buffer to ensure an almost neutral pH-value[6].

All pump curves are available in our selection programme winPSP which you can download from our website[7]. We can also supply an object function or app that allows you to integrate pump selection in your design programme or other commercial simulation software.

Overview of CCS projects

CCS projects are currently in operation and being developed in more than 30 countries all over the globe. Here is a brief overview:

- In North America, the United States has about 80 projects, and Canada has about 15 projects in various phases of development[2].
- The first project in China was completed in June 2022 and is now due for commissioning[2].
- In the Middle East, four facilities are in operation, and at least four more are in the planning phase[2].
- The EU recently awarded funding to four different projects: Kairos@C[8], BECCS @ STHLM[9], K6[10], and SHARC[11].
- Three major oil companies (Shell, Equinor, and Total Energies) have entered a partnership called Northern Light which aims to store 1.5 Mt/year by mid-2024 and expand to 5.0 Mt/year if required[12,13].
- The port of Dunkirk in France is considered to become a future European CO_2 hub with a capacity of 8.1 Mt/year over the first decade, and the LINCCS consortium in Norway is aiming to reduce costs by 70% by optimizing the entire CCS value chain and contributing to the development of new solutions[14].
- Several equipment suppliers to the maritime industry are investigating the possibilities for Carbon Capture on ships[15,16,17,18]. For example, Wärtsila and tank ship operator Solvang are currently installing a pilot project to capture 80% of the CO_2 in the exhaust gases and store it onboard as liquid in tanks at - 35°C18. Shipping accounts for 2.2% of the world's carbon emissions, or ~800 Mt/year. To put it all into perspective, the global energy-related emission of CO_2 was 36300 MT/year in 2021[19].

Conclusion

If CCS is to make a significant contribution to reaching the world's climate targets, the technology needs to be developed further. Researchers worldwide are intensively searching for more efficient liquids that require less energy for regeneration. However, this will usually be at the cost of reduced reactivity so that larger scrubbers must be used, or more liquid must be circulated to catch the same amount of CO_2. There is little doubt that such challenges will be overcome, and future CCS solutions will become more effective, capturing ever larger amounts of CO_2 while using as little energy as possible.

Pumps are not the only important component of a CCS plant, and other components such as compressors and reboilers consume far more electricity. However, given the number and scale of future CCS plants, and given the fact that succeeding at the green transformation will require us to lower energy consumption in all industrial sectors, and all aspects of human life generally, selecting energy-efficient pumps for CCS applications not only makes good financial sense; it is also an effective way of contributing to reaching current and future climate targets.

Click here to see our range of centrifugal pumps for CCS and other applications. https://www.desmi.com/products-solutions-library/?segment=marine-offshore

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HERITAGE HOURGLASS: INVENTIONS OF THE QUEST OF THE OCEANS

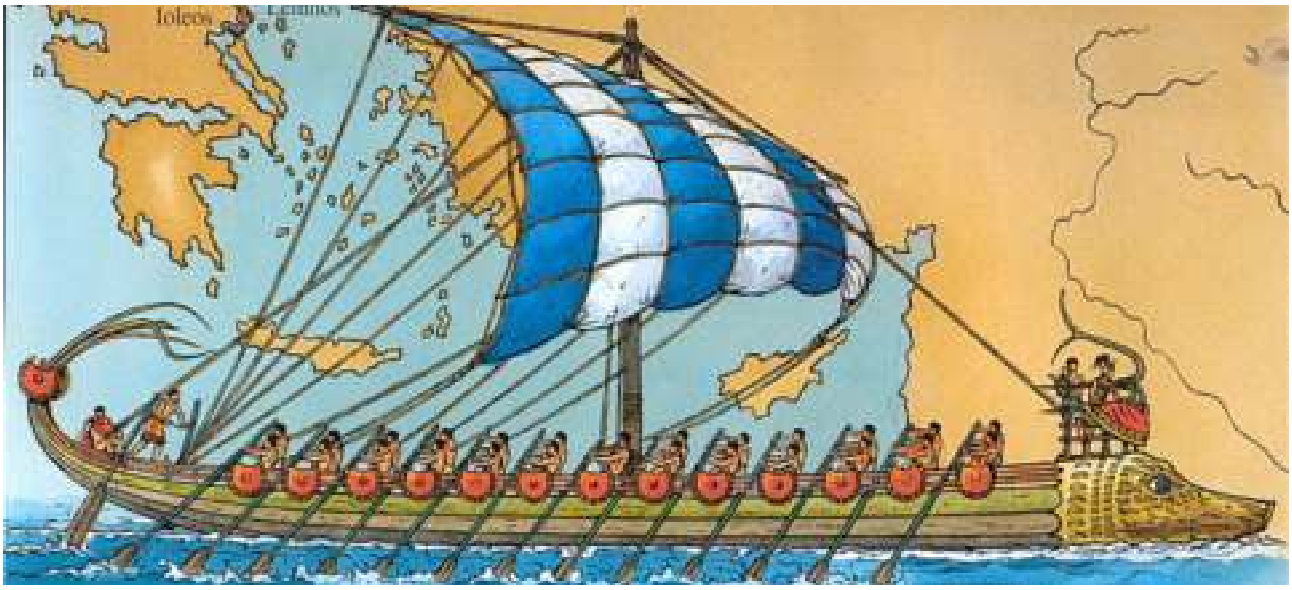

Figure 1. 100 Oar ship in Rig-Veda.

Uma Kabe

Navigation and voyages through the 'Global Commons' have stimulated greater interaction amongst people. This has thereby resulted in cultural exchanges amongst various civilisations. Connecting the dots and bringing the world closer, Indians have been navigating through the oceans and seas since about 6000 years ago. Blessed with conforming physical and strategic geography, India has been always at the forefront of maritime trade and commerce. Literary references (Rigveda, columns from Indus Valley Civilisation, Yukti Kalpa Taru) illustrate the ancient prosperous Indian sea-borne trade, and explain India's prowess in shipping and shipbuilding.

The word 'Navigation' derives its roots from the ancient Sanskrit word – *Navgaith*. Standing true to the test of time, ancient Indian texts like Vedas and Puranas mention the knowledge that ancient Indians had pertaining to the sea routes, types and qualities of boats, expeditions, and so on. This indicates the strong presence of navigational equipments which would have helped them to carry out easy and successful transits. If mankind had to ply the seas, it would be pertinent for them to know their position. In the world of oceanic navigation, position fixing is important in order to chart the course; to reach either destination or return home, and understand various factors like speed, winds, tides etc. The requirement to know and understand these critical elements of an ocean crossing led to the discovery of various instruments and calculations. Humans have always looked up to the Sun as an important source of life. In navigation as well, the sun was effectively used to ascertain the time of the day and the course of explorations. Over the years, by examining and studying the positions of the moon, stars, and planets, humans gained better expertise in the field, and the age of discoveries forced humans to develop technologies (instruments and aids) that would aid in their quest to finding routes. This article aims to study the evolution of navigational aids and equipment in the ancient era.

1. Celestial Navigation

Even before the invention of the mariner's compass, navigational experts sailed by plotting the course of the sun, moon, and the major constellations, tracking their positions and movements. The renowned Indian astronomers Aryabhatta and Varahamihira, have precisely mapped the positions of celestial bodies by developing a method of computing ships position from stars.[1] This was achieved even by the Phoenician sailors who made use of natural navigation to get a navigational edge.[2] The calculation of distance covered from one point to another was by multiplying the time underway by the speed of the vessel.[3] Most of these calculations were not accurate as the time then was measured using a sandglass and the speed was estimated by watching the pieces of seaweed pass by the hull of the ship.[4] Another definite method was by letting go of a rope with knots at specified and measured intervals with respect to time behind a ship to calculate speed. This was commonly known as a log line.[5] More importantly, once the sailors lost sight of the land, it was very difficult for them to determine the accurate longitude and latitude. Approximation was made through the entire time taken for the entire voyage by a simple form of Dead Reckoning. Keeping factors like wind speed and ocean currents constant, dead reckoning assesses the current location of a ship based on its previous

location and catering for its known speed and course followed. Celestial navigation laid the foundation for the development of more sophisticated aids like the sextant which helped the seafarers navigate better.

2. The Magnetic Compass

Magnetite commonly referred to as Lodestone was ideally used to make the magnetic compass. When allowed to rotate, this variety of iron ore with its magnetic properties and own magnetic field revolves around its axis and to align with the Earth's magnetic field.

There are claims that the first to devise the magnetic compass were the Chinese, around third century BCE. The Chinese mariner's Compass comprised a square bronze bottom plate with edges inscribed with the names of the most important constellations and points of the compass. The needle/ pointer of the compass shaped either in the form of a ladle or spoon would be made of lodestone and would be allowed to turn around freely with the handle of the ladle/spoon pointing towards the magnetic South Pole.

As maritime trade contact between the European and the Chinese was maintained predominantly through the Arabs, evidence of the European Mariner's Compass being very similar in design to that of the Chinese Mariners Compass directs a huge influence of the Chinese on them. Using the mariner's compass for navigational purposes, the Chinese navigators in ancient times carried with them a lodestone to restore the magnetic field of the iron needles which were magnetised and suspended on a small piece of wood floating in a bowl of water.[6]

Celestial navigation laid the foundation for the development of more sophisticated aids like the sextant which helped the seafarers navigate better

Mr JL Reid, a member of the Institute of Naval Architects and Shipbuilders in England, mentions that the Indian navigators used the mariner's compass approximately 1500 to 2000 years ago. He even stated that "the early Hindus are said to have used the magnet, in fixing the North and East, in laying foundations, and other religious ceremonies. The Hindu Compass was an iron fish that floated in a vessel of oil and pointed to North."[7] It was even claimed to have got its name as a mariner's compass from the Sanskrit word '*Maccha Yantra*' which meant 'Fish Machine'. What is fascinating is that the Ancient Hindu mythology also talks about the *'Dus Dishaein'*.

Figure 2. Celestial Navigation in Ancient times.

Figure 3. Chinese Mariner's Compass

Figure 4. A representation of the Indian Maccha Yantra

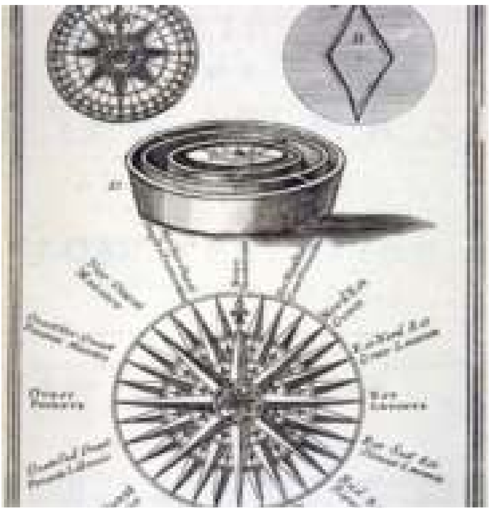

Figure 5. Dry Card Compass

Today, there has been a gradual evolution in the mariner's compass since its inception. With the new technological invention of the Dry Compass (a compass needle mounted on a pin and enclosed in a small glass cover box) and a Compass Card (marking the four cardinal points on the top of the needle), the history of the Mariner's Compass took a change of sophistication and precision.[8] As time passed, the dry compass was replaced by a liquid compass (wherein ethyl alcohol was infused to moisten the movement of the compass needle).

The Hindu Compass was an iron fish that floated in a vessel of oil and pointed to North

The Magnetic Compass in use today represents North by zero/ three hundred and sixty degrees, east by ninety degrees, south by one hundred and eighty degrees, and west by two hundred and seventy degrees.[9]

3. Lead Line

Also called Hand Lead Line in naval parlance, the apparatus lead line facilitated the assessment and gauging of the depth of water and the characteristics of the ocean floor. It comprised of a rope that either had knots that were equally spaced or pieces of coloured cloth that were sewn into it. The sounding lead which was attached to the thread was then lowered into the water and allowed to sink up to the seabed. The water depth could certainly be defined by the mark or could be conjectured by the depth as each mark on the thread was different and there was a constant space between the marks for easy identification. Due to the tallow packed into a small depression in its bottom, the sounding lead brought up a sample of the seabed that could be used to locate a secure anchorage when hauled aboard.[10] Based on the assessment of the seabed, the ships sailed from one depth to another.

4. The Astrolabe

An astrolabe is a navigational tool that is used by mariners to measure the altitude of the sun and track the position and movement of the stars and planets during their voyages. In Sanskrit, it is referred to as the '*yantraraja*' which implies 'King of Instruments. It was even used to determine the latitude of the ship at sea by assessing the angle between the horizon and the North Star, also known as Polaris. It is claimed that the Astrolabe was invented by the Greeks around 15 BCE.[11]

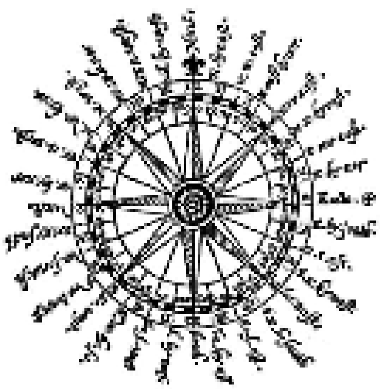

Figure 6. A 32-pointer's mariner's Compass Card

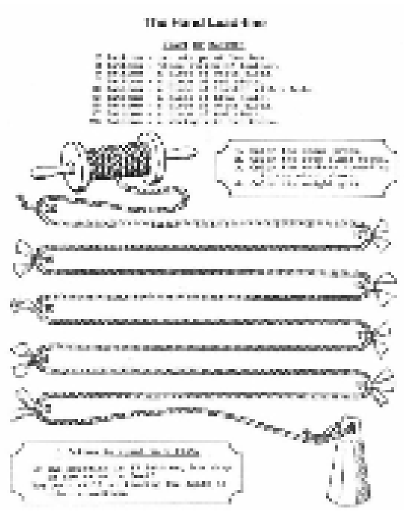

Figure 7. Lead Line

Figure 8. An Astrolabe

Figure 9. A Cross-Staff

5. Cross Staff

The twelfth century saw the invention of the Cross-Staff which contributed immensely to the ease of navigation. It was a 3.5- to 4-foot-long square staff with four graduated-length sliding cross-pieces or transversals and a scale. One transversal was used at a time, and it was chosen based on the object's height in the sky —the longer the transversal, the higher the body. The Mariner was to then hold one end of the staff up to his eye, slid the transversal onto the far end, and then moved it back and forth until its upper and lower edges appeared to touch the body being observed and the horizon, respectively. The location of the transversal on the scale was converted by a table into degrees of latitude.[12]

The Ancient Indian mariners too used the Sextant which was called 'Vruttashanga – Bhaga'

6. Sextant

An American inventor, Thomas Godfrey, and an English mathematician, John Hadley, have been credited with inventing the Sextant. A sextant similar to the Astrolabe has been in use to determine the accurate angle and distance between the horizon and the celestial objects. Sextant is claimed to be much easier to operate than the Astrolabe. The Ancient Indian mariners too used the Sextant which was called '*Vruttashanga – Bhaga*'.[13]

7. Traverse Board

A traverse board helped the mariner determine the course of the ship during the watch. The traverse board comprised a wooden board with holes and small wooden nails and was further divided into two sections.[14] The first section (top part) of the traverse board comprised of thirty-two compass points. This section was used to track the direction in which the ship sailed. The second section (bottom part) of the traverse board was used to calculate the speed of the ship. The mariner during his duty of the watch had to insert a peg in the top section of the transverse board thereby noting the last known position of the ship. This would help estimate the general course of the ship with the help of the placement of the nails. The second section of the board will at the same time keep the track of the speed of the ship in knots. The transverse board can thus be equated to the crude dead reckoning system that existed in the earlier days.

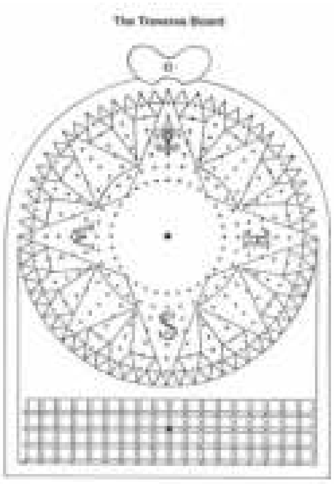

Figure 10: The Traverse Board

Conclusion

The influence of the sea grew over a period of time and the art of navigation, therefore, connected the world together by cultivating trade and cultural relations. Trade *sans* proper navigational skillset and equipment wouldn't have been possible. The navigational equipment developed in the ancient era, therefore, laid a foundation for the development of more sophisticated navigational tools in the years to come. Since the art of navigation picked up pace gradually, the advancements, complexity, and precision in navigational equipment have helped determine accurately the ship's position, speed, and course. This has since then helped ease navigation.

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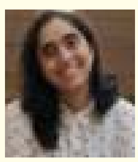
About the Author



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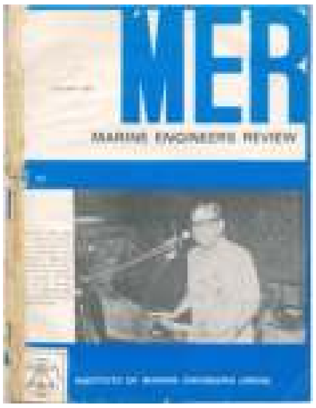
COLUMNS

GOING ASTERN INTO MER ARCHIVES



MER… Four decades back…
The February 1983 Issue

The Feb '83 issue starts with the Editorial discussing conversions. Tankers becoming drill ships, floating docks etc., were economic options. While 1983 was the year for conversions, 2023 could be for retrofits. The 'Opinion' section bats for increased fund support for R&D, a look at alternate materials (steel, Titanium and Aluminium get a mention) and fuel standards (one article exclusively discusses this in the issue).

The first article is on trend analysis and engine monitoring. (This aligns with the Feb 2023 issue also.)

Three extracts are projected with parts of the analyses. These are simple and interesting. Two more extracts on Lube Oil pressure and AC compressor can also be of interest. I hope you would like to dig out this issue and read the rest.

Table 1: Engine variables for trend analysis.

Cylinder compression pressure
Cylinder firing pressure
Fuel rack setting or fuel consumption
Cylinder exhaust temperatures
General exhaust temperature
Crankcase vacuum/pressure
Lube oil pressure
Lube oil consumption
Supercharger air pressure
Wear metal concentration in sump oil
Lube oil dilution by fuel oil
Lube oil TBN

Bearing wear

The bearings may be assumed satisfactory if lube oil pressure remains constant and there is no increase of bearing material particles in the sump oil. In Fig 2 at point 'B' the increase of copper and lead is due to initial running-in of the new bearings when the wear rate is high. At point 'C' the lube oil pressure has dropped but the wear metal concentration has remained unchanged. This needs investigation.

Performance of cylinder unit

A deterioration in tightness of the cylinder unit will lower compression and firing pressures while increasing lube oil consumption, wear metal concentration and crankcase pressure. After the line 'ZZ' in Fig 1 it will be observed that all these conditions have become pronounced, so one can assume that piston rings and/or liners need attention.

State of combustion

Fig 3 shows the performance parameters of fuel consumption, supercharger air pressure and exhaust temperature which indicate the state of combustion in the engine. Increases in exhaust temperature and fuel consumption indicate engine overload. Increase of these values at point 'E' is accompanied by a decrease in supercharger pressure, which indicates that the pressure should be restored when the overload has been rectified, and exhaust temperature and fuel consumption will attain their normal values.

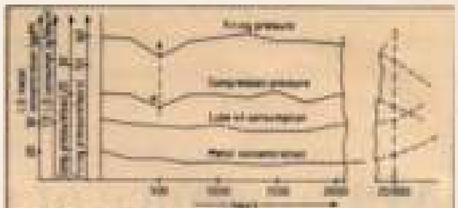


Fig 1: Cylinder performance

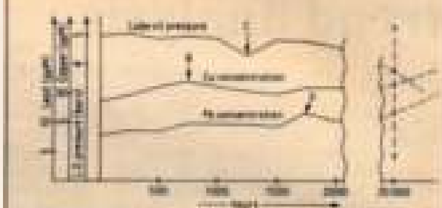
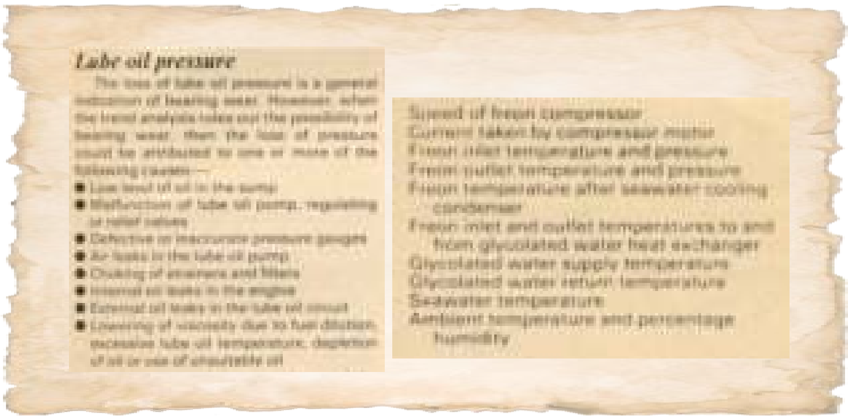


Fig 2: Bearing wear

Fig 3: State of combustion



Lube oil pressure

The loss of lube oil pressure is a general indication of bearing wear. However, when the trend analysis rules out the possibility of bearing wear, then the loss of pressure could be attributed to one or more of the following causes—

- Low level of oil in the sump
- Malfunction of lube oil pump, regulating or relief valves
- Defective or inaccurate pressure gauges
- Air leaks in the lube oil pump
- Choking of strainers and filters
- Internal oil leaks in the engine
- External oil leaks in the lube oil circuit
- Lowering of viscosity due to fuel dilution, excessive lube oil temperature, depletion of oil or use of unsuitable oil

Speed of freon compressor
Current taken by compressor motor
Freon inlet temperature and pressure
Freon outlet temperature and pressure
Freon temperature after seawater cooling condenser
Freon inlet and outlet temperatures to and from glycolated water heat exchanger
Glycolated water supply temperature
Glycolated water return temperature
Seawater temperature
Ambient temperature and percentage humidity

From the Postbag, I pick four letters and leave for you to reflect upon (the one on exhaust boiler fire and manning are worth our contemplation). And there are two problems worth reading about: Contaminated fuel damaging the injectors and diesel bunker overflow on to hot surfaces causing a fire.

Fires in uptakes

Sir,
A fire in the uptake has seriously damaged the exhaust gas boiler in a vessel delivered in May 1982. She is a 17 000 dwt general cargo carrier fitted out to carry 400 containers. The main engine is a 14-cylinder medium-speed MaK diesel. The oil-fired donkey boiler, installed high up in the engine room, provides the steam for the water-tube exhaust gas boiler.

The damage sustained by the exhaust gas boiler is total; it will be replaced. How the fire occurred and continued without detection is a mystery. Even when a centre section of the tube bank collapsed and fell down into the engine room, the fire was not detected. A noise was heard but a search failed to find the cause. (The tube bank section had been arrested by guards near the turbochargers). It was only when the exhaust gas boiler was put on load, by entry of water from the boiler, that everything happened.

Members' help in this respect would be appreciated.

C Tye

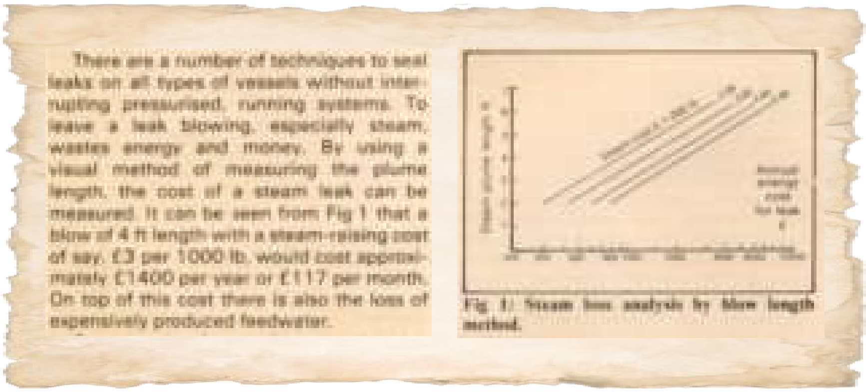
Sunderland

Mr Tye has been sent a copy of the Institute publication 'Marine Steam Boilers' by Milton and Leach, where explanations of the cause of such fires are described. Additional advice and experiences of similar problems and their solutions are requested from members for publication— Editor.

This is followed by another R&M article on fixing leaks on pressure lines. This has an interesting way of analysing loss due to steam leaks. The idea is to base the loss on the plume length of steam issuing from the leak location. I have the graph and the short explanation inserted. Anyone has used such techniques to analyse? Another R&M article follows discussing the scope of repairs on board by specialists.

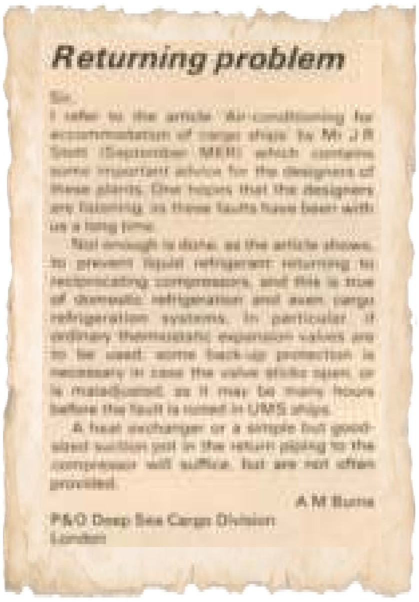
Other write-ups of merit are on:

- Turbo alternator operation (note: thrust pad failure)
- Hull maintenance (cleaning & AF paints)
- Feeder vessels (coal fired options: any takers?)



There are a number of techniques to seal leaks on all types of vessels without interrupting pressurised, running systems. To leave a leak blowing, especially steam, wastes energy and money. By using a visual method of measuring the plume length, the cost of a steam leak can be measured. It can be seen from Fig 1 that a blow of 4 ft length with a steam-raising cost of say, £3 per 1000 lb, would cost approximately £1400 per year or £117 per month. On top of this cost there is also the loss of expensively produced feedwater.

Fig 1: Steam loss analysis by blow length method.



Returning problem

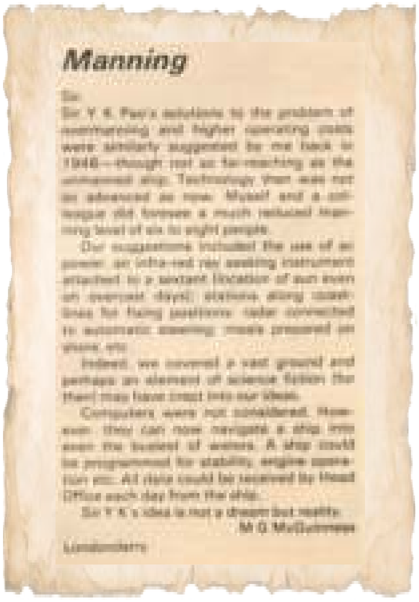
Sir,
I refer to the article 'Air-conditioning for accommodation of cargo ships' by Mr J R Stott (September MER) which contains some important advice for the designers of these plants. One hopes that the designers are listening, as these faults have been with us a long time.

Not enough is done, as the article shows, to prevent liquid refrigerant returning to reciprocating compressors, and this is true of domestic refrigeration and even cargo refrigeration systems. In particular, if ordinary thermostatic expansion valves are to be used, some back-up protection is necessary in case the valve sticks open, or is maladjusted, as it may be many hours before the fault is noted in UMS ships.

A heat exchanger or a simple but good-sized suction pot in the return piping to the compressor will suffice, but are not often provided.

A M Burns

P&O Deep Sea Cargo Division
London



Manning

Sir,
Sir Y K Pao's solutions to the problem of overmanning and higher operating costs were similarly suggested by me back in 1948—though not as far-reaching as the unmanned ship. Technology then was not so advanced as now. Myself and a colleague did foresee a much reduced manning level of six to eight people.

Our suggestions included the use of air power; an infra-red ray seeking instrument attached to a sextant (location of sun even on overcast days); stations along coastlines for fixing positions; radar connected to automatic steering; meals prepared on shore etc.

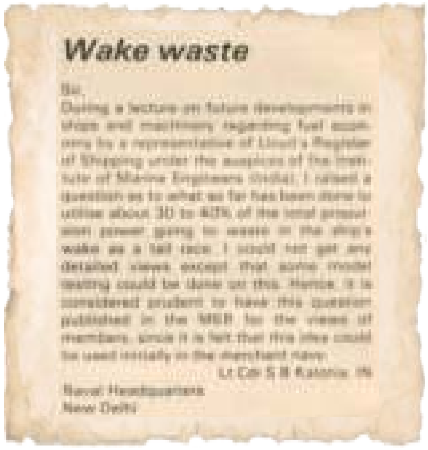
Indeed, we covered a vast ground and perhaps an element of science fiction (for then) may have crept into our ideas.

Computers were not considered. However, they can now navigate a ship into even the busiest of waters. A ship could be programmed for stability, engine operation etc. All data could be received by Head Office each day from the ship.

Sir Y K's idea is not a dream but reality.

M G McGuinness

Londonderry



Wake waste

Sir,
During a lecture on future developments in ships and machinery regarding fuel economy by a representative of Lloyd's Register of Shipping under the auspices of the Institute of Marine Engineers (India), I raised a question as to what so far has been done to utilise about 30 to 40% of the total propulsion power going to waste in the ship's wake as a tail race. I could not get any detailed views except that some model testing could be done on this. Hence, it is considered prudent to have this question published in the MER for the views of members, since it is felt that this idea could be used initially in the merchant navy.

Lt Cdr S B Katoria IN

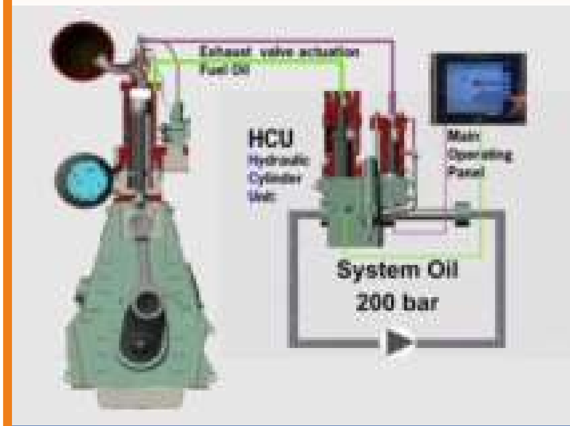
Naval Headquarters
New Delhi

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

MASSA Maritime Academy, Chennai

The Institute of Marine Engineers (India)

Electronic Engine Familiarisation Course (ME-Type Engine) Delivered online with Cloud access to ME Engine Simulator



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.

Course Aims and Objectives:

The course aims to provide practical understanding of the principles, design, operation and maintenance of the ME Engine System, enabling participants to safely and efficiently operate the engine and perform fault-finding in the control system.

Coverage / Program Focus:

This course deals with the following training areas:

- **Introduction to ME Engine**
- **Hydraulic Power Supply (HPS)**
- **Hydraulic Cylinder Unit (HCU)**
- **Engine Control System (ECS)**
- **Main Operating Panel (MOP)**
- **Standard Operation**

Entry Requirement / Target Group:

Entry is open to all Ship's Engineers and Electro Technical Officers with basic knowledge of diesel engines.

DATE & TIMING : **21st, 22nd, 23rd February 2023/ 21st, 22nd, 23rd March 2023/ 18th, 19th, 20th April 2023/ 23rd, 24th, 25th May 2023/ 20th, 21st, 22nd June 2023 8:00 am - 4:00 pm IST**

VENUE : Web Platform / Zoom**. APPLICATION LINK:** https://forms.gle/e4As7kCucR5xoJBm9

REGISTRATION & PAYMENT : Rs. 15,000/- /- per participant – inclusive of taxes.
For IME(I) Members 13,500/- per participant - inclusive of taxes.
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