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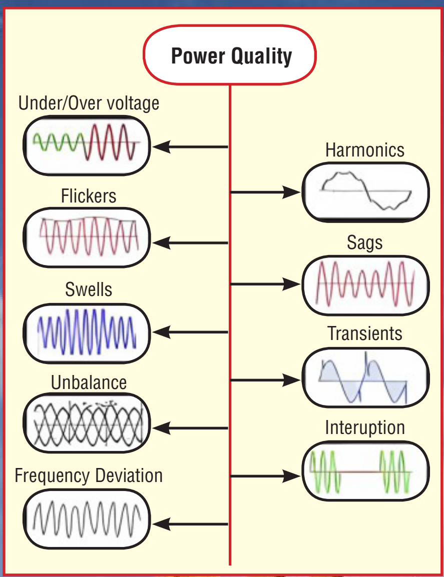

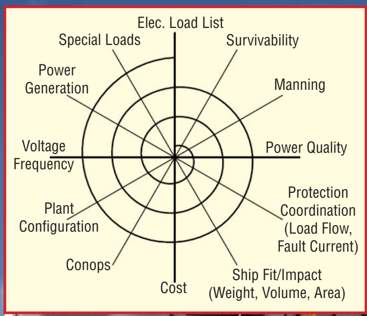

The Quality of Power in Marine Power Systems

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EDITORIAL

If it is important to you, you will find a way. If not, you'll find an excuse.
- Ryan Blair, American Author

Two trade routes have been figuring in the discourses, the Northern Sea Route and the India-Middle East-European Union Corridor (IMEC). The Corridor appears closer and curious enough due to the geopolitics of the region. The Corridor in two parts, the India-Gulf Eastern Corridor and the Gulf-Europe Northern Corridor is expected to bring a host of benefits apart from reducing the distance, time and emissions, of course (India-Europe in about 10 days; works to about 40% faster than through the Suez). Interestingly, the routes are based on a sea-rail-road combination and connect up ports from the Indian shores in the Arabian Sea (Mumbai, Kandla, Mundra) to Mediterranean ports of Greece, Italy and France. The name-dropping of ports and places aside, the intriguing part is the corridor coming across Saudi Arabia connecting up to Haifa.

The railway to run across the Arabian Peninsula is expected to cover several brownfield and greenfield projects. What raises the hope is that many of the sections of this corridor are already under construction. It is reported that of the 2900km (approx.) Fujairah-Haifa route, about 1900km have been completed and work is in progress for the remaining distance of about 1000km and other gaps are also being made good. The double tracks on the deserts will stretch through UAE, Saudi Arabia, Jordan and Israel. The sea route-spokes from Haifa will reach Piraeus (Greece), Messina (Italy) and Marseille (France). Described as the 'transformative integration of Asia, Europe and the Middle East', it is to be seen how much of this would counter the Belt initiative of China or the already existing Chinese presence in Greece and the Etihad Rail Project of the Emirates.

This appears important enough for India (notwithstanding the Chabahar port issues) to pursue and find ways to overcome the challenges. After all, history shows that trade had opened unknown routes and gates. There should be such reasons on success and not excuses.

In this issue...

Power Systems have become all the more important on board. With VFD drives and electric propulsion maturing, the quality of the generated power becomes an equitable demand. The factors affecting electrical power vary from variations of voltage and frequency, harmonic distortion etc. Dr. Veda takes us through these and management of the active/reactive power, in particular. Briskly moving through the harmonic distortion and filters, electromagnetic interference etc., the part on Classification Societies defining the indices is an interesting takeaway.

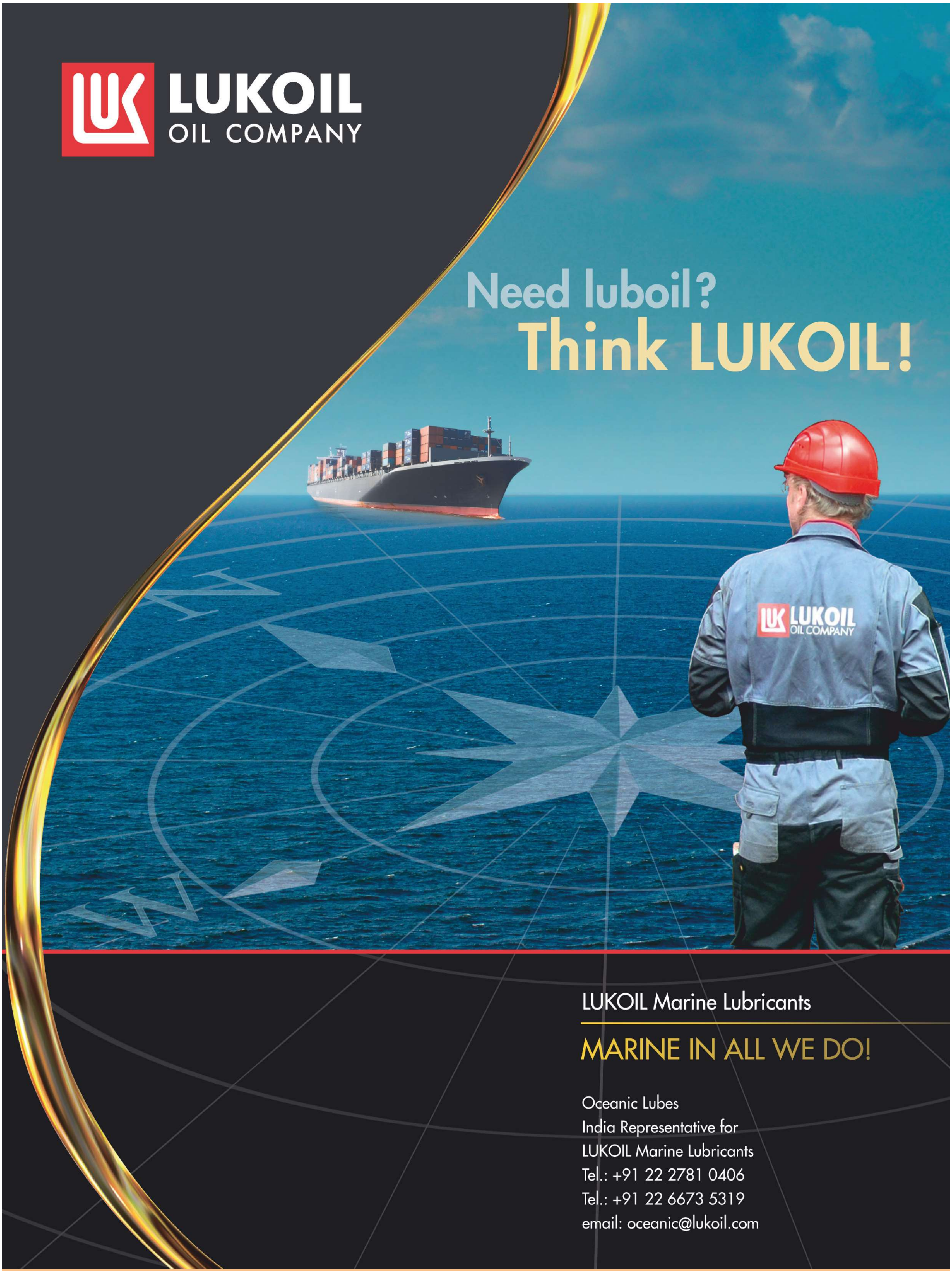
In automated systems, the function of the sensors is crucial. From space to deep seas, systems rely on inputs from sensing the variables. In this discussion, Dr.Srinivasan et al., describe the process of testing Conductivity, Temperature, Depth (CTD) sensors. The principle and physical descriptions followed by the testing are easy to comprehend. The CTD sensor is for deep sea vehicles and will find their uses in the Samudrayaan expeditions, we may hope.

Following the sensor testing, we have an exposition on Green Initiatives. The Author, Sudeeptho Ghosh lists out the trends in ship's hull and a slew of measures, which have had many mentions for some time. A good connection to the introductory part on 'maturity of options' and 'acceptability and feasibility' would have made the discussion interesting.

Lube Matters go on with the talks on lubrication of the camshaft train etc. The dig from the MER Archives (Oct'83) has an interesting discussion on how Japan maintained its productivity and quality in shipbuilding. We also have the renowned marine engineer-maritime historian Narasiah returning with a write up on the Periplus. This will be a leisurely read.

The weeks to follow hold a lot of sporting events to keep us at the corner of our couches (Asian Games at Hangzhou and the Cricket World Cup at our backyards). Hoping for hundreds, here is the October issue for your reading pleasure.

Dr Rajoo Balaji
Honorary Editor
editormer@imare.in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Administration Office
IMEI House
Plot No. 94, Sector - 19, Nerul,
Navi Mumbai 400 706.
Tel. : +91 22 2770 16 64
Fax : +91 22 2771 16 63
E-mail : editormer@imare.in
Website : www.imare.in

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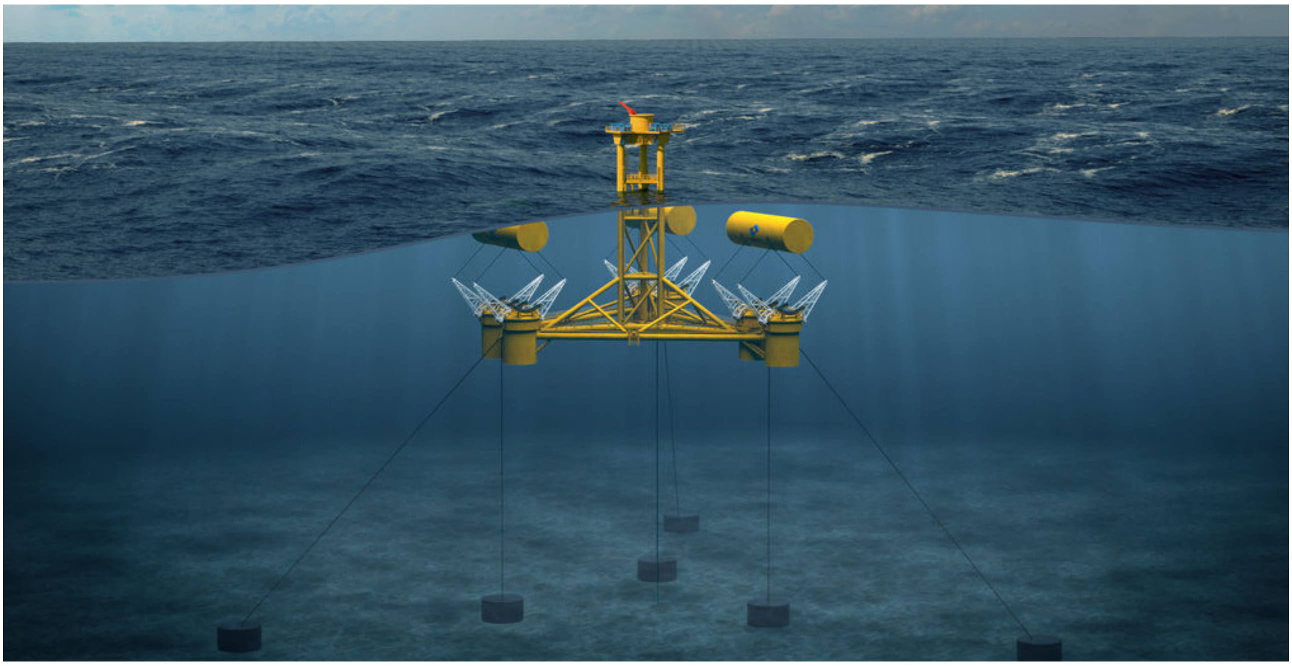
Improvement of Power Quality in Marine Power Systems



N. Vedachalam

Abstract

Ensuring power quality is one of the key requirements in modern marine power systems comprising of power electronics-enabled multi-megawatt capacity integrated electric propulsion systems. The paper discusses the importance of including power quality as an integral part of modern marine power system design spiral and the methodologies adopted in improving power quality through effective management of active and reactive power, reducing voltage and current harmonics using active filters and following standards for achieving electro-magnetic compatibility.

Index terms: Active Filters, EMC, IEPS, Harmonics, VSD

Introduction

The global fleet of more than 94,171 ships categorised into passenger vessels, containers, tanks, gas carriers, bulk, dry and cargo carriers, with a consolidated dead weight tonnage (DWT) of ~2 Billion Tons contribute to ~90% of the global trade. The International Maritime Organization (IMO) has adopted strategies to increase the operational efficiency and reduce greenhouse gas (GHG) emissions from the ships by ~50% by 2050 through effective implementation of strategies including Energy Efficiency Design Index (EEDI), Energy Efficiency Operational Indicator (EEOI) and Ship Energy Efficiency Management Plan (SEEMP).

Over the past few decades, with the advancements in power- electronics systems, electric propulsion has proved to be a solution to improve fuel efficiency and reduce environmental emissions. The first diesel-electric vessel (river tanker Vandal) was developed in 1903, and the first naval vessel with electrical propulsion (Jupiter) was operational in 1912. The operational, economic and environmental benefits such as reduced fuel costs, redundancy, reduced number of prime movers, shorter shaft lines, increased survivability, improved manoeuvrability, greater efficiency, arrangement flexibility, excellent torque-speed characteristics (including fast dynamics), reduced vibrations, and use of common power source for propulsive and non-propulsive loads, have led to the increased adoption of Integrated Electric Propulsion System (IEPS).

With the advancements in IEPS, the present power generation capacity has reached ~120 MW for cruise liners of ~230000 GT, 360m long, 47m beam and speed >20 knots; and ~80MW for multi-mission stealth ships. Modern multi-megawatt vessel IEPS **(Figure. 1)** comprises diesel

> *The first diesel-electric vessel (river tanker Vandal) was developed in 1903, and the first naval vessel with electrical propulsion (Jupiter) was operational in 1912*

engine/steam turbine-driven alternators connected to the main distribution Medium Voltage (MV) bus operating at voltages 6-15kV, from which propulsion and utility loads are supplied through Variable Speed Drives (VSD) operated using power-electronic converters. Several utility transformer feeders are used to supply the remainder of the vessel's electrical load, the consumer voltage typically being 415V. The system protection is ensured by using rated circuit breakers (making and breaking capacities) and proper coordination of protection relays capable of isolating the faulty section during a fault. The importance of power quality in ensuring vessel/platform safety is evident from failure investigations on RMS Queen Mary II which lost manoeuvrability due total power outage as a result of catastrophic failure of a capacitor in harmonic filter, and the explosion in the gas compression module of Tern Alpha oil platform as a result of overheating of the high-voltage electric motor due to high level of harmonics distortion.

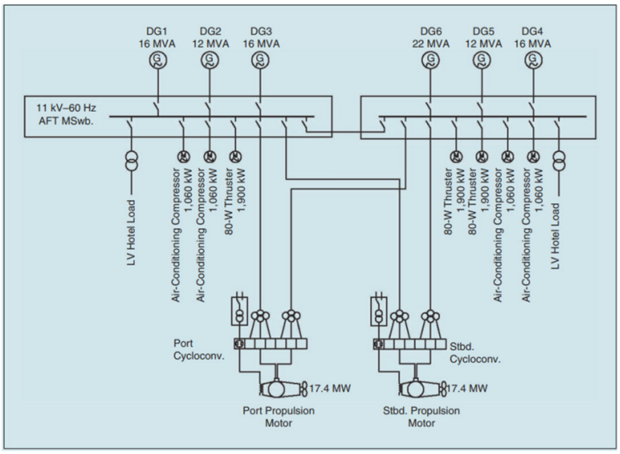


Figure 1. Typical IEPS in a commercial multi-MW capacity vessel

Power quality as a part of power system design

The design of a marine/vessel electrical power generation and distribution network requires a careful trade-off between various design factors including operational safety and fuel efficiency. Power quality is one of the key requirements in modern power electronics-enabled multi-megawatt capacity IEPS design spiral **(Figure.2),** which is presently undertaken as an integral component of vessel power system design.

The power quality aspects in marine power systems include voltage variations, frequency variations, voltage asymmetry, harmonic distortions, transient pulse disturbances and improper distribution of active and reactive power between generating sets operating in parallel **(Figure.4).** Marine power generating sets are "weak" power sources (with 15-20 % impedance) compared to "stiff" sources (4-6% impedance) more common in land industrial applications. Power-electronic converters operating in the high-impedance ship mains generate harmonic and inter-harmonic distortions creating inadmissible disturbances in power system which could result in harmonic distortions up to 20%. In addition to these, adoption of standards and practices for achieving electro-magnetic compatibility (including interference and susceptibility to conducted and radiated noise) are essential.

> **Reversal of active power flow leads to motoring operation, and reversal of reactive power leads to reactive power consumption**

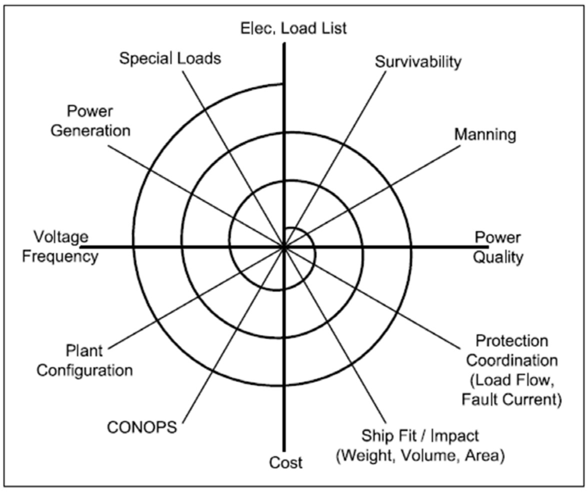


Figure 2. Iterative system engineering of vessel power systems

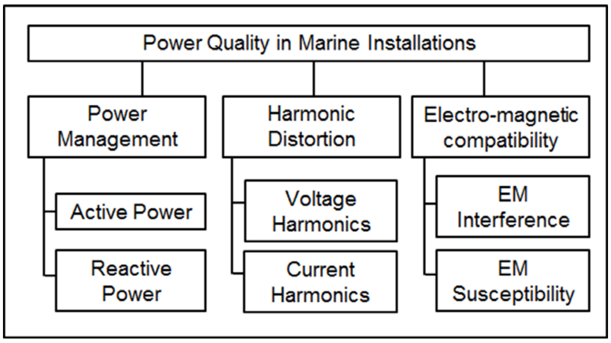


Figure. 3. Power quality parameters in modern marine systems

Figure. 4a and b represents variations of rms voltage and frequency during the start-up and running of the 1.3 MW electric motor-driven thrusters, when two generators with power 1.75 MVA each operated in parallel. **Figure. 4c** shows the voltage asymmetry recorded during the failure of a harmonic filter (3-phase LC passive filter). **Figure. 4d** shows 4.4% voltage-THD on vessel main distribution board 220VAC bus. **Figure. 4e** shows the notching caused by commutation over-voltage in power converter, which has resulted in ~14% Voltage-THD. The power quality standards followed in the marine industry based on IEC standards are summarised in **Table. 1.**

Table.1. Power quality standards adopted in marine industry

Parameter	Allowable range
Steady voltage deviations	+6 % to –10%
Steady frequency deviations	± 5 %
Voltage asymmetry	3%
Voltage transient amplitude	5.5 Un
Transient Increase/ Decrease time	1.2µs/ 50µs

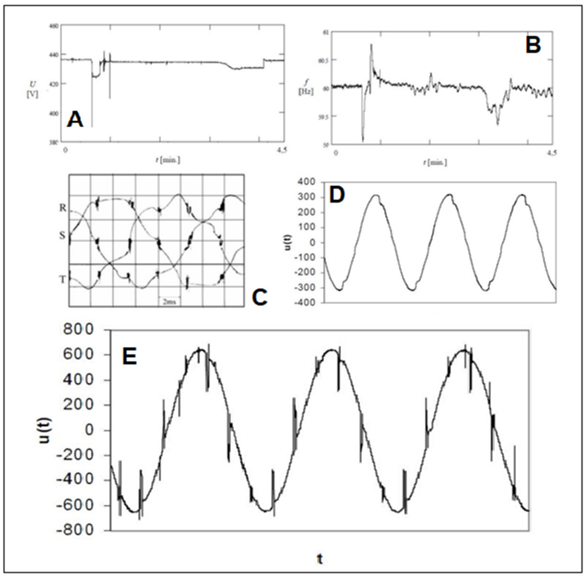


Figure. 4. Power quality parameters in vessel power systems
Management of active and reactive power in IEPS

Modern IEPS encompass vessel Power Management Systems (PMS) are configured to manage the generation and utilisation of active (kW/Frequency) and reactive (kVAR/Voltage) power. The Equivalent Consumption Minimization Strategy (ECMS)-based supervisory control **(Figure. 5)** facilitates optimisation of fuel consumption by converting electrical power into the equivalent fuel consumption ensuring optimal active and reactive load sharing between the power generators and other power sources such as ship-board batteries and renewable systems.

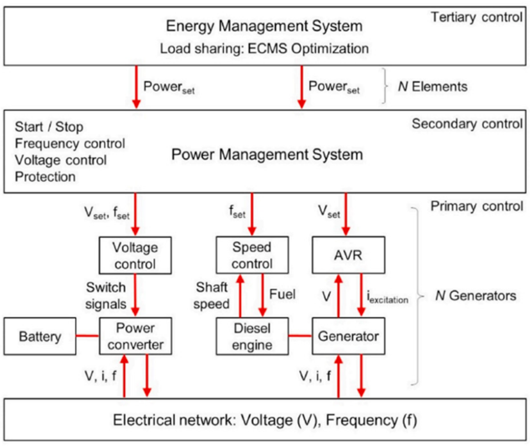


Figure. 5. ECMS for marine power system

During uncertainties in dynamic response and time-varying weather conditions, modern ECMS uses predictive control methods such as Particle Swarm Optimization (PSO) techniques to mitigate power system instabilities and maintaining energy efficiency and reducing emissions. Intelligent power management (such as a digital twin) is required to deal with the high-level complexity of the IEPS configuration together with dynamic non-linear loads arising from a wide variety of propulsion load profiles in various sea states. The presence of such loads causes marine engines to operate in unpredictable conditions which in turn impair ship fuel/ energy efficiency. Thus the ECMS helps to achieve IMO-mandated EEDI, EEOI and SEEMP targets.

An electric generator is designed to deliver active and reactive power. Reversal of active power flow leads to motoring operation, and reversal of reactive power leads to reactive power consumption. Such reversals influence the power system by creating instabilities in frequency and power factor. In case of steam turbines, if the turbine fails and a reverse active power flow occur, a reduction of the steam flow reduces the cooling effect on the turbine blades leading to overheating. Consumption of reactive power by the alternators affects the bus power factor. The modes of operation in four quadrants are depicted in **Figure.6.**

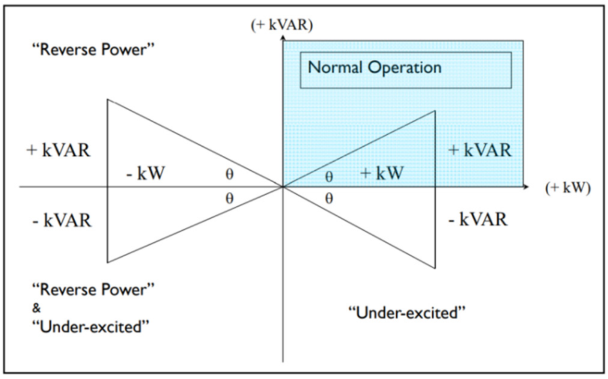


Figure. 6. Operating regions of power generator in nominal and off-nominal modes

The directional reactive power relay offers protection to the mains-synchronised alternator stator during loss of excitation and preventing it from drawing reactive power from the mains. When the excitation is lost, the equivalent alternator impedance traces a curve from the first quadrant of R-X diagram into a region of the fourth quadrant **(Figure. 6).** When an alternator pole slips and falls out-of-step with the power system, the generator and system voltages sweep past one another at a slip frequency, producing a pulsating current, which can be greater than a three-phase fault at the generator terminals which could detected using alternator pole slipping relays. The voltage jump/vector surge relay isolates the alternator rapidly from the mains within a cycle during momentary overloads.

While the active power sharing between generating sets during parallel operation is governed by the engine speed governor droop characteristics, the reactive power (kVAr) sharing is controlled by the alternator's Automatic Voltage Regulator (AVR). There are various load-sharing methods, such as isochronous load sharing, cross-current compensation and quadrature droop load sharing. The quadrature droop-load sharing comprises of a Droop Current Transformer (CT) fitted on one of the alternator's output phases. The current signal from the droop CT secondary winding is converted to a voltage signal across a burden resistor within the AVR **(Figure.7).** This voltage signal is then added vectorially to the AVR sensing voltage so that the AVR will be "tricked" to droop the voltage by adjusting the excitation levels accordingly, in proportion to the levels of load current and power factor. Normally AVR droop setting for all paralleled alternators is set at 3% (at 0.8pf) to ensure proportional kVAr sharing among the generating sets.

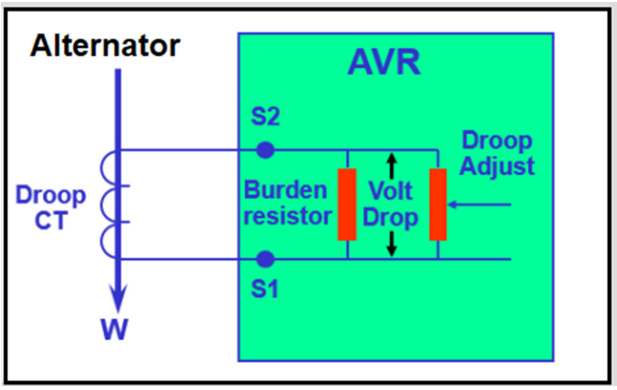


Figure. 7. Sensing and droop setting for AVR

Power factor could be improved using static capacitors, synchronous condenser and phase advancers. Using static capacitors, the power factor can be improved by connecting capacitors in parallel with the equipment operating at lagging power factor. A synchronous motor takes a leading current when over-excited and, therefore, behaves as a capacitor. The phase advancer (which is economical for motors >200 HP) is mounted on the same shaft as the main motor and is connected in the rotor circuit of the motor.

The active power sharing between diesel generators/ steam turbines operated in parallel is described in **Figure. 8.** The envelopes indicate droop characteristics (5%) of individual generators for various set speeds. When an active power demand comes on to the system, the generator/turbine with lower droop slope takes a higher share of the active power, and vice versa. Thus droop settings have to be coordinated so as to ensure proper load sharing by the engines/ turbines of different capacities when operating in parallel.

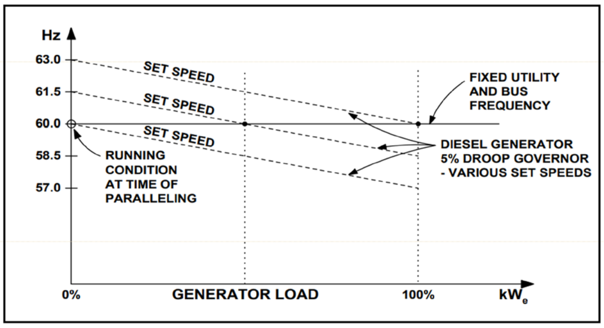


Figure.8. Active power sharing by generators in parallel

In order to ensure this, ship classification societies (DNV, ABS, LR) define appropriate indices δPi and δQi as characterising a proportionality of the active Pi and reactive Qi powers distribution of the i-th generators working in parallel. **Usually, this means that the active or reactive load of any generator is not to differ more than ±15% (active load—δPi) or 10% (reactive load—δQi) of the rated output of the largest generator from its proportionate share of the combined active or reactive load. Incorrect values of these indices are the most common cause of blackouts in ship/platforms.** Therefore, the indices δP and δQ should be set and tuned during the operations.

Advanced electrical network modelling and simulation tools help to analyse the power system dynamics, transients and determine the range and settings of the AVR and speed governor. Thus determining the power quality for the vessel mains, in terms of voltage and frequency variations (**Table. 1**) is a part of the design spiral. Modelling with the subsystem characteristics could help to determine effective load sharing between different steam turbines/diesel generators, both in steady-state and during transients. In droop control, each machine adjusts its power output for changes in load and therefore frequency according to a linear curve describing a relationship between frequency and active power **(Figure.8).**

"In order to ensure this, ship classification societies (DNV, ABS, LR) define appropriate indices δPi and δQi as characterising a proportionality of the active Pi and reactive Qi powers distribution of the i-th generators working in parallel"

Reactive power load sharing may be performed using reactive droop, reactive differential (crosscurrent) compensation, or network-based reactive power load sharing. Reactive differential compensation uses a similar compensation method as in reactive droop; however, it also sends and receives a compensation signal to and from another generator, thereby allowing sharing of reactive load. Reactive droop and reactive differential compensation can be modelled as described in IEEE 421.5.

Power system modelling tools such as MATLAB Simulink and Power Sim are used for modelling and simulating a multi-generator model **(Figure.9)** for transient and steady-state performances during various phases of normal and off-nominal operations. In **Figure.10,** P_T, I_T, V_T, Q_T represents terminal active power, terminal current, terminal voltage and terminal reactive power. Parameters S_{LS}, P_{LS} Q_{LS} represents apparent power load sharing, active power load sharing and reactive power load sharing. The terms ω, ω_C, ω_{REF}, ω_{bias} represents speed, compensated speed, speed reference and speed bias. P_{REF} and P_M represents power reference and mechanical power.

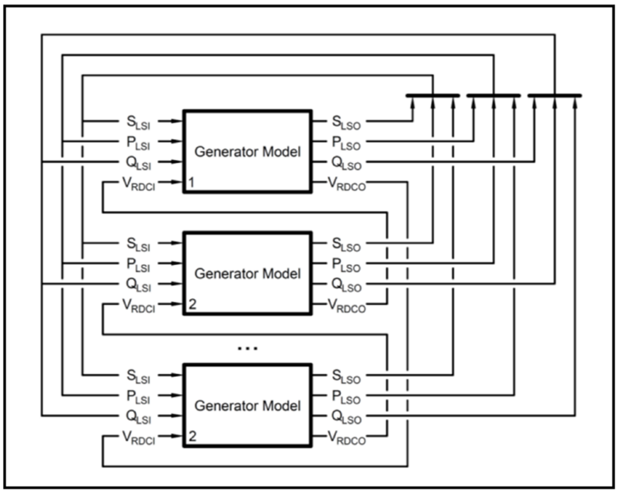


Figure.9. Model for simulating multiple generators feeding the ship mains

Figure.10. shows the block model for simulating the behaviour of the IEPS taking into consideration of the synchronised generators, their speed governor and exciter characteristics. The synchronous machine model includes rated frequency, voltage, pole pairs, stator resistance, d- and q-axis synchronous, transient and sub-transient reactance, leakage reactance, d- and q-axis transient and sub-transient open-circuit time constant and the machine inertia constant. The excitation system models include voltage regulator gain, damping constant, excitation gain, exciter range and saturation levels. P_{MWSET} represents load reference of this supervisory load control loop. Parameters V_{RDC}, V_{REF}, V_{STAB}, V_{BIAS}, V_C, EFD represents reactive differential compensation voltage, voltage reference, power system stabilizer voltage, voltage bias, compensated voltage and field voltage, respectively.

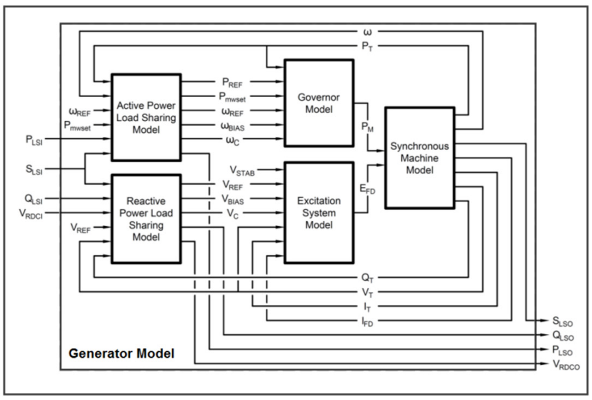


Figure.10. Model for simulating a typical vessel IEPS

Harmonics and active filters

Developments in high-power semiconductors, control electronics and system engineering supported by the finite element electro-thermal modelling tools, redundant architectures, autonomous intelligence, diagnostics and prognostics capabilities have helped in achieving safe, reliable, efficient water-cooled Medium Voltage-Multi-Megawatt (MV-MW-VSD) variable speed propulsion systems. Their capacities range up to 40 MVA with power densities of ~1.5 MVA/m^3. The architecture of MV-Multi-Megawatt Active Front End VSD (MW AFE-VSD) comprising of power, control and cooling systems is shown in **Figure.13.**

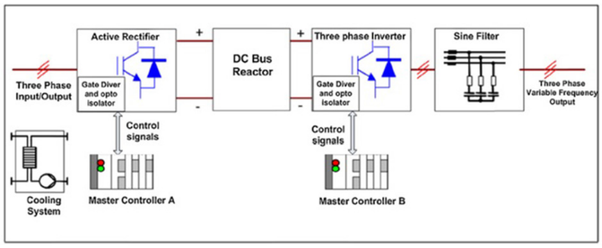


Figure.11. Architecture of a typical MV-MW AFE-VSD

Power regulation by varying the output voltage and frequency is done in the machine bridge and in the mains bridge (AFE) sections of the VFD. The AFE feature enables bi-directional power transfer between the propulsion motor and power generators during vessel deceleration. The IGBT are active components in the VFD, that regulates power based on Pulse Width Modulation (PWM) techniques, which produce harmonics. The VSD output Total Harmonic Distortion (THD) is reduced by suitably designed sine filters or by interlaced switching of multiple IGBT stacks. Typical 12, 18 and 24 pulse inverters have voltage THD of 10, 5 and 3%, respectively. According to IEEE 519 requirements, the voltage THD should be <1.2% and the current THD to be <5 %. The AFE has the advantage that the voltage THD is ~5% and they require lesser filters.

Thus increased use of power-electronic converters/ VSD and other non-linear loads leads to higher harmonic generation and could result in Voltage-THD up to 20%, in which 3rd and 5th harmonics could reach up to 20% of the fundamental, depending on the dynamic loading conditions. The order of the harmonics produced by the multi-pulse VSD depends upon the inverter switching frequency. These higher order harmonics generated by VSD switching are usually mitigated using k-rated converter transformers with multiple phase-shifted secondary windings **(Figure. 13).** The THC and THD for the voltage and current waveforms are described in **Figure. 12.** According to IEC 61000-3-2, the total harmonic current (*THC*) is equal the total RMS value of the harmonic current components of orders 2 to 40. According to IEC 61000-3-2, the THD is defined as the ratio of the RMS value of the sum of the harmonic components (in this context, harmonic current components Ih of orders 2 to 40) to the RMS value of the fundamental component I1, expressed as:

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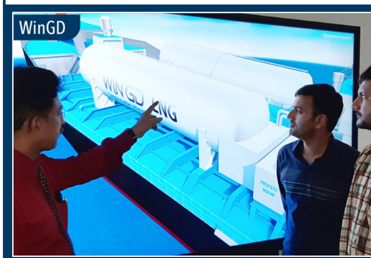

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$$THC = \sqrt{\sum_{h=2}^{40} I_h^2} \qquad THD = \sqrt{\sum_{h=2}^{40} \left(\frac{I_h}{I_1}\right)^2}$$

Figure. 12. Definition of THC and THD

Harmonics lead to overloading of power factor correction capacitors, motor heating, overloading and heating of transformers, and increased iron losses leading to reduction in efficiency, tripping of protection devices and electric insulation degradation. For mitigating the harmonics generated by other non-linear loads, passive and active harmonic filters are used. These harmonic filters must be installed as close as possible to the loads that are generating harmonics, as voltage distortion at the point of common coupling (PCC) can be aggravated due to of resonances between the power factor compensation capacitors and the inductance of the distribution systems. Standards recommend minimum power quality that limits the maximum distortion levels for the voltage supplied at the PCC. According to IEC 61000-2-4 for LV networks, Class 1 and 2 recommend THD of <5 and 8 %, respectively. Class 2 involves power supply to sensitive electronics systems and Class 3 for normal networks. As power factor correction capacitors are vulnerable to harmonics, IEC 60831 recommends capacitor manufacturers to design with 30% higher than the nominal current.

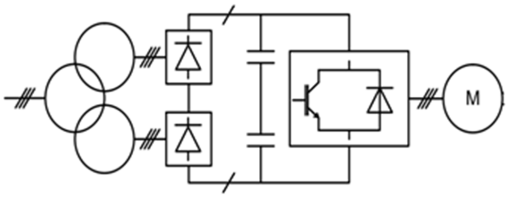

Figure. 13. Converter transformer connected in a 12-pulse VSD

Active filters that inject current at the PCC are categorised as selective Fast Fourier Transform (FFT) and broadband FFT operating techniques. The selective FFT filters respond in 40-50ms and mitigate only the selected order of the harmonics, while the broadband filters that respond in <100μs treat all the non-fundamental components, and not just integer harmonics. Based on the technological trends in the harmonic mitigation systems, DNV-OS-201 A201 section and Section 11 of ABS recommends THD to be <5% as the limit in marine power systems. The international and marine regulatory agencies standards that recommend harmonic emission limits for units and systems connected to the network are summarised in **Table. 2 and 3,** respectively.

Table. 2. Standards on harmonic emission limits

Standard	Tests
IEC-61000-2	EMC for LF conducted emissions in LV networks
IEC-61000-3	Limits for harmonic current emissions
IEEE-519-2014	Practices and requirements for harmonic control in electric power systems

It can been be seen that DNV, ABS and KR all have individual harmonic limit that is not dependent of harmonic order – which means that the maximum of 5 % of for example DNV applies equally at 5th harmonic as well as at 49th harmonic. Surely, 5% is much more damaging at higher harmonic orders. CCS, BV, RINA and RS circumvents this by specifying a falling curve from 15th harmonic to 100th harmonic – linear curve for CCS and logarithmic for BV, RINA and RS.

Active filters are a controlled current sources or controlled voltage sources used for effective control

Table. 3. Marine standards for harmonics

Class and Reference	THD U	Individual harmonic limit
DNV Rules for classification: Ships (Oct. 2019) Part 4, Chapter 8, Section 2, 1.2.7	<8%	<5%
ABS Rules for Building and Classing Steel Vessels (Jul. 2019) Part 4, Chapter 8, Section 2, 7.21		
KR Rules for the Classification of Steel Ships (2019) Part 6, Chapter 1, Section 8		<3%
BV Rules for Classification of Steel Ships (Jan. 2020) Part C, Chapter 2, Section 2, 2.4.2		≤ 15th: 5 %, then falling logarithmic to 1 % at 100th
LR Rules and Regulations for the Classification of Ships (July 2019) Part 6, Chapter 2, Section 1, 1.8.3		None of the harmonics above 25th shall exceed 1.5 %
RINA Rules for the Classification of Ships (Jan. 2020) Part C, Chapter 2, Section 2, 2.2.2	<10%	≤ 15th: 5 %, then falling logarithmic to 1 % at 100th
CCS Rules for Classification of Sea-Going Ships (Jul. 2018) Part 8, Chapter 15.2.2.2		≤ 15th: 5 %, then falling linearly to 1 % at 100th
RS Rules for the Classification and Construction of Sea-Going Ships (Jan. 2020) Part XI, Section 2.2.1		≤ 15th: < 10 % 16th – 99th: falling logarithmic to 1 % 100th – 200th: < 1 %

of harmonics, unbalanced components, power factor, voltage sags or swells and damping low-frequency harmonic oscillations. The shunt filter compensates for harmonic currents drawn by the load. The power stage comprises of a Voltage Source Inverter (VSI), energy storage capacitor and direct current (DC) link, inductor filter Lfp and small passive filters Zfp to provide a low impedance path to the high-frequency components of the produced current by the VSI denoted as ILfp. The control stage presents measurement and instrumentation circuits, microcontrollers, and VSI drivers. The reference current produced by the VSI (i*) is determined based on the applied control algorithms, which presents the load current (I_L), grid voltage (Vs) and the DC-link voltage (V_{DC}) as inputs. There is also a PWM controller for keeping ILfp inconformity with the reference current (i*).

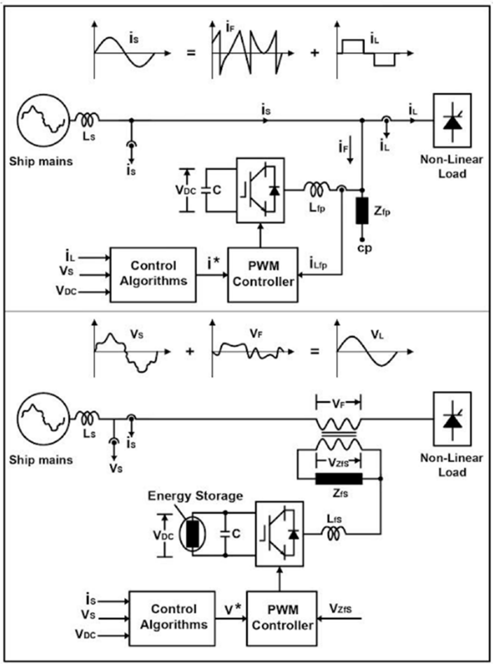

Figure. 14. Architecture of series and shunt active filters

Figure.14.b illustrates a simplified scheme of the series active filter compensating harmonics and voltage sag, with the reference voltage (V*) being determined through the applied control algorithms, which presents the grid current (Is), grid voltage (Vs), and the DC-link voltage (V_{DC}) as inputs. There is a PWM controller for producing the VSI filtered voltage (VZsf). An additional storage energy element is necessary if sag compensation is required. The functions of the series and shunt active filters are summarised in **Table.4**

Table.4. Functions of series and shunt active filters

Active filter	Functionality
Series active filter	Voltage harmonics control, Unbalanced voltage compensation, Voltage sag/swell compensation
Shunt active filter	Current harmonics control, unbalanced currents compensation, Power factor correction

Electromagnetic compatibility

Electro-Magnetic Interference (EMI) refers to the emitted, transmitted, conducted or radiated noise from power-electronic equipment and systems, while Electro-Magnetic Compatibility (EMC) is the ability of electrical/ electronic/communication equipment and systems to function or operate, reliably, in the presence of EMI **(Figure.15).**

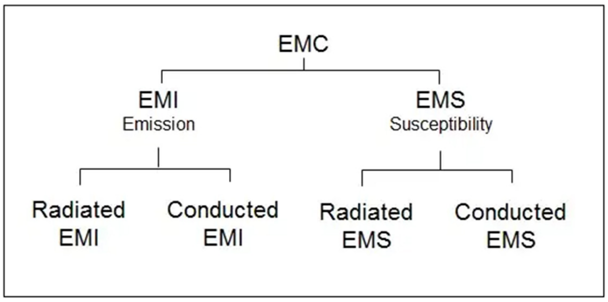

Figure. 15. EMC considerations for marine systems

Incorporating these in the design cycle will ensure compliance with applicable international test requirements. For EMC, International Association of Classification Societies (IACS) Unified Requirements UR-E10 covers minimum standards for equipment on-board commercial ships. The SOLAS convention is supplemented with IEC 60533 and 945 standards for EMC regulations for operational and safety of on-board electrical and electronics equipment. They cover equipment steady state and transient immunity tests with conducted and radiated emissions in the range of 10 kHz-30MHz and 50 kHz-2 GHz, respectively. The conducted emissions (CE) begins at 10 kHz (to 30MHz) and radiated emissions (RE) begins at 150 kHz (to 2GHz). Both CE and RE standards apply a stricter limit for equipment used on the vessel bridge or deck zones (Class B) compared to equipment below deck and considered general power distribution zone (Class A**) (Figure.16).**

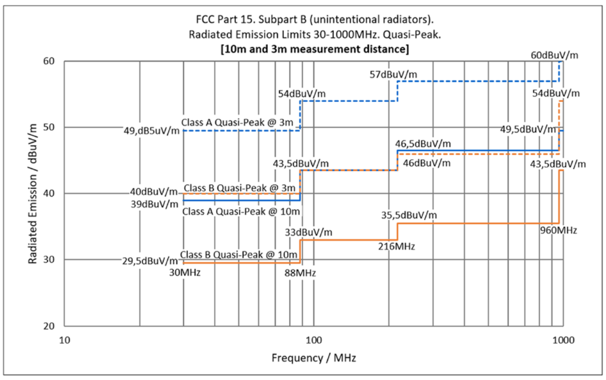

Figure.16. Radiated emission standards for Class A and B

The tighter bridge and deck limits are applied to protect communications and navigation equipment, which are typically in close proximity to these bridge and deck zones. In addition, the 156-165 MHz range includes a very tight emissions limit of 24dbµV/m to protect the marine VHF radio communications. The IEC and CIPR standards applicable for voltage variations, harmonics and EMC are summarised in **Figure.17.**

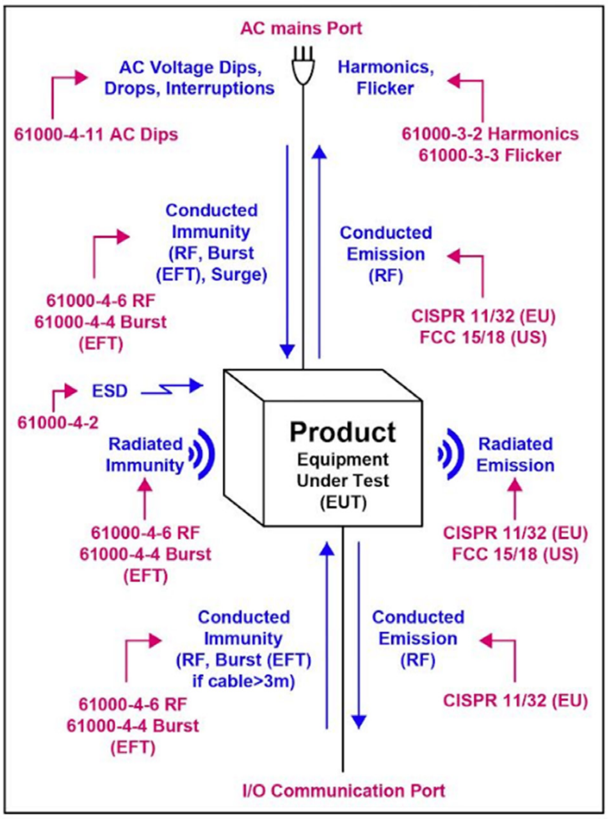

Figure.17. IEC and CISPR standards for voltage variations, harmonics and EMC compliance

Conclusion

Electric power networks in ships/offshore platforms have distinctive features which distinguishes these systems from their land-based counterparts. The paramount criterion in dealing with these electric power systems is safety. Recent developments in power electronics technology and their application in alternating current drives and control systems have now enabled vessel Integrated Electric Propulsion Systems with improved manoeuvrability, efficiency and compactness, as well as a reduction in greenhouse gas emissions. However, the introduction of these technologies has introduced a whole new set of power quality challenges on ships and offshore platforms, including improper operation of sensitive electronic equipment due to electromagnetic interference, increased reactive losses, increased insulation stresses leading to thermal-driven breakdowns, resonance phenomena, and increased electromagnetic signature. In light of the increasing trends in all-electric ships and platforms, the article discussed the latest techniques for improving power quality through effective management of active and reactive power, reducing voltage and current harmonics using active filters and following standards for achieving electro-magnetic compatibility. The information presented justified the importance of including power quality as an integral part of the design spiral so as to ensure operational safety at sea.

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About the author

Dr. N. Vedachalam is currently Scientist G in Deep Sea Technologies division of National Institute of Ocean Technology (NIOT), Ministry of Earth Sciences, India. He is the technical lead for India's first indigenously-developed deep-water manned scientific submarine Matsya6000. He holds a Bachelor's degree in Electrical and Electronics engineering from Coimbatore Institute of Technology (1995) and PhD in Techno-economics of marine gas hydrates from College of Engineering - Anna University, India. His 27 years of experience include industrial power, process, offshore and subsea domains at Aditya Birla group, General Electric & Alstom Power Conversion in France. Technical exposure includes development of multi-megawatt subsea power and control systems for Ormen Lange subsea compression pilot; Ocean Thermal Energy Conversion and wave energy systems; subsea renewable power grids; unmanned and manned underwater vehicles; ocean observation technologies and industrial systems. His research interests include energy, subsea robotics and reliability. He has more than 100 publications in indexed journals, holds an international and two national patents in subsea robotics and subsea processing. He is a recipient of the national meritorious invention award in 2019 for the development and usage of underwater robotic vehicles. He is a member of Indian Naval Research Board, member of Bureau of Indian Standards and was the Secretary of IEEE OES - India Chapter. He is a regular contributor to MER.

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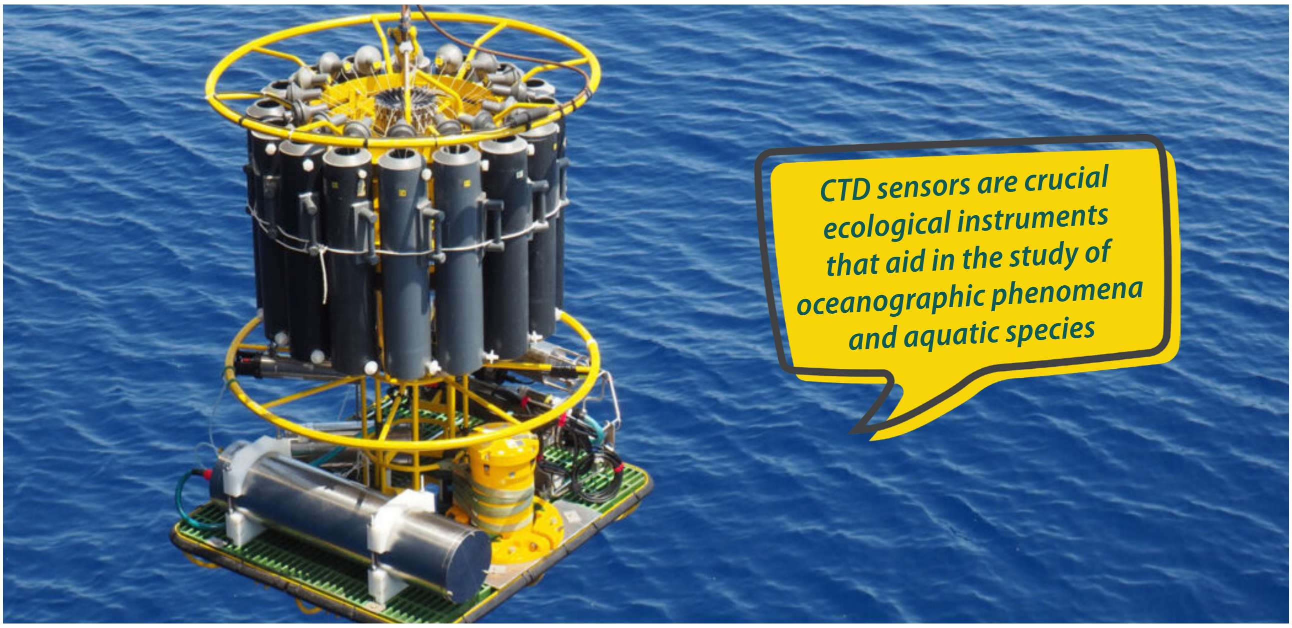
Design and Structural Assessment of CTD Sensor Enclosure Rated for 1000m depth Sea Operations



Srinivasan. R, Anand Kishor, Yuvaraj. S, Tata Sudhakar

Abstract

One of the most often used equipment in the oceanographic discipline is the Conductivity, Temperature, and Depth (CTD) sensor. These devices are majorly used to collect ocean parameters to the full ocean depth. The integrated Conductivity, Temperature, and Depth sensor has largely replaced stand-alone sensors and made field data collection easy. As conductivity is highly influenced by variations in temperature and water density and salinity, accurate conductivity measurement is not that easy compared to other physical parameters. The National Institute of Ocean Technology (NIOT) has initiated the indigenous development of CTD sensors based on capacitance-coupled conductivity measurement techniques along with temperature and depth sensors. This article presents the results of the design, structural assessment, and hydrostatic pressure test of a 1000 m water depth-rated stainless steel CTD sensor enclosure. Structural analysis of sensor enclosure is carried out to estimate the subsection stresses and strains using finite element analysis. Thus, the design is ensured for operations up to 1000m water depth.

Keywords: *CTD (Conductivity, Temperature and Depth) sensor, 1000-meter sea water depth rated enclosure, hydrostatic pressure test.*

Introduction

Most of the planet's surface is covered by oceans, and its impact on people, plants, and animals is sometimes underappreciated. The crucial role that the oceans play in the rapidly transforming global climate, has significantly increased the importance of understanding the oceans. For the study of the marine environment, it is crucial to measure the vital physical characteristics of the ocean, such as temperature, salinity, and depth/pressure. The main research instruments for such traits are conductivity, temperature, and depth (CTD) sensors, which provide data on oceanic circulation, mixing, and climatic processes. CTD sensors are crucial ecological instruments that aid in the study of oceanographic phenomena and aquatic species. Small, precise, and low-powered CTD sensors are becoming essential for autonomous instruments like moored buoys, underwater profiling floats, gliders, and autonomous underwater vehicles (AUVs).

The eminent Danish scientist Martin Knudsen developed a key technique for determining the temperature and salinity of saltwater on-site in 1898. He developed a device to monitor salinity and temperature instantly later in 1900. Under the terms of a subcontract with the Woods Hole Oceanographic Institution, A. W. Jacobsen developed the mechanical bathythermograph (MBT) in the 1940s. The MBTs for use on submarines and research submersibles down to 400 meters were improved by Allyn Vine [1-3]. Schiemerm, Pritchard, and Esterson developed an induction conductivity-temperature indicator in the 1950s employing energizing and signal transformers [4]. In 1958, Bruce Hamon and Neil Brown, the fathers of CTD systems designed and developed a temperature-chlorinity-depth recorder for 1000 meters. Through the development of three measuring probes for temperature, conductivity, and pressure for multi-conductor cables, Kroebel constructed the first efficient CTD profilers, often referred to as 'bathysondes', in 1961 [5]. In 1964, the first CTD with electronic components was developed by Neil Brown. He developed an improved contact-type CTD sensor with four electrodes (MK IIIB) to measure four pole resistance in 1970 [6-8]. The practical salinity scale, a benchmark scale, was created in 1978 to clear up the conflicting conductivity-temperature-pressure relationships for seawater [9].

"According to the literature review, developing electronic sensors for maritime applications demands an enclosure that is highly corrosion-resistant, leak-proof, and can survive significant temperature gradients and hydrostatic pressure"

Beginning in 1987, the Mark V CTD was developed to use microprocessor technology, which allowed for the majority of custom adjustments and calibration changes in software compared to hardware, shortening the production process. The adoption of a six-electrode conductivity cell, which offers significantly better stability, is another significant distinction. At one end of the cell, it is responsive to seawater from the outside but not to the seawater within. All six electrodes are inside the cell, remote from its sensitive area. As compared to the Mark III system's sensor, the Mark V CTD's titanium pressure sensor is around three times more precise [10].

According to the literature review, developing electronic sensors for maritime applications demands an enclosure that is highly corrosion-resistant, leak-proof, and can survive significant temperature gradients and hydrostatic pressure. Some steel, aluminium, and titanium alloys are utilized in marine applications; however, aluminium alloys are less strong than steel and titanium alloys in these applications. Despite having a better strength than stainless steel alloys, titanium alloys are more expensive [11]. Stainless steel (SS316) was chosen for this investigation, Because of its resistance to corrosion, better yield strength, and reasonable cost [12-15].

Design Conditions

The input data were used to determine the cylindrical pressure casing's critical dimensions. The design is for 1000 m of seawater depths or 10 MPa of external pressure. The cylindrical pressure shell's internal diameter is 52.5 mm with a thickness of 6.25 mm. The material properties of Stainless Steel (SS316) that were utilized in calculations and finite element analysis are listed in **Table 1**.

Table 1. AISI 316 Stainless Steel Material Properties [20]

Property	Value	Unit
Yield Strength	172	MPa
Tensile Strength	520	MPa
Poisson's Ratio	0.27	-
Modulus of Elasticity	193000	MPa

Analytical procedure

Generally, pressure vessels are constructed in compliance with ASME Code, Section VIII, Division 1 & 2 [16]. Division 1 is designed by rules and does not need a thorough analysis of all stresses. High localized and secondary bending stresses are acknowledged to be possible, but they are compensated for by using a greater design margin and design guidelines for details. However, it is necessary to take into account all loadings i.e., the forces placed on a vessel or its structural attachments [17].

In Section VIII, Division 2 describes the design by rules requirements (Part 4). Though being categorized as design-by-rules, the design margin is less than in Division 1, demanding greater study. Part 4 makes it clear that analysis by Part 5 or design-by-analysis must be carried out if guidelines are not supplied for a specific detail, geometry, or loading. The majority of Part 4 vessels will adhere to both Part 4's rules and Part 5's special procedures. The pressure envelope's load combinations are found in Parts 4 and 5 [18].

The following equation can be used to estimate the stress induced in a cylindrical tube due to external pressure [21].

$$(S)max. = \frac{2 * b^2}{b^2 - a^2}\,(p)$$

where p = external pressure.

b = outer radius of tube.

a = inner radius of tube.

(S)max. = maximum stress induced in the tube.

The external pressure that can lead to elastic buckling of cylindrical tube can be estimated using the following equation [21].

$$p_e = \frac{2 * E}{1 - \mu^2}\,({}^{t}/_{D_0})$$

where = elastic buckling pressure.

E = modulus of elasticity.

μ= Poisson›s ratio.

t = wall thickness of tube.

Do = outside diameter of tube.

The flat circular end caps used in the enclosure design can be considered as simply supported around its edge and the following equation can be used to estimate the stresses induced due to external pressure [21].

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where p = external pressure.

a = radius of unsupported plate.

t = radius of unsupported plate.

m= reciprocal of Poisson's ratio.

(S)max. = maximum stress induced in the tube.

The pressure corresponding to a given sea water depth can be approximately estimated using the following equation [21].

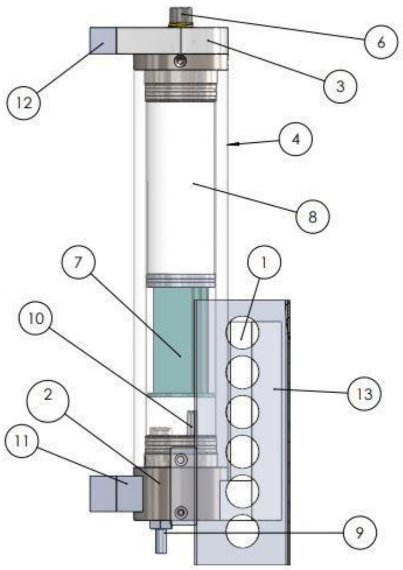
$$p = 0.01 * h$$

where p = pressure in MPa.

h = sea depth in meters.

A better estimation of pressure variation along the sea water depth would need to consider the sea water density variation and compressibility. But, the linear relation between pressure and depth has been used in this study as the error is less that 0.02 of the estimated depth [22].

Design Parameters of CTD Sensor Components



Part No	Part Name
1	Conductivity Probe
2	Upper Cap
3	Lower Cap
4	Outer Cover
5	Sensor Guard
6	Connector - mcbhf5- wb
7	Electronic box
8	Battery box
9	Temperature Sensor
10	pressure sensor
11 &12	clamps

Figure 1. Components of CTD Sensor

Figure 1 shows the assembled view of CTD sensor components. It has twelve elements, including an outside cover, end caps, conductivity probe, electronic parts, etc. that are discussed in subsequent subsections.

4.1 Conductivity Probe

The conductivity probe is fastened to the lower-end cover, which is made of Nylon with copper inserts, using four 3.6 mm screws, one at each corner. The conductivity inserts are mounted to a 24 mm-thick, 150 mm-long hollow bar. The conductivity probe is covered by a protective sheet of an inverted U shape made of SS316 with 6 circular holes on each side, each measuring 25 mm in diameter as shown in **Figure 1.**

4.2 Upper-End Cap

The upper-end cap is constructed in stainless steel (SS316). It has a length of 56mm and a diameter of 65 mm. A hole with a diameter of 24 mm and a depth of 20 mm is intended to accommodate the communication connection. To guarantee leak-proof housing, the diameter is decreased to 12 mm for the remaining depth with two grooves. The end cap's outer flange is 20 mm in length and 65 mm in diameter as shown in **Figure 2.** The machining deviations of all casing components were by Indian Standards (IS: 2102-1). [19]

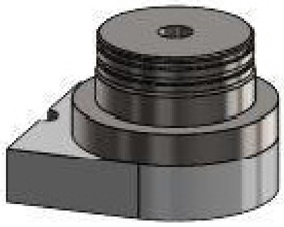


Figure 2. Upper Cap

4.3 Lower-End Cap

The conductivity, temperature, and pressure sensors are mounted on the lower-end cap. It has a length of 64mm and is composed of stainless steel (SS316). The lower-end cap is made with a 65 mm diameter and a 40mm depth to serve as an outside flange as shown in **Figure 3.** To guarantee leak-proof housing, the remaining piece is reduced to a diameter of 52.5mm with two grooves. There are two holes: the pressure sensor is placed in the first hole, which has a diameter of 13 mm and a length of 52 mm. A temperature sensor is placed in the second hole, which has a 13mm diameter over its entire length. A pinhole of 4 mm in diameter and 5 mm in depth is used to attach the conductivity probe to the bottom cover.

Figure 3. Lower Cap

4.4 Outer Cover

The safety of sensors and sensor electronics depends heavily on the outside cover. The stainless steel (SS316) exterior cylindrical enclosure of the CTD sensor has a thickness of 6.25mm and an overall length of 300mm as shown in **Figure 1.** To create a leak-proof casing, the top and bottom sections of the cylinder are composed of two grooves for seating O rings. With a tolerance of 0.01mm, the first and second grooves along the cylinder's length are each 0.5mm and 0.75mm deep. To guarantee the proper fit of the top and bottom caps, both grooves create an angle of 110º and 135º degrees with the horizontal in a counter clockwise (CCW) direction as shown in **Figure 4.**

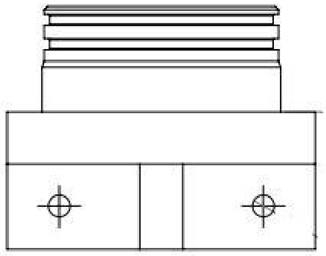


Figure 4. Groove on the End Caps

4.5 Temperature Sensor Housing

The housing has an overall length of 37mm and is constructed of stainless steel (SS316). The thermistor bead is intended to be housed by a 3.2 mm hole that is 35 mm deep in a bar with a 6 mm diameter and a 12 mm flange diameter.

4.6 O rings and Clamps

O rings are mostly used to stop fluid leaks. The three types of O rings employed in the design of CTD casing are as follows:

1. Upper and Lower End caps – Parker 2-033
2. Sea Surface Temperature casing – Parker 2-013
3. Conductivity Probe Fixture - Parker 2-012

To attach the CTD sensor, two nylon clamps with 20 mm thickness are attached to the top and lower caps.

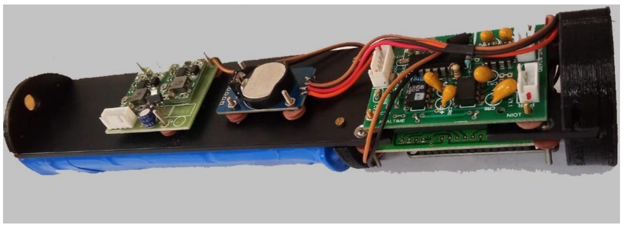


Figure 5. PCB and Battery Pack

Internal PCB & Battery Pack mounting setup

The internal PCB's configuration for data collection, storage, and transmission from the sensors is shown in **Figure 5.** The battery pack is placed on the other side of the high-density polyethylene (HDPE) divider from where the PCD is mounted.

Finite Element Analysis

Figure 6 depicts the 3D model of the CTD sensor enclosure with end caps. Solid elements are generated using an improved blended curvature-based mesher with 16 Jacobian points to ensure the high-quality mesh is used for simulations. Solidworks® 2021 simulation software package is used for the analysis. The bottom nodes of the lower-end cap are fixed in all directions, and all other faces of the model are subjected to a uniform 10 MPa pressure. A stress analysis is conducted based on the SS316's yield strength and the von-mises stress at hydrostatic pressure.

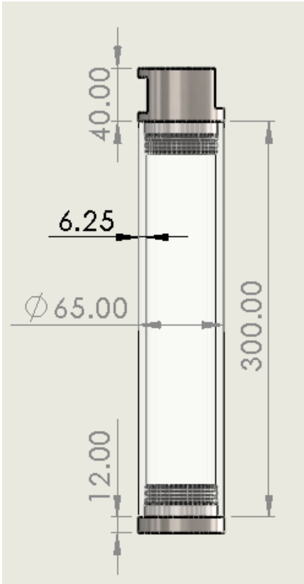


Figure 6. 3D Model of CTD Sensor with End Caps

Mesh/grid independence study was carried and the mesh was optimised accordingly. The details of the mesh and nodes has been presented in **Table 2.**

Table 2. Mesh information

Mesh type	Solid Mesh
Mesher Used:	Blended curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	8.12687 mm
Minimum element size	0.406343 mm
Total Nodes	667663
Total Elements	432364
Maximum Aspect Ratio	7.873
% of elements with Aspect Ratio < 3	97.4
Percentage of elements with Aspect Ratio > 10	0
Percentage of distorted elements	0

Hydrostatic Pressure Test – Hyperbaric test facility

In the hyperbaric chamber, the CTD sensor enclosure is hydrostatically loaded up to 12 MPa and tested for leak resistance. **Figure 7** shows the applied load's time step. The operating pressure and temperature of the hyperbaric chamber are 90 MPa and 4.5° C to 50° C, respectively, and it is constructed of steel alloy SAE Grade 3 Class 2 is shown in the **Figure 8.**

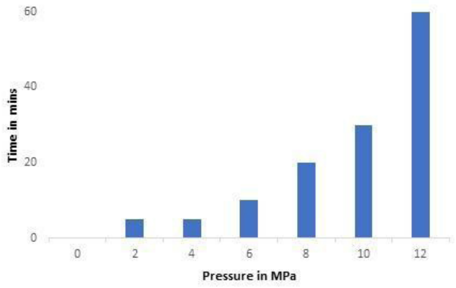


Figure 7. Time Step of Applied Load

Figure 8. Hyperbaric Test Facility

Results and Discussion

The outcomes of the finite element analysis of the CTD sensor enclosure are shown in **Figure 9.** The optimal thickness among the cylindrical shell's four variables is determined through analysis. The finite element results for various shell thicknesses are shown in Table 3.

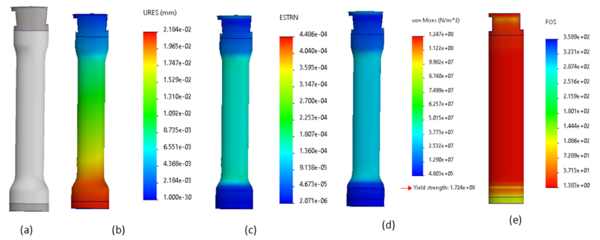


Figure 9. a) Deformed Shape scale (1600) (b)Displacement (c) Strain (d) Stress (e) FoS

Table 3. The factor of safety for various shell thickness

Shell Thickness (mm)	Displacement (mm)	Strain	Von-mises Stress (MPa)	Factor of Safety FoS
5	0.04	0.0005	$1.726*10^2$	1.02
5.25	0.038	0.00046	$1.518*10^2$	1.14
5.5	0.035	0.00041	$1.263*10^2$	1.37
5.75	0.033	0.00038	$1.138*10^2$	1.52
6	0.030	0.00033	$1.062*10^2$	1.63
6.25	0.028	0.00032	$1.012*10^2$	1.71
6.5	0.023	0.00024	$0.967*10^2$	1.79
6.75	0.019	0.00019	$0.951*10^2$	1.82
7	0.016	0.00016	$0.920*10^2$	1.88

Figure 10 shows the analysis's displacement results, which follow a linear pattern for different thicknesses. It is found that a slight difference in the linear pattern affects the strain value when the thickness is between 6 and 6.5 mm.

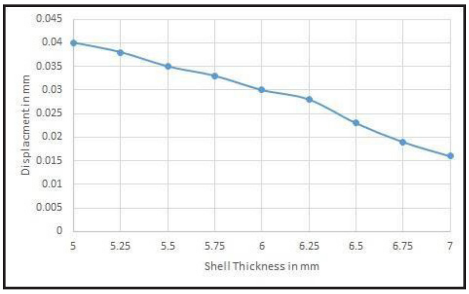


Figure 10. Displacement for different shell thickness

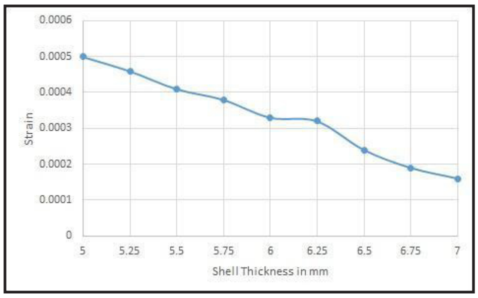


Figure 11. Maximum strain for different shell thickness

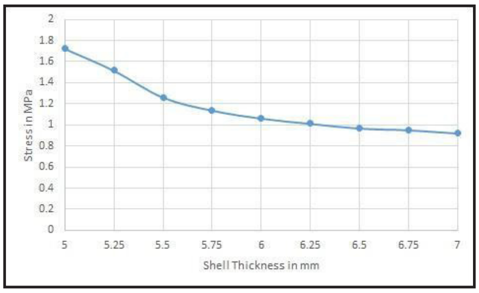


Figure 12. Maximum Von-mises stress for different shell thicknesses

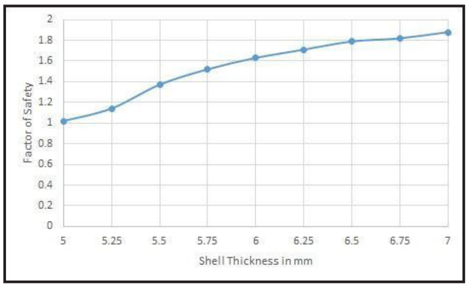


Figure 13. The factor of safety for different shell thickness

As seen in **Figure 11**, the maximum strain caused also follows a linear pattern in various thicknesses. It should be observed that the strain between 6 and 6.25 mm is nearly the same despite the slight slope deviation. **Figure 12** shows that the slopes of the von-mises stress plot are higher up to a shell thickness of 6 mm and become linear thereafter due to a minor fluctuation in the stress values. **Figure 13** shows that the factor of safety for the CTD enclosure varies with a steep gradient up to 6 mm and

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Conclusion

The CTD sensor enclosure is constructed with a wall thickness of 6.25 mm with end caps based on the findings of the finite element analysis and is tested in a hyperbaric chamber up to 12 MPa in a time step as indicated in **Figure 7 and Figure 8.** The constructed enclosure had successfully survived the hydrostatic time loading. **Therefore, it is possible to conclude that the design is robust down to 1,000 meters of seawater depth.** The weight-to-strength ratio may be improved by using Titanium or other non-corrosive materials as an alternative to SS316, but that may lead to an increase in material and machining costs.

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About the authors

Dr. R. Srinivasan is currently a senior scientist in National Institute of Ocean Technology (NIOT), Earth System Science Organization (ESSO), Ministry of Earth Sciences, Govt of India. He is the technical lead for the indigenization of Drifting Buoys with INSAT Communication, Development of capacitive coupled noncontact type conductivity measurement scheme in CTD sensor and Adapting Drone Technology for Ocean Observation Applications. He received his B.E. from the Bharath Institute of Science and Technology, Madras University, Chennai, India in 1998 and Ph.D. degree in Electronics and Communication Engineering from VISTAS, Chennai, India in 2022. He is consistently working on the development of ocean observation technologies and systems in the last two decades. He is member in IETE-India, Instrumentation Society of America (ISA), OSI-India and Board of Studies - VISTAS, Chennai and Drone Federation of India. He has published more than 30 peer reviewed articles in indexed National/International journals and he was granted with 3 Indian patents. He worked at Kaleesuwari Refineries Limited before joining NIOT. He is researching in areas such as indigenization of new Ocean observation systems and Technologies, sensors, Instrumentation and high resolution measurements.

Email: rsrinivasan.niot@gov.in

Dr. S. Yuvaraj, born in 1990, received his B.E. Mechanical Engineering (2011), and Master's degree in Engineering Design (2013) from Anna University, Chennai, India. He completed his PhD (2020) in the field of Robotic Gripper Design at Anna University. He has published 10 Journal articles (peer reviewed) and presented 12 papers in National/International Conferences. He also works as Project Scientist II in National Institute of Ocean Technology, Chennai, Tamil Nadu, India.

Anand Kishor received his B.Tech in Mechanical Engineering from the Institute of Technology, Guru Ghasidas Central University, Chhattisgarh (2013) and M.Tech in Thermal Engineering from the Indian Institute of Technology, Madras (2022). Currently, he is pursuing a Ph.D. at the Indian Institute of Technology, Madras in the field of Ocean Thermal Energy Conversion using Ocean Vertical Temperature with the help of suitable Phase Change Material for underwater ocean observation vehicles viz. ARGO floats, gliders, etc. He is working as Scientist D at the National Institute of Ocean Technology, Chennai. He has over a decade of experience in marine technology development. His areas of interest are the development of technologies for harnessing ocean resources and energy, viz. open-sea fish cages, thermal engines for underwater ocean observation vehicles, underwater vehicle dynamics, etc.

Dr. Tata Sudhakar received his M.Tech. (2004) and Ph.D. (2021) degrees in Electronics and Communication Engineering from Sathyabama University, Chennai, India. He was headings the technology division groups such as Ocean Electronics and Ocean Observation Network at National Institute of Ocean Technology. He received the National Geo Science Award for excellence from Ministry of Mines, Govt. of India in 2013, the recipient of Best Scientist award from Ministry of Earth Sciences, Govt. of India in 2016 and IETE – Thoshniwal Award in 2017. He has published over 30 Journal articles (peer reviewed) and presented over 60 papers in National/International Conferences. He has granted with 5 Indian patents. He had 15 years of Oceanography experience in National Institute of Oceanography prior joining NIOT. His areas of interests are development of new innovative technologies towards ocean applications, sensors, and Instrumentation.

Green Initiatives in Inland and Coastal Transportation

Sudeeptho Ghosh

Abstract

The impetus on green technology has gained tremendous significance worldwide since the Global warming has been recognised as a dominant threat to the community. International efforts to address this problem have been ongoing for the last two decades with countries across the world contributing their bit through common forum known as United Nations Framework for Climate Change Convention (UNFCCC). The inland and Costal Transportation has received little attention in sustainability transition research. This sector is mature and heterogeneous, which suggest the need for a more nuanced perspective on socio-technical regimes to understand variations in conditions for adoption of novel technologies that may support sustainability transitions. The current paper brings out the history of Global Warming, International efforts towards climate change, Gap analysis in Inland and Coastal Transportation Toward Green Initiatives, various climate prevention measures adopted across the globe, details of green initiatives undertaken by world, Hull, Engineering and Electrical Initiatives Toward Go Green Mission. Finally, the paper list down recommendations and way ahead to take forward 'Green Mission' with induction of New Technology.

Given the current GHG concentrations and ongoing emissions, an increase in average global mean temperature by 1-2 degree Celsius and sea level rise by 40 – 63 cms by the year 2100 is expected

Introduction

Climate change concerns have brought energy and environment sustainability to the forefront of global discourse. The current global warming trend is of particular significance as it is human induced and increasing at an alarming rate. It, therefore has emerged as one of the biggest challenges that the world is facing today, a challenge that can only be mitigated with some all-inclusive efforts. The dependence on conventional energy sources has led to a sharp increase in the demands for fossil fuels across the globe; leading to the emissions of green house gases in abundance. As a result, Global Warming has been recognized as a dominant threat to the community. The increased quantity of GHGs post industrialization has resulted in increase in average global temperature, average sea level and shrinking of ice in Arctic. Given the current GHG concentrations and ongoing emissions, an increase in average global mean temperature by 1-2 degree Celsius and sea level rise by 40 – 63 cms by the year 2100 is expected [1].

In order to alleviate the global issue, United Nations Framework convention on Climate Change (UNFCC) with an objective to "Stabilize GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" was set up at Earth Summit in Rio-de-Janeiro in 1992 [2]. The framework, however, did not contain any enforcement mechanism or set a binding limit on GHG emission. This was followed by Kyoto Protocol which came into force on 16 Feb 2005 and put legal binding obligations for member countries to reduce their GHG emissions by 5.2% below their 1990 levels. The protocol first commitment period started in 2008 and ended in 2012, second commitment period was agreed on in 2012 (Doha Amendment).[3] Another instrument under UNFCCC was adopted in Dec 15 known as 'Paris Agreement' with a sole aim to keep the rise of global temperature below 2 degree Celsius.[4]

Over energy, food and transportation since last two decades socio-technical system perspectives have risen to prominence in unpacking and explaining the complex challenges. This 'sustainability transitions' literature comprises a set of key approaches or perspectives, including the multi-level perspective and the technological innovation systems approach. In the realm of transport, sustainability transitions research has mainly devoted attention to innovation and change related to automobiles and personal mobility. More recently, however, sustainability transition scholars have begun to address sustainability transitions also in shipping. The main aim of the paper is to portray the need for Green Initiative in Inland and Coastal transportation and the new technologies which can be adopted for implementation of the Green Imitative.

Theoretical Framework. An Inspiration drawn from Turnheim and Nykvist (2019, 780), who suggested a set of key conditions "under which the realisation of transitions pathways may become more feasible, in terms of the critical real-world constraints at play and the specific hurdles and requirements that may be anticipated." These are maturity of options, system integration and infrastructure, and political and social feasibility, which are arguably generic features of socio-technical perspectives on sustainability transitions. While the original focus of this framework is to assess the feasibility of different potential transition pathways in a sector, we use it to assess the influence of task and institutional environments on the conditions for realizing one specific pathway (battery-electric technology) in different user segments (ferries, offshore supply and fishing) in the same sector (coastal shipping).

Technology maturity/fit. The first dimension introduced by Turnheim and Nykvist (2019) is "maturity of options". They argue that it is critical to consider the readiness and commercial availability of an innovation at a particular point of time, as well as its current development trends.

In this paper, we focus on key aspects of maturity as perceived by potential users when faced with a new technology, such as whether the technological option has matured enough to perform as needed, whether supply chains are in place so that 'off-the-shelf' solutions are available commercially or if adoption would imply becoming involved in experimental activities, if there are particular technical risks that users need to handle, and if the users' customers demand or incentivize technological change.

System integration and infrastructure. The second dimension highlights the importance of integrating new technologies in existing systems and infrastructures, through adaptation of the former and/or transformation of the latter.

We take this to imply that new technologies need to be able to access – and be compatible with – existing socio-technical systems in the entire value chain, stretching from the sourcing of natural resources, via production and distribution, to use.

For example, in the case of electrification of shipping (or transport in general), this relates to system integration of ships with the energy production and distributions side (potentially including storage) in grids and charging devices. Since operating conditions differ between segments, the availability and accessibility of suitable systems and infrastructures are likely to differ as well. Moreover, we expect that users within different segments will be in different positions with regards to financing and implementing large-scale infrastructure investments.

For example, in the case of electrification of shipping (or transport in general), this relates to system integration of ships with the energy production and distributions side (potentially including storage) in grids and charging devices

Acceptability and legitimacy. The final transition condition combines two of the feasibility dimensions:

(a) Social acceptability

(b) Political feasibility

Social acceptability highlights the importance of considering "issues, controversies, or anxieties with the expected deployment and use of any particular option" among the general public, including perceived desirability and legitimacy of the technology and the actors advocating and implementing it.

Political feasibility refers to "the likelihood of decisions supporting a particular path to become implemented, or conversely of obstacles that may result from the resistance of particular actors", where decisions could, for example, include public innovation and transition policies. Bringing these two dimensions together, we conceptualize "acceptability and legitimacy" as different types of implicit and explicit collective commitments to and acceptance of a particular technological option in relation to specific user segments. In transport, a well-known legitimacy issue is, for example range, anxiety for battery-electric vehicles, which is less of a problem in urban than rural areas. Another aspect that may suggest variety between segments for instance in transport relates to whether or not transport/logistics companies serve customers in other sectors with strong or weak pressures to reduce

their overall carbon footprint, thus potentially providing legitimacy to LoZeC solutions in general but no clear direction in terms of technology choice.

India and Climate Change. To address the issues pertaining to the climate change, Government of India had launched National Action Plan on Climate Change (NAPCC) in Jun 2008 with eight "National Missions" [5].

(a) Jawaharlal Nehru National Solar Mission (JNNSM).

(b) National Mission for Enhanced Energy Efficiency (NMEEE).

(c) National Mission on Sustainable Habitat (NMSH).

(d) National Water Mission (NWM).

(e) National Mission on Green India.

(f) National Mission on Sustaining Himalayan Ecosystem (NMSHE).

(g) National Mission on Sustainable Agriculture (NMSA).

(h) National Mission on Strategic Knowledge for Climate Change

Gap Analysis in Implementation on National Missions. India's NAPCC is considered to be very ambitious. The implementation of the plans, however, requires various gaps to be fulfilled in order to make it a success. It is opined that there would be profuse finance required for execution of the plans. While some financial support has been assured by International organizations, the deficit will have to be met from own GDP and hence government will have to prioritize between economic development and climate change. Another gap envisaged is availability of technology. The global technologies available in renewable energy resources such as ocean energy, tidal energy, etc. are not available in the country and hence will have to depend on foreign players for the same. Lack of knowledge on impact of climate and which action would specifically affect mitigation efforts is also considered to be lacking at the local level. The above, factors would significantly affect the implementations of the plans and hence various factors such as reforms of existing policies, seeking more international climate fund and coordination with other foreign countries will have to be considered by the government in order to achieve the set targets.

Green Initiatives – World

United States. The United states is actively developing and participating in energy, environmental and climate change initiatives towards use of alternative energy and conservation of world resources. During the Rim of the Pacific (RIMPAC) exercises in the year 2020, the entire fleet of the USS war ships were known as "Green Fleet". This was achieved by the US solely by using alternative fuel, either nuclear or advanced bio-fuel blends. Almost all the Inland and Costal transportation vessels used in US are using these fuels as Green Initiative which was launched in the year 2016 [6].

Australian fleet. Australian fleet of the IWT and costal transportation has defined its Estate Energy Strategy to manage its energy requirements and implement energy saving initiatives across the wide range of assets and activities. The strategy caters for improving the efficiency of existing assets and equipment, providing efficient new infrastructure and equipments, using energy renewable and alternative sources and driving energy saving behaviour. Australian oil company Southern Oil Refining has built a plant at Gladstone, Queensland to produce 200 million litres of advanced bio-fuel annually suitable for marine, military and aviation use [7].

Japan. Japan has implemented the green initiatives program by partnering with US for supply of bio fuel [8].

Inland and Costal Transportation. Water Transport in India has played a significant role in the country's economy and is indispensable to foreign trade. India is endowed with an extensive network of waterways in the form of rivers, canals, backwaters, creeks and a long coastline accessible through the seas and oceans. It has the largest carrying capacity of any form of transport and is most suitable for carrying bulky goods over long distances. It is one of the most cheap modes of transport in India, as it takes advantage of natural track and does not require huge capital investment in construction and maintenance except in the case of canals. Its fuel efficiency contributes to lower operating costs and reduced environmental impact due to carbon. India has 14500 km of inland waterways. Out of which only 5685 km are navigable by mechanized vessels.[9] Globally, many countries are dependent heavily on coastal and inland transportation for cargo movement as the movement is cheaper, reliable and less polluting compared to other modes, such as road or rail. India is yet to fully tap and extract the maximum potential of these green and cheap transport modules as bulk of the inland movement is still happening by roads increasing the overall ownership experience and the load on the road transport network impact adversely on the costs per ton moved.

Green Initiatives in Hull Design. The green initiatives during ship building can go a long way by adopting energy efficient equipments for new construction Inland and Costal transportation. The concept of green ship building is being adopted worldwide now to cater for climate change and growing energy needs. Technologies such as variable frequency drive motors, exhaust gas recovery system, solar and fuel cells, exhaust gas scrubber system, optimum design of cooling water system etc. are available towards reduction of emissions and improving energy efficiency. The technologies have proved to be successful and hence can be implemented in new construction sea ways transportation. The initial cost of the technology is observed to be high, however, considering the ships life of 25-30 years, the cost can be easily recovered with an added advantage of huge reduction in carbon footprint of the ship. Another aspect that can be considered during the construction phase of these transportation vessels is reduction of appendages.

(a) Large Diameter Propellers. Propeller diameter increases with the size of the ship. As the diameter increases, the blades of the propeller offer more resistance to travel through the water. This creates potentially damaging drag on smaller engines, for larger ships, a larger diameter provides more propulsion power for the given engine and RPM. Apart from improved propulsive efficiency, if it is axially moved aft wards, improvement of other factors such as hull efficiency, suction on the hull and wake profile can be gained. The increased clearance reduces the pressure pulses transferred to the hull.

> **With the application of the twisted rudder concepts in Inland and Costal transportation the owners/company can save an approx 2.39 % on fuel consumption**

(b) Fitment of ships with bulbous bows. A bulbous bow can reduce a ship's wave making resistance thereby increasing its fuel efficiency. The technology is widely used on merchant ships as it typically reduces the fuel consumption [10] by about 5 % at cruising speeds. Post a large number of the experiments with refinement of bulbous bow design for calm and rough seas, the United States has retrofitted its Arliegh Bulk destroyers with Bulbous bows and claims to save approx 3.9% in its annual fuel consumption. A large number of studies and model experiments have proved this to be a successful design for improvement of fuel efficiency of the ships.

(c) Stern Flaps. A stern flap is a relatively small plate that extends behind a ships transom, lengthening the bottom surface of the hull. The flap is mounted to the transom at an angle relative to the centre line of the ship. The flap creates a vertical lift force at the transom, and modifies the pressure distribution on the after portion of the hull. The pressure distribution in turn leads to the principal performance enhancement on a displacement hull. It causes the flow to slow down under the hull at a location extending from its position to a point generally forward of the propellers. This decreased flow velocity causes an increase in the pressure underwater hull, which in turn reduce the ship's resistance and increase fuel efficiency ([11]).

(d) Hull and Propeller coatings. Hull fouling increases the frictional resistance of ships and raises the power requirements, there by increasing the fuel consumption. The present long lasting paint scheme used onboard ships is silicon based, low surface energy coating wherein the fouling organisms stick to the top coat and get washed away by hydrodynamic shear forces while underway rather than their eradication as was done earlier. The surface properties of the coating make it difficult for bio fouling to adhere too tightly and hence the bio fouling gets washed away when the ship is underway ensuring smooth hull and propeller. The coating on propeller is claimed to increase the propulsive efficiency by 5% only. The additional benefits include reduced wear/tear of the paint and lower maintenance.

(e) In-water survey of Hull. The in-water survey is undertaken by the divers visually wherein condition of the paint film, structural condition etc are checked. Hand held USG gauges may also be used for the survey. The entire underwater hull survey process is recorded and is submitted to the class for survey. These results of in-water survey increase the life cycle cost of the ship and is also a green initiative to increase the operationalization of the sea transportation to a larger extent.

(f) Twisted Rudder. A Twisted Rudder (TR) is a type of full-spade rudder with upper and lower sides that are designed asymmetrically to consider the wake inlet angle of the propellers [12]. With the application of the twisted rudder concepts in Inland and Costal transportation the owners/company can save an approx 2.39 % on fuel consumption. This concept of Twisted rudder is a green initiative from the transportation of the goods and services by Inland and Coastal transportation.

(g) Contra- Rotating Propellers. A rotating propeller induces a rotating motion in its wake, which reduces the efficiency of the propeller. In order to recover this energy, two propellers behind each other are used on concentric shafts, also called Contra-Rotating Propellers. The two propellers rotate in opposite directions. The pitch and loading of the two propellers are designed such that the resulting rotational energy in the wake is zero.

(h) Wake adapted Propellers. Most common propeller design methods use the series propeller data to design the propellers. These propellers are then modified to match the engine specifications by means of well-established engine propeller matching to attain the perfect balance. However, the shape of the hull modifies the wake field in the aft region, which disturbs this balance thereby reducing the efficiency. A custom propeller can then be optimally designed to match the unique in flow properties of the vessels.

Engineering Initiatives. The greatest contributor of environmental pollution on a ship is the engine room wherein machinery present utilizes fuel and release CO, SOx, and NOx by burning marine fuels. In accordance with MARPOL regulations (Annex VI amendments) w.r.t Sulphur in fuel content, NOx emission, EDDI and SEEMP has been laid down and the ship builders are adhered to follow these regulations. The important Engineering technologies w.r.t Green Initiatives in Inland and Costal Transportation are: -

(a) Design/ Selection of Engines. Green ship of the future projects should focus on optimizing efficiency of the engine in order to reduce emissions. More precise and flexible technology promises significant energy savings. Auto-tuned engines and optimized low speed marine engines replace infrequent, manual adjustments with ongoing electronic ones. They potentially reduce fuel consumption by up to 3 % by constantly adjusting to factors like engine load and operating conditions [13]. This kind of innovation has also adapted Selective Catalytic Reduction (SCR) systems to marine engines. The SCR prototypes achieved an 80 % reduction of NOx emissions over the same engine without SCR.

(b) Fuel. The Green initiative in Inland and Costal transportation seek both immediate and long term solutions to reducing fuel consumption. Frequent, onboard fuel composition analysis on existing ships can help to reduce especially SOx emissions. At the same time, researchers are exploring liquid natural gas (LNG) as a future alternative fuel. For instance, it has been shown that a high speed ferry by moving from diesel to LNG can cut CO2 emissions by 25 %, NOx by 35 % and eliminate SOx emissions completely. When moving from heavy fuel oil to LNG the reduction of NOx emissions can naturally be significantly higher, possibly 85-90 %. Bio diesel implementation should be followed rigorously and the transporters should set targets progressively for replacing the diesel with bio fuel [14]. An impediment here could be high cost of bio diesel, however, it is opined that the same can be offset with the mass production. It is also proposed that the government should make this a thrust area and get private players into production of bio diesels to cater for some future requirements.

(c) Waste Heat. As a part of the green initiative the transporters should develop ways to recover wasted heat either as electrical power or use it to heat up cargo areas. Committed to practical, feasible solutions, members have focused on how to install Waste Heat Recovery/Utilization systems while retaining the ship's basic design. Fuel accounts for a very large part of a ship's operating costs. Reusing the waste heat from engines to heat up cargo areas can save up to 20 % of a ship's total annual fuel consumption, thereby reducing CO2 emissions and saving fuel costs. Also, studies show that recovering waste heat as electrical power can save up to 8 tons of fuel oil per day for a tanker that would normally use 42 tons per day. In tests, emissions were reduced up to 14 % by recovering otherwise wasted heat as electrical power [15].

(d) Hybrid Electric Device (HED) Propulsion. The hybrid propulsion approach therefore, takes advantage of both the electrical propulsion system since it is more efficient to operate at lower ship speed/power levels where a larger mechanical propulsion system is less efficient and the mechanical propulsion system because it is designed to meet maximum ship speed and is more efficient at higher ship speed/power levels and requires less cost, space and weight than an electrical propulsion system. The premise for a practical hybrid ship propulsion system application it must be affordable, fit within the ship with minimal machinery space arrangement impact and be capable of at least providing basic steerage speed with some margin to address additional power necessary for a fowled hull and sea state conditions including current wind and shallow water drag [16].

> *SSL refers to the type of illumination that uses light emitting diodes (LED) as source of solution rather than electrical filament, plasma or gas. LEDs emit visible light when DC current is passed through them*

Electrical Initiatives. Following areas of green ship initiatives have been identified for usage/implementation onboard for future construction of inland and coastal transportation.

(a) Solid State Lightning. SSL refers to the type of illumination that uses light emitting diodes (LED) as source of solution rather than electrical filament, plasma or gas. LEDs emit visible light when DC current is passed through them. The fixtures of these lightning are designed to use numerous small, point source LEDs in place of an incandescent or fluorescent light. Integral to the SSL fixture is a driver circuit that converts AC to constant DC power. The inland and coastal transport ships can use incandescent and tube light fixtures with an average of 60W and 40W power consumption per fixture respectively.

(b) Shipboard Energy Storage Bank. An energy storage module, which is essentially a large UPS, installed onboard ships will provide more efficient energy management by providing a reliable backup power. The implication of this technology is used where the ships are equipped with two DGs and the total load of the ship can be utilized by single DG set, thus resulting in under loading and in-efficient use of generators.

(c) High Efficiency Motors and Variable Speed Drivers. The most popularly used motors onboard the inland and coastal transportation are the AC motors, which accounts for almost 50-60 % of power supply load. The popularity of 3 phase induction motors onboard ships is because of their simple, robust construction and high reliability factor in the sea environment. A 3 phase induction motor can be used for various applications with various speeds and load requirements. 3 phase induction motors are used in almost all pumps, all engine room auxiliaries etc. These motors run at a constant designed speed and doesn't

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change with the load hence resulting in wastage of power, which can be avoided with the more advanced motor variants such as Variable Speed Drives (VSDs) or Variable Frequency Drives (VFDs) [17].

(d) Improving HVAC efficiency. The HVAC can be improved onboard the ships by adoption of below mentioned technologies.

(i) Intermediate temperature cooling loop for electronics and equipment.

(ii) Demand control Ventilation.

(iii) Dedicated Outdoor Air system with Energy recovery.

(iv) Radiant Heating and Cooling.

(v) Magnetic Bearing Compressor

Energy Conservation Awareness and Awards. The energy conservation awareness is the key in progressing with our green initiatives. A large number of measures are already in place such as environment week, costal clean up day etc. However, it is opined that none of these measures actually relate to the energy conservation on ships. Hiring of the consultants can be looked into and these consultants can go into the ships for increasing the awareness. Also, Inland and Costal transporters can look into incentives for energy conservation in form of a trophy or monetary award or incentives for ship achieving the best results.

Recommendation and Way Ahead for the Green Mission. The sustainable development with the clean energy is the need of the hour, especially for an Indian environment. While a large number of initiatives are in progress in line with the National Mission, the efficiency in fuel consumption by the ships would be a big boost to the effort. Further, majority of the energy issues can be addressed by identifying and implementing, future technologies for reducing fuel consumption, producing useful alternative fuels and achieving efficiency in operations. By implementation of Energy Dashboard that provides a real-time assessment of energy usage and recommends actions to be undertaken to reduce the fuel and electrical power consumption. Although the ships total load can be monitored, individual load of equipment is not displayed to the user and may be measured using conventional methods. The process is cumbersome and require human effort for monitoring of individual equipment load. The instant system can overcome the above challenges by providing real time energy consumption of running equipment.

CONCLUSION

The green initiatives program in India towards Inland and Costal transportation is presently at nascent stage and much is desired to be achieved. With the world pressure mounting and scarcity of energy resources the clear way forward is use of alternative fuels and energy resources, thus reducing the dependency on fossil fuels, adoption of energy efficiency in equipment procured at the time of ship building/construction. The progress in this area can be achieved more effectively through greater cooperation among the Industry, academia, research institute and business organization supported by the budget. A detailed analysis is required to be undertaken vis-à-vis balance life of the ship and the technology being inducted to ensure sustainable development.

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

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About the author

Commandant (JG) **Sudeeptho Ghosh** is an alumnus of 12th Indian Naval Academy Ezhimala and has pursued M. Tech in Technology Management from Defence Institute of Advanced Technology, Pune. The officer joined Indian Coast Guard on 03 Jan 2011 and has served on board both Fast Patrol Vessels and Offshore Patrol Vessels in Coast Guard Ships. Some of his key appointments include Technical Officer of ICGS Akkadevi and Rajshree, Senior Engineer Officer of ICGS Samarth, Engineer Officer of ICGS Vishwast, and District Technical Officer (Goa). The Officer is presently posted at Coast Guard Regional Headquarters, North East Kolkata as Regional Technical Officer Refit and Officer in charge Local Procurement Cell. The Officer is also an alumnus of Naval War College and has successfully completed Post Graduate Diploma in Business Management from Jamna Lal Bajaj University, Mumbai and Master of Arts in Maritime Management from University of Mumbai. The Officer is presently pursuing Doctoral Degree (DBA) in Maritime Studies from Swiss School of Business Management, Geneva. The Officer has published Nine papers in Indian journal magazines while pursuing M.Tech in the year 2015-17. Further, for his outstanding academic in M.Tech, the Officer was awarded with Gold Medal from Shri Late Arun Jaitley, ex-Finance Minister of India in the year 2017.

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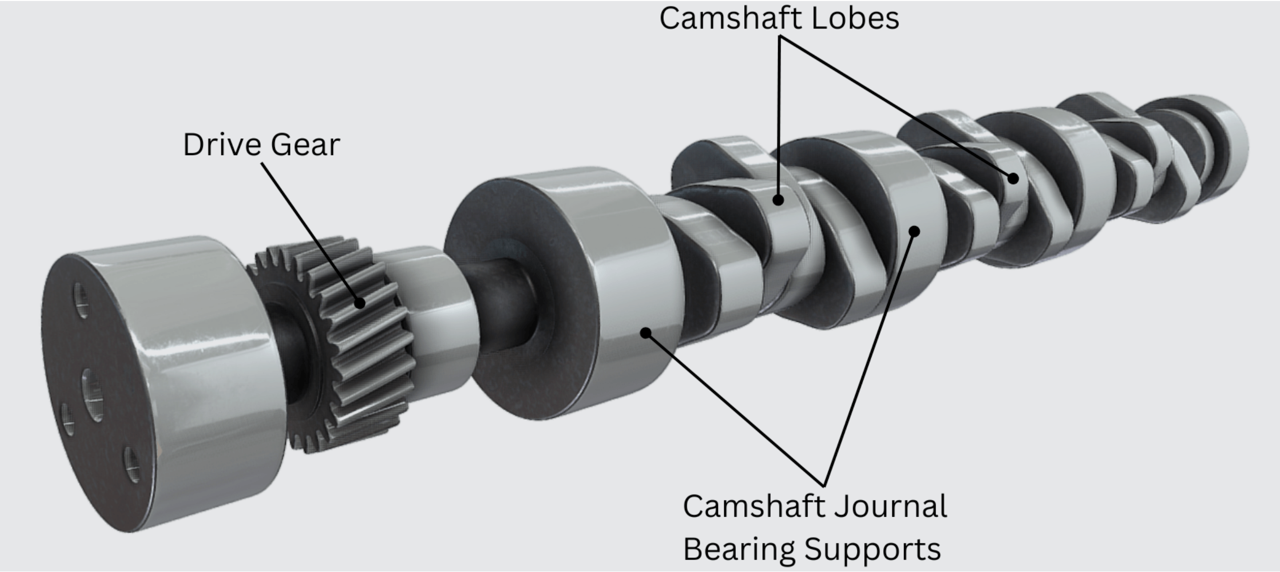
LUBE MATTERS # 27

TRIBOLOGY OF MARINE DIESEL ENGINE COMPONENTS IV: VALVE TRAIN AND CAMSHAFT



Introduction

Poppet valves are commonly used to control the gas flow in internal combustion engines. Cams are used to provide the desired motion to the valves. The flow of the gases past the valves during the intake or exhaust strokes of the combustion cycle expose valves to elevated temperatures, corrosive gases, and high stresses from firing and seating.

Valve Train Design and Components

In many current 4-Stroke engine designs, there is one cam piece for each cylinder with separate bearing pieces in between. The cam and bearing pieces are held together with flange connections. This allows removing of the camshaft pieces sideways. The drop forged completely hardened camshaft pieces have fixed cams. The camshaft bearing housings are integrated in the engine block casting. The movement of the cams is transferred to the valve stem through the cam follower, pushrod, and rocker arm. The stem guide block is integrated into the cylinder head block. The valve tappets are of piston type with self-adjustment of roller against the cam to give an even distribution of the contact pressure. Double valve springs make the valve mechanism dynamically stable. The camshafts are driven by the crankshaft through a gear train **(Figure.1).**

Figure. 1. Sketch of overhead valve type valve train system (1)

Valve Wear

Valve/valve seat wear has been a significant issue for OEMs and users for a long time. New materials have been frequently developed for these components. However, increasing power demands from engines; combined with trends towards lower oil consumption; lower emissions; reduction in sulphur content in fuel; and introduction of corrosive fuels such as gases; have usually outpaced the improvements brought about by new materials.

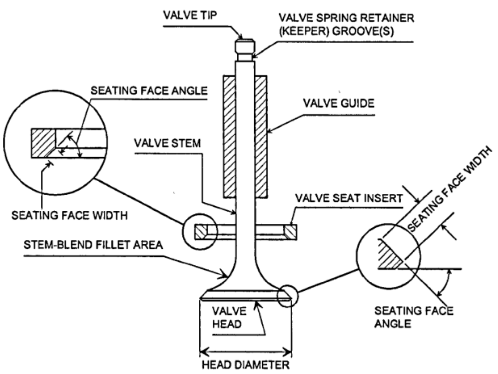


Figure. 2. Valve and Seat insert terminology (2)

An important mechanism causing valve and seat wear is the impact of the valve closing on the seat. The profile of the cam and its follower defines the theoretical valve motion. The motion is further influenced by the stiffness and damping of the springs, and the frictional behaviour of various elements of the valve train. Wear in known to increase with valve closing velocity. Valve "bounce" can occur if the impact velocity is too high or if the valve spring stiffness is too low **(Figure. 3).**

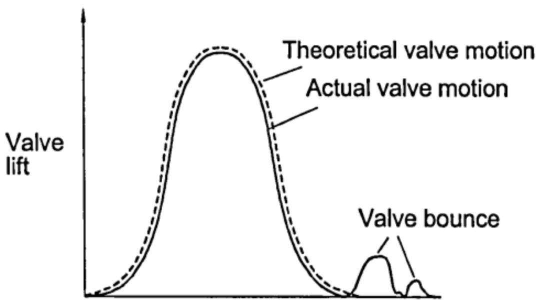


Figure. 3. Theoretical and actual valve motion (2)

Another major cause of wear is the sliding of the valve in the seat. During each ignition/combustion event, high stresses are imposed on the combustion side of the valve head. These stresses are proportional to the peak combustion pressure.

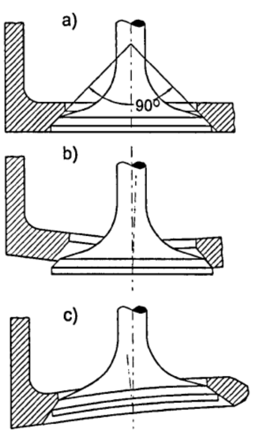


Figure. 4a. Deformation of cylinder head bottom and valve due to combustion pressure (a) valve seated in plane cylinder head bottom; (b) downward bottom deflection, valve making one sided contact; (c) upward bottom deflection and bending of valve disc under gas pressure (3)

Figure. 4a-4b: The valve head and cylinder head bottom deflect under these high pressures, resulting in movement between the valve and the valve seat in the cylinder head. This relative motion results in fretting between valve and seat.

Lubrication of the valve/seat interface reduces wear significantly. However, in modern engines the lubrication of valve stem is just sufficient to lubricate the valve guide and barely any oil makes it to the valve seat, **Figure.11.** As a result, the inlet valve can be easily damaged if fretting is excessive. The exhaust valve seat gets coated by oil mixed with the exhaust gases and, hence, fretting wear is controlled to some extent.

Other causes of valve wear include incorrect tightening or misalignment of seat in head, thermal distortion of seat due to uneven cooling, etc.

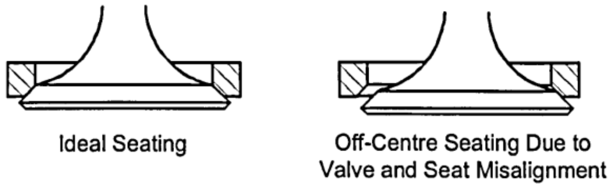
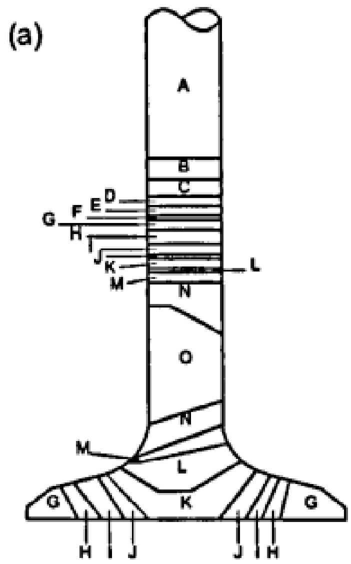


Figure. 4b. Off-Centre seating due to valve misalignment (2)

Role of Temperature

Although both inlet valves and exhaust valves receive heat from combustion, the inlet valve is cooled by scavenge air, while the exhaust valve head and seat receive additional heat from exhaust gases and experience a rapid rise in temperature **(Figure. 5).**



A	BELOW 450
B	450-500
C	500-525
D	525-550
E	550-575
F	575-600
G	600-625
H	625-650
I	650-675
J	675-700
K	700-725
L	725-750
M	750-775
N	775-800
O	800-825

Figure. 5. Typical Exhaust valve temperature profile (2)

Over 75 - 80% of the heat from the valve is lost to the seat/seat insert. The rest is lost through the valve stem to the valve guide. Effective heat transfers from valve to seat to cylinder head is essential. Heat transfer can be impeded by valve seat deposits and valve bounce.

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> *Over 75 - 80% of the heat from the valve is lost to the seat/seat insert. The rest is lost through the valve stem to the valve guide*

Deposits

Valve deposits are produced from engine oil, fuel, and soot like particles. Deposits on exhaust valve are influenced by oil leakage at valve guides, valve temperature, exhaust gas recirculation, positive crankshaft ventilation, etc. Exhaust valve deposits can help lubrication on the valve seat contact surface.

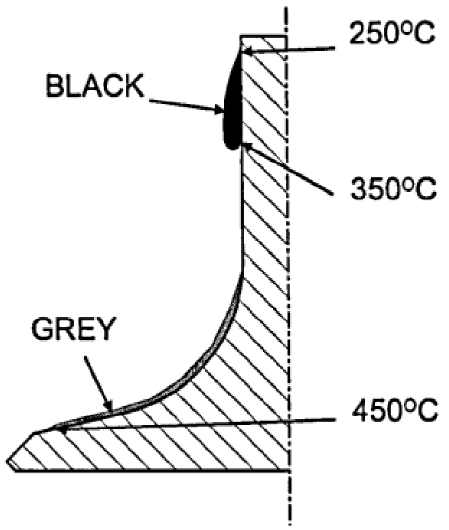


Figure. 6. Depiction of valve temperature dependent inlet valve deposits (2).

Deposits accumulating on inlet valves can reduce power output, increase exhaust emissions, and fuel consumption. Black deposits are of concentrated engine oil, oxidation products, and pre-carbonisation products. Grey deposits comprise calcium sulphate from neutralised additives. Lubricating oil that leaked through the valve stems on to the valve stem fillets can be source.

Oil from stem leakage may also cause lacquer formation if the oil oxidises when it is subject to extremely hot temperatures experienced at valve seating face. This may result in reduction of the heat transfer from the valve head, further encouraging lacquer formation.

Valve Failure Mechanisms

The consequences of an engine valve failure can vary from minor repairs and replacement to the destruction of other components that can lead to the catastrophic destruction of the engine itself. The most common valve failure mechanisms are recession, guttering and torching.

Major causes of valve failures include:

(a) Formation of hard glazed deposits which when they break away provide passages through which hot combustion gases can flow. Valve failures resulting from valve face deposits usually take a while to become apparent. Excessive low load and idle operation, ashes from lube oil additives, etc. can lead to deposit formation. Incomplete combustion of fuel rich mixtures leads to the formation of carbonaceous deposits and can also lead to severe fuel dilution of engine lubricating oils.

Figure. 7. Hard glazed deposits on valve (5)

(b) Inadequate tappet clearances or weak valve springs which prevent a valve from seating properly. Weak springs can also cause valve "float" when the valves do not seat. These failures show up quickly.

Recession

The wear of the valve and seat causing a valve to sink or recede into the seat, altering the closed position of the valve, relative to the cylinder head is known as valve recession **(Figure. 8).**

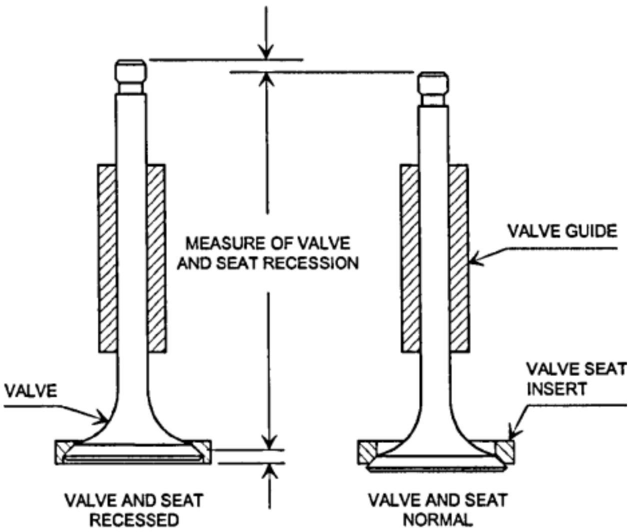


Figure. 8. Valve Recession (2)

Valve recession occurs due to loss of material from the valve and/or valve seat insert caused by fretting described under valve wear above. Metal abrasion and elevated temperature corrosion, etc. can also cause recession.

Black deposits are of concentrated engine oil, oxidation products, and pre-carbonisation products. Grey deposits comprise calcium sulphate from neutralised additives

Recession results in a reduction in the valve lift which alters gas flow. In addition, in the closed position, this recession leads to an increase in the size of the combustion chamber which may cause incomplete combustion, imperfect sealing of the chamber, at the same time creating hot spots. It may also result in Increased pollution and reduced fuel efficiency.

Guttering

Guttering is a hot temperature corrosive process that usually occurs in exhaust valves. Guttering causes a leakage path to form radially across the sealing area between the valve seating face and the seat insert. In some cases, the channel enlarges, and as combustion occurs in the cylinder, the gases follow the leak path into the valve port, rapidly melting, or "torching" the valve.

Guttering valve wear eventually causes excessive leakage of cylinder compression and misfiring results in loss of power. A common cause for exhaust valve guttering in diesel engines is the flaking of deposits from the valve/sea insert surface initiating leakage path across a valve seating face/seat insert interface where a flake is missing. The path then becomes wider and wider.

Figure. 9: Valve Guttering (5)

Figure. 10. Exhaust gas blow by through cracked seat (5)

Besides deposits from oils, combustion of fuels with high levels of Vanadium and Sodium can form hot, sticky, corrosive deposits of V+Na compounds. If the ratio of Va: Na is around 3:1, the melting point of the resulting compound is at its lowest, (about 350 – 450^{0} C) and there is an increased likelihood of hot corrosion from these deposits leading to guttering on exhaust valves and seats.

Cam and Follower

Cams provide a specific motion to the valve train system. The forces to open the intake and exhaust of a conventional valve train system are strongly influenced by the stiffness and the damping of the valve spring and the valve seat, inertial masses of the components, their geometries, gas pressures, and frictional behaviour of contacting elements of valve train components. The motion of cam and follower is complex and is transferred to valve train by direct contact under conditions of high contact stresses, elevated temperatures, and little lubrication. Such severe conditions can result in wear of these components and affect the performance of the engine dramatically. Hence, the contact surfaces of the cam and follower are invariably surface hardened by some thermo-chemical process.

The variation in relative speed between the cam and follower is significant and can involve both rolling and sliding. The lubrication varies between boundary, hydrodynamic, and elasto-hydrodynamic regimes, and the oil film thickness and friction vary accordingly. The thickness of the oil film in most areas is too small to ideally separate all the asperities and irregularities of the mating surfaces.

Wear of the cam lobes is influenced by the oil film condition and is highest in positions where the velocity of the contact over the follower is low and hydrodynamic lubrication conditions are poor. The cam–follower pair works under hertzian loads and surface fatigue resulting in pitting is a major cause of failure. Adhesive

A common cause for exhaust valve guttering in diesel engines is the flaking of deposits from the valve/ sea insert surface initiating leakage path across a valve seating face/seat insert interface where a flake is missing wear is another a major wear mechanism, since there is considerable variation in oil film thickness in the cam–follower contact area), due to both load, and temperature change, which may lead to welding and breaking of the junctions between the peaks of the asperities in the contact areas. Analysis of cam-follower lubrication have indicated the oil film thickness may vary from near zero 0 to 1.4 microns., **Figure. 11.**

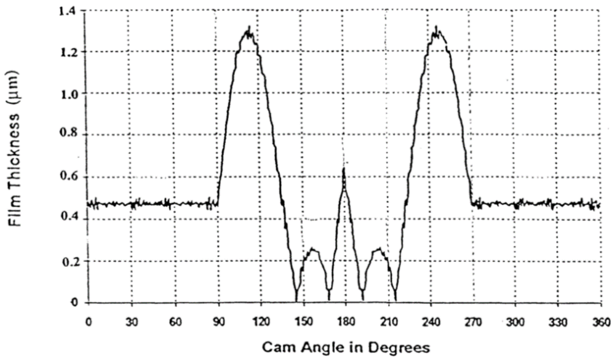


Figure. 11. Oil film thickness in cam-follower interface (7)

Those conditions are usually aggravated by plastic deformation. Scuffing (caused by breaking through the oil film) or scoring (scratches in the surface) are typical damage that results. Usually, the face of the follower shows even wear over the whole area. In case of scuffing and pitting, wear may be more pronounced the middle area.

The main factors affecting cam– follower wear are the materials that the mating elements are made from, the hardening processes they have undergone, the rotational speed, the dynamics of the camshaft follower kinematic pair, the temperature and viscosity of the oil and operational conditions.

Lubrication of Valve Train Components

Engine lubricants have been found to both increase and decrease valve and seat wear depending on the additive composition and the amount of oil that reaches the valve/seat interface.

In inlet valves, liquid film lubrication is most dominant as temperatures are not high enough to volatilize the lubricant hydrocarbons and additives. Exhaust valves, however, are lubricated by solid films formed at the higher operating temperatures by oil additive ash compounds such as alkaline-earth and other metal oxides, sulphates, and phosphates e.g., calcium, barium, magnesium, sodium, zinc, and molybdenum. Adequate ash deposits can prevent valve recession. However, if the ash content is too high, excessive deposits may lead to valve guttering or torching due to flaking. For natural gas engines, the right amount of ash deposits (as per engine design and gas type) is of utmost importance.

The control of lubrication oil dilution by unburnt and partially combusted fuel is extremely critical to valve deposit formation. Operating the engine within its capacity, with correct air and fuel supply, and cooling, maintaining oil condition, using original spares, are critical to maintaining problem free equipment.

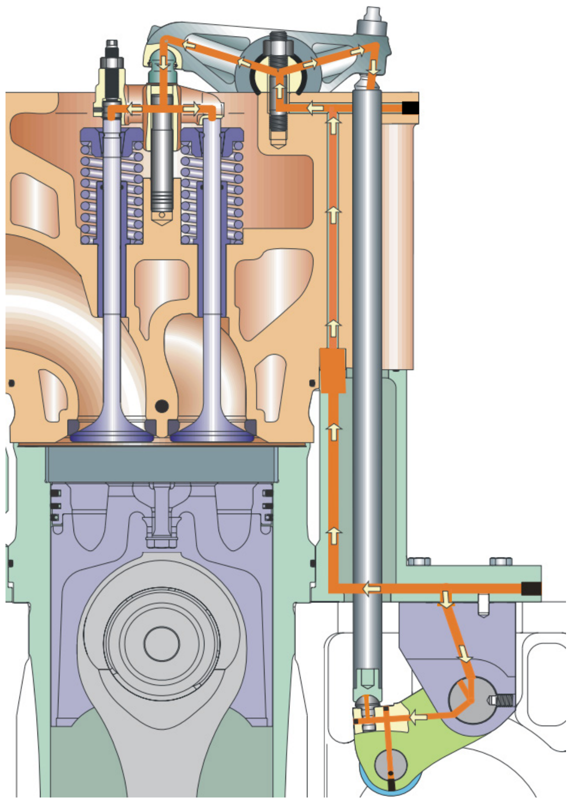
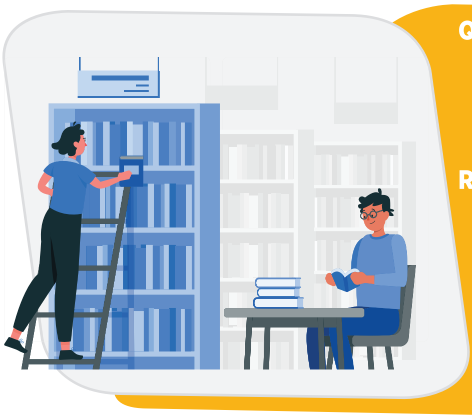


Fig. 12: Lubricating oil flow in valve train and cylinder heads (6)



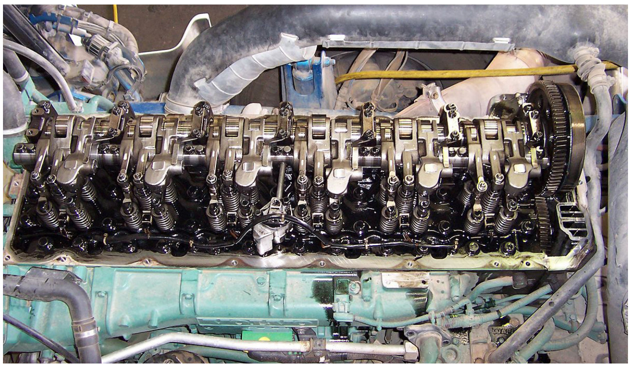


Figure. 12. shows the lubricating oil flow in valve trains and cylinder head. The lubricating oil supplied from oil channel of the engine block flows into fuel injection pump, swing arm rollers and valve train components such as rocker arm, yoke, and valve. Then the lubricating oil returns to oil sump after circulating.

Clean oil and good surface finish is essential to maintain oil films. Proper oil flow between the pin and roller and between the lobe and roller, will help reduce friction, and wear on the components. Lack of lubrication, due to too much clearance, or blocked oil passages will set off rapid wear.

Conclusion

Engine performance is influenced by the valve lift duration during the cycle, which controls the gas flow rates into and out of the cylinder, at the desired time. Valve motion is induced by the valve train.

The geometry of the cam determines the valve lift motion. The proper selection of cam profile is an especially important aspect in a diesel engine design.

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About the author

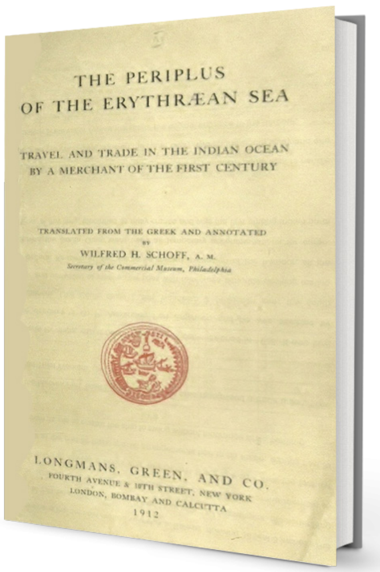
Sanjiv Wazir is a mechanical engineer from IIT-Bombay. He is a marine engineer and a consultant on marine lubrication. Sanjiv is a Certified Lubrication Specialist (CLS) from the Society of Tribologists & Lubrication Engineers (STLE), USA; a fellow of the Institute of Marine Engineers (India); and a member of the Tribology Society of India. He often lectures on tribology and lubrication. For MER, he has written a series of articles on tribology & lubrication issues under "Lube Matters."

Email: sanjiv.wazir@gmail.com

A RELOOK AT THE FIRST NAVIGATIONAL GUIDE (Part 1)

K R A Narasiah

World's first written navigational guide was in Greek and written by a sailor, in ordinary spoken language of his, of that time - the Periplus of the Erythraean Sea. It is believed that the text was written in the first century CE.



Copy of Periplus in Toronto Public Library

The experts believe that the text is derived from an early Byzantine 10th-century manuscript in minuscule hand, kept in the University Library Heidelberg. Another copy belonging to 14/15th century C E, is preserved in the British Museum.

First publication of the Periplus was made in 1533, as edited by Sigismund Gelenius (1497 – 1554) an eminent Greek scholar of Prague; but it contained too many errors; however, it was the basis of later works on this book as it served as the basic text for other researchers till another 10th century Heidelberg manuscript was rediscovered.

Wilfred Harvey Schoff (1874 – 1932) was an early twentieth century American scholar antiquarian who was studying old text materials in depth and by historical analysis fixed the date of original text of The Periplus of the Erythraean Sea to be of 60 CE, in 1912. Fixing of such an old text to a single year almost two millenniums later by any standard was unbelievable, but all subsequent researchers agreed with his date.

BACKGROUND

Roman trade through the Red Sea corridor was well established from very early days; through land the traders reached Alexandria and then by land to the river port Juliopolis on the Nile. Then they sailed by the Nile south and it took 20 days to Coptos (another port down on the Nile). From Coptos by land, loaded on camels, cargo moved to either Myos Hormos (then known as Mussel) or Bernice, both Red Sea ports. An alternate route was sailing from Italian coast to reach Alexandria by sea and then following the above said route. The cargo comprised fabricated tin, copper, and Alexandrian glass vessels and European wine. There were also singing girls and boys, and the rich Indian rulers enjoyed receiving them. (Tamil Sangam literature confirms this by a poem in Purananuru (56:18-20), that says the good aromatic wine brought by ships in urns by Yavanas, is given to the King in golden vessel by girls wearing bangles. . .)

At the time of Periplus, independent areas of the Indian sub-continent were ruled by Indo-Scythian kingdom in the North West (Sakas), Western Satraps in the central land, Satvahanas in the Mid-South and Cholas, Pandyas and Cheras in the South, and the civilisation was much advanced and trading with these kings was profitable for the western traders and the spices, gemstones, pearls and textiles from south India were in great demand in the West.

Strabo

Strabo, (64 BCE – 24 CE) best known for his work *Geographica* (Geography), that gave a descriptive history of people and places from different regions of the world known during his lifetime, says, that the merchants of Alexandria were sailing with fleets by way of the Nile and the Arabian Gulf as far as India, as these regions had become far better known then to their predecessors. According to him, as many as one hundred and twenty vessels were sailing from Myos Hormos to India regularly.

Pliny, The Elder

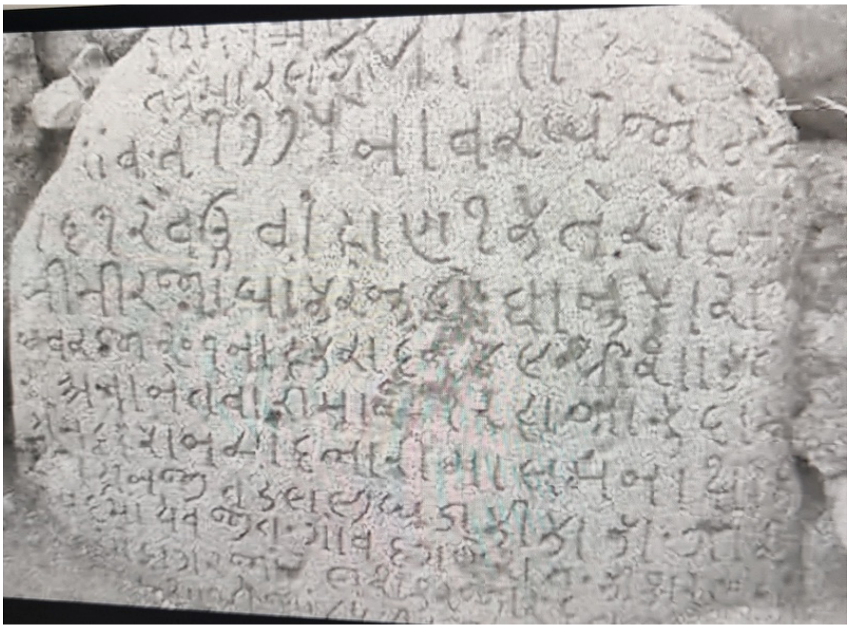
Gaius Plinius Secundus (AD 23/24 – AD 79), commonly known as Pliny the Elder, a Roman author, who authored *Naturalis Historia* (*Natural History*), confirms by noting, "If the wind, called Hippalus (south-west Monsoon), happens to be blowing, it is possible to arrive in forty days at the nearest market in India, Muziris (today's Pattanam in Kerala) by name. The name of the king of this place is Caelobothras(Cheras). Another port, and a much more convenient one, is that which lies in the territory of the people called Neacyndi, Barace (Kottayam and Vakkarai) by name. Here king Pandion used to reign, dwelling at a considerable distance from the market in the interior, at a city known as Modiera". From this statement it can be seen that as early as first century the Pandian administration was so advanced that they could rule the sea ports from a considerable distance. More importantly he says, "Travellers set sail from India on their return to Europe, at the beginning of the Egyptian month of Tybia, which is our December, or at all events before the sixth day of the Egyptian month Mechir, the same as our January; if they do this they can go and return in the same year." This statement is worth considering as during the same period with a bit of interval the months of Tamil calendar are called *Thai* and *Masi;* It can be seen how the names of the months sound similar; There is a saying in Tamil, though the origin of it is not clear, that says when the month of Thai is born, a way is born. The meaning of this cannot be missed.

The first paragraph of the Periplus says, "Of the designated ports on the Erythraean Sea, and the market-towns around it, the first is the Egyptian port of Mussel Harbour. To those sailing down from that place, on the right hand, after eighteen hundred stadia, there is Berenice. The harbours of both are at the boundary of Egypt, and are bays opening from the Erythraean Sea." (In this article only selected paragraphs concerning our interest are discussed)

The name *Eritrea* is derived from the ancient Greek name for the Red Sea, based on the adjective Erythros, meaning red and so the Red Sea was known then as Erythraean Sea. **The Greeks believed any water after the Mediterranean Sea was part of the Red Sea and so the Arabian Sea was also known to them as the Red Sea, and thus the guide to sailing beyond the Mediterranean was named the Periplus of the Erythraean Sea.**

In 1999 to 2003, the University of Southampton conducted excavations at the site of Quseir al-Qadim,

"The Greeks believed any water after the Mediterranean Sea was part of the Red Sea and so the Arabian Sea was also known to them as the Red Sea, and thus the guide to sailing beyond the Mediterranean was named the Periplus of the Erythraean Sea"



Socotra Island Inscription

prompted by the idea that the site was not the minor port of Leucos Limen – as thought by previous excavators from the University of Chicago - but the important site of Myos Hormos (Mussel harbour in the Periplus). During excavation they found a potsherd with some scribbling in an unknown language belonging to early period. The scribbling was later recognized by late Iravatham Mahadevan (an expert in Tamil Brahmi script) as Tamil Brahmi and dated to 1st century CE. The inscription reads *Paanai uRi* that is, pot (suspended) in a rope net. This stands testimony to Tamil sailors having sailed to that area very early.

The second and third paras read as, "On the right-hand coast next below Berenice is the country of the Berbers. . . after sailing about four thousand stadia from Berenice, called Ptolemais of the Hunts, from which the hunters started for the interior under the dynasty of the Ptolemies. . .the place has no harbour and is reached only by small boats."

The 4th para is important as it says, "Below Ptolemais of the Hunts, at a distance of about three thousand stadia, there is Adulis, a port established by law, lying at the inner end of a bay that runs in toward the south. . . They used formerly to anchor at the very head of the bay, by an island called Diodorus. . ."

Diodorus is now called Socotra. G.W.B. Huntingford remarks that the name *Socotra* derives from the Sanskrit *sukhadhara - island of bliss.* In 2001 a group of Belgian speleologists of the Socotra Karst Project made a spectacular discovery. Deep inside a huge cave they came across a large number of inscriptions, drawings and archaeological objects which were left by sailors who visited the island between the 1st century BC and the 6th century AD. The majority of the texts is written in the Indian Brahmi and one in Kharosthi script.

While the following paragraphs are descriptive of the Egyptian coast and sailing beyond, Indian interest starts with 38th paragraph.

"Beyond this region, the continent making a wide curve from the east across the depths of the bays, there follows the coast district of Scythia, which lies above toward the north; the whole marshy; from which flows down the river Sinthus, the greatest of all the rivers that flow into the Erythraean Sea, bringing down an enormous volume of water; so that a long way out at sea, before reaching this country, the water of the ocean is fresh from it. Now as a sign of approach to this country to those coming from the sea, there are serpents coming forth from the depths to meet you; and a sign of the places just mentioned and in Persia, are those called graoe. This river has seven mouths, very shallow and marshy, so that they are not navigable, except the one in the middle; at which by the shore, is the market-town, Barbaricum. Before it there lies a small island, and inland behind it is the metropolis of Scythia, Minnagara (today's Karachi); it is subject to Parthian princes who are constantly driving each other out." Obviously, the recording sailor had heard about the constant fights among the states!

About the author

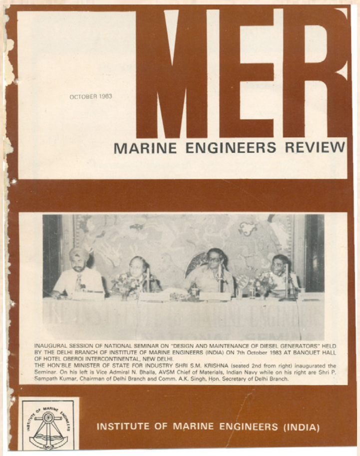
K R A Narasiah is a well-read writer in Tamil and English and a recipient of Awards (four instances) by Tamil Nadu State Government for Tamil literature. He did his marine engineering training in the Naval Training centre, I N S Shivaji (1949-1953) and sailed on board naval ships for 10 years. While in Navy he was deputed to Harland & Wolff Shipyard in Belfast to standby during the construction of the India's first Aircraft Carrier I N S Vikrant and later, took over as its first Indian Flight Deck Chief.

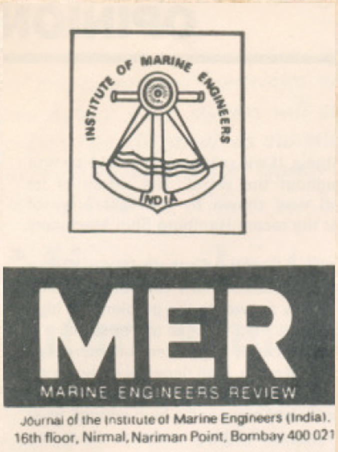
Selected through the UPSC, he joined Vizag Port in 1965 as a marine engineer, where he rose to the position of the Chief Mechanical Engineer in 1986 and retired in 1991.He was called by the Indian Navy during the liberation struggle of Bangladesh and served under the Eastern Naval Command. He also worked as a Consultant for Indian Ports Association.

He was also a visiting faculty for the NIPM, IIPM, AMET University and other marine Institutes. In 1994 The World Bank invited him to join as a marine consultant (ports) for a mission for Emergency rehabilitation programme of Cambodia where he served with distinction from 1994 to 1996. He was also a consultant to Asian Development Bank for port development. He contributes to The Hindu regularly as a reviewer of Books and to the Times of India for its South Pole columns. His main area of research continues to be the colonial and maritime history.

Email: narasiah267@gmail.com

Going Astern into MER Archives:





MER... Four decades back...
The October 1983 Issue

We start with the 'Opinion' column. The first part talks about the marine engineer not being 'economy conscious'. It is interpreted that keeping fuel and maintenance costs constitute to this consciousness. There is a brief discussion on why not to incentivise the engineer with bonuses (there is a counter argument that he is already paid to do the job, why extra?) to achieve this. Any thoughts on this?

The second part discusses shaft generators and the attainment of constant frequency. Guess the SGs have matured and come a long way. Would welcome some technical talks on this.

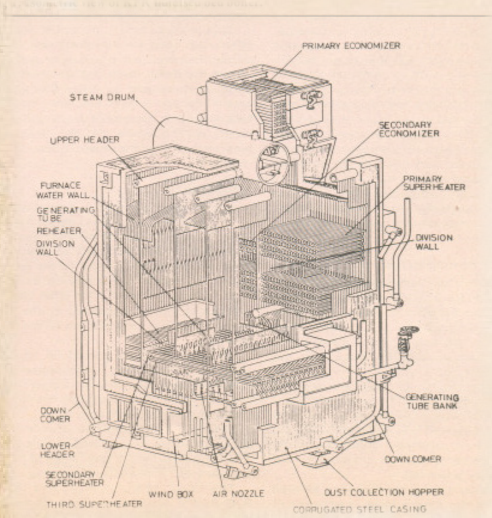
The third part gets more interesting than the first one: Are marine equipment in UK uncompetitively priced? No, they are highly competitive, says the British Marine Equipment Council. Long sailing engineers can throw some light on this.

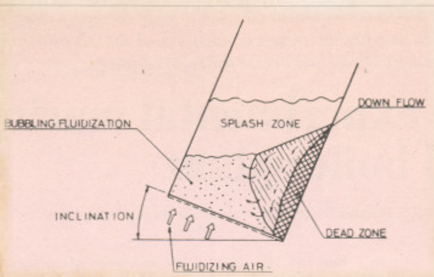
We then step into an article of intrigue. There are quite a few interesting takeaways as to how Japan managed to stay in the top league in spite of setbacks. Recession etc. I list a few significant ones:

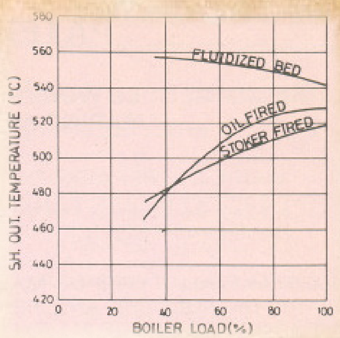
1. Post WW II, Japan converted the warship building experience (technologies along with cheap but highly skilled labour force) into big ship building ventures.
2. Push out old-fashioned shipyards. (survival of the fittest?)
3. Manpower optimisation: Individual enterprises settle workers independently; passed on skilled workers to where need was present.
4. Meeting material requirements locally thus keeping the costs low. (Supply chain resilience).
5. Ultra - modernisation by adopting new methods and technologies.

Do we have a guide book from this or Indian shipbuilding industry?

The next one in the pages is on the fluidised bed boilers. Any old timers with this experience? Some extracts are projected to fan the interest in the topic.





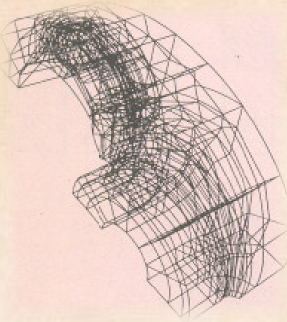


Another familiar topic is on welded crankshafts. The discussion is with LMC engines in focus. The merits are worth noting for Competency exams:

1. Cylinder distance reduced and hence overall engine length is reduced.
2. Width of bedplate and height of engine also reduced (better head clearance for piston overhaul/maintenance).
3. Reduction in thickness. Length of webs.
4. Longer bearing length; average specific bearing pressure lowered.
5. Weight of crankshaft reduced (no shrink fits); no overlap restriction while choosing larger diameter crankshafts.

6. All above leading to lesser crankshaft inertia; lower torsional vibrations;

This could attarct the attention of some of us and also to Lamb's Q&A.



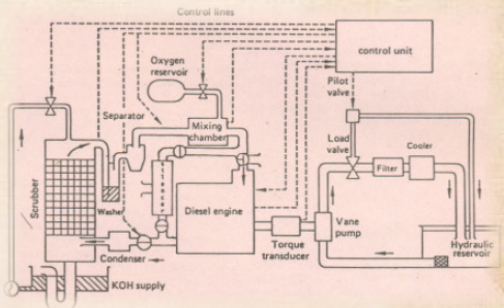
Following this is an essay on marine marine surveyors and what is expected of an expert witness. Some extarcts for your amusement.

"Standing in the bilges with the water rising"

'—Nor ramble on and on —'

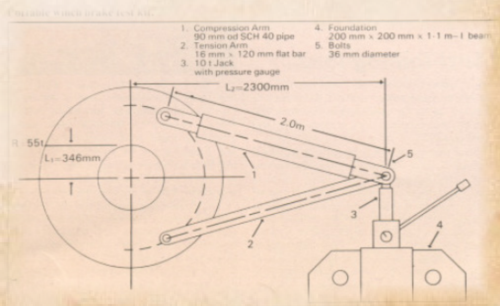
'Avoid gestures ... which cannot be recorded'

And there is a serious one on diesel engine for underwater systems. This closed cycle engine cycle should drive some of us to the archives, I hope.



'Postbag' has a mixed lot: halon, Injection timing, electrostatic hazards on oil tankers and a multi-purpose cargo carrier designed for operation with a crew of only 12 persons.

And one for the road... testing mooring winches (See under 'Operation'). Just the extract will do for all those who have done this.



POSTBAG

Fire-fighting with Halon

Sir,
The Halogenated hydrocarbon fire extinguishing agent has gained prominence over the last decade. Its advantages have been well publicised (MER June) but it does have limitations.

The effectiveness of Halon depends on the rapid release of the extinguishing agent, ie, within 20 s. This poses a problem in the design of total flooding systems for large installations which have very long pipework and many bends which increase pipe pressure losses.

Halon is not suitable for fighting deep-seated fires. A fire that smoulders will have to be fought by other means after the initial release of Halon has controlled the flames.

Exposure to personnel from BCF (Halon 1211) at concentrations used for fire-fighting can impair co-ordination and reduce mental activity. BTM (Halon 1301) is considered safer than BCF but prolonged exposure when personnel are under severe stress (which causes high levels of adrenalin in the body) can lead to irregular heart action called 'arrythmia'.

For local applications, where portable extinguishers can be used, Halon 1211 is more appropriate since it vapourises less rapidly than Halon 1301. A mixture of Halon 1211 and 1301 has been used for portable extinguishers to combine the best characteristics of each. Another problem is that recharging facilities are not widely available.

The above points do not detract from the excellent fire-fighting capabilities of Halon, but serve to emphasise that correct use of the appropriate agent will yield the best results.

Malay K Dutta

Houston, Renfrewshire

Trend analysis

Sir,
The points raised by Mr T K Das Gupta in September Postbag are quite valid and in general agreement with the contents of my article in the February issue. Some apparent differences are due to interpretation. For example the fact that 'injection timing' was listed at the top of the causes for low firing pressure did not mean it was the foremost cause. The subsequent discussion on 'firing pressure' clarified this as all more likely causes were to be investigated before injection timing.

The point 'F' in Fig 3 was meant to illustrate the importance of injection timing which might have been disturbed by a previous intervention; there was, of course, no suggestion that it had altered by itself during normal running.

Mr Das Gupta's remarks on changing of injection timings pertain to low-speed diesels with individual fuel pumps. The slow engines, with their comfortable combustion process, can tolerate a certain amount of deviation from designed timing and need little attention. An anomaly in their injection can be easily detected from the indicator cards. On the other hand high-speed diesels, especially fixed-speed types as used with generators, are very sensitive to timing.

Use of monoblock fuel pumps makes adjustment of timing fairly easy. The coupling drive to the fuel pump usually provides for adjustment of about ± 5 to 10 degrees with an accuracy of about $\frac{1}{2}$ deg.

At point E in Fig 3, high exhaust temperature and fuel consumption were due to loss of supercharger air pressure. The graph conveyed this but editing of the text left some doubts. Mr Das Gupta's interpretation of restoration of supercharger air pressure is correct, and I thank him for clarifying it.

K F Sair

Saudi Arabia

Electrostatic hazards on oil tankers

Sir,
While I am in general agreement with most of the conclusions of this article on p10 of the June issue, there are a few points which do not accord with our experience.

BP considered the electrostatics problem and came to the conclusion that it would be satisfactory to have: either a fully conductive grp pipe or a pipe with an outside integral conducting layer with earth connections near the ends.

To keep within a maximum of 1000 V on the pipe due to inert gas, tank washing and product flow through the pipeline, the latter was considered the most onerous. It was calculated that the maximum resistance between the ends of the pipe should not exceed $10^8\,\Omega$ as against Shell's $1.5\mathrm{M}\Omega$/m for product carriers.

Non-conducting grp pipes immersed in crude oil had a surface resistivity of more than $10^{11}\,\Omega$/square (although we failed to obtain incendive discharges on rubbing with paper). Since the surface resistivity of non-conducting pipes could increase on washing, we, unlike Shell, rejected their use in crude oil ships and aimed for the $10^8\,\Omega$ resistance, end-to-end, of pipe for both crude oil ships and product carriers.

Since a homogeneously conductive pipe would require a carbon content greater than 30%, which could affect its physical properties, we specified an outer 1 mm conductive layer. The pipes are tested prior to, and after, installation. To date, 153 lengths have been installed and, as far as I am aware, no real problems have been encountered. The pipes have been purchased from Redland, Bristol Composite and Wavin.

Shell describes grp pipes as homogeneously conducting but I feel this is not strictly true because there is a network of carbon filaments. Hence, the pipe may not be fully conductive and suffers from the same disadvantages as layered pipes. However, our experience does not indicate that this is a problem.

The article contains some interesting findings on the charge generation of inert gas systems which are relevant to non-flammable conditions. But the question is, would conditions be hazardous if the system broke down and air entered the tank? It seems to me that current procedures would prevent such an occurrence and the question is somewhat academic.

With reference to tank washing, the 10 kV criterion for discharges from water slugs is used extensively throughout the article. The location of the 10 kV is of paramount importance to operators of non-inert gas ships. Where does it occur? in the vicinity of the water gun, the centre of the tank or at the slug at the instance of discharge? Some clarification would be appreciated.

The criterion for incendivity of discharges from a liquid surface is quoted in the article as a surface potential exceeding -45 kV. Some research workers at the University of Southampton and at the BP Research Centre have observed incendive discharges at -25 kV.

In my opinion the charge transfer is a more appropriate criterion than voltage and is applicable to both positively and negatively charged liquids. However, I do concede that a voltage criterion is more easily understood, even if not valid.

W D Rees

BP International Ltd

A crew of 12?

Sir,
I was most interested in the item in the May issue on British Shipbuilders' new MP17 ship design, stated to be a multipurpose cargo carrier. The design, apart from fuel/speed economy, is specially aimed at reduction in crew numbers.

It would be interesting to know how a crew of 12 could cope after discharge of, say, bulk sugar which requires all holds and 'tweendecks cleared of dunnage, swept etc and then being thoroughly hosed down with salt-water to prevent acid corrosion. In such a case, if the vessel had to load at the same port or one a couple of days passage away, costly shore labour would be required to do this, with likely delay. Similarly, with reduced crew, no maintenance or continuous survey work could be carried out on the voyage, leading to increased repairs and drydocking time ashore.

It is not clear what is meant by 'mooring is mechanised' as, even with thrusters or gill jet units, mooring ropes, wires etc require to be man-handled and, on a vessel of nearly 500 ft, these are fairly large.

Unless the vessel was trading to regular ports with specially equipped berths, a minimum of three crew members would be required at each end of the vessel, ie, half the proposed crew; say, two on the bridge and two for the engine room, one wireless operator and one spare GP/Cook Steward!

J R B Robertson

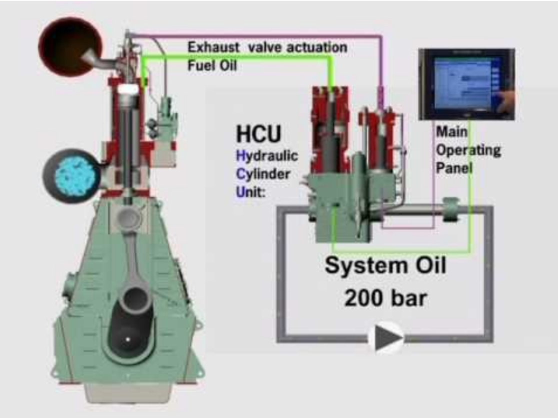
North Shields

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	:	**25th, 26th, 27th October 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. Payment to be made to: https://imare.in/buy-online.aspx (Under Category - Value added Courses) *10% discount available for IME(I) members*
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