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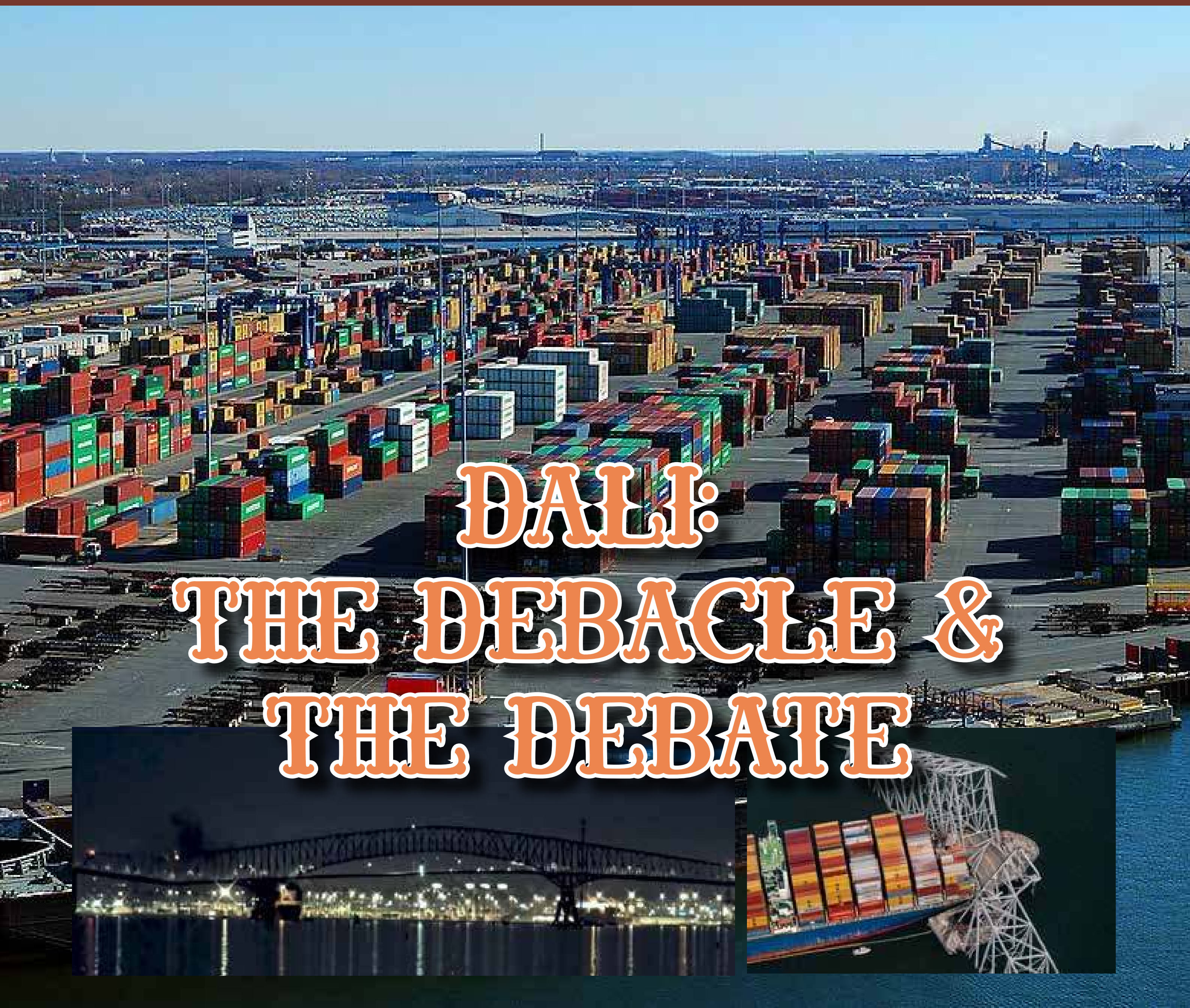

DALI: THE DEBACLE & THE DEBATE

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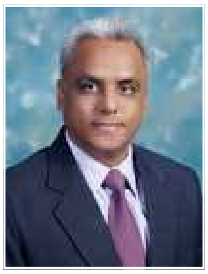
EDITORIAL

If you want something new, you have to stop doing something old.
– Peter Drucker



The just gone by Budget needs a consideration. In most of these revenue-expense exercises, in reckoning, shipping had remained a distant service as compared to other transport sectors of rail or road ways (for optics also, cars, trucks and rails are seen more than ships!). Post Sagarmala launch, the foghorns have got louder and shipping has been drawing some attention. In the current budget works, the major shipping-related feature is the ₹25000 Cr. apportioning to the Maritime Development Fund (MDF). The wish on which this mammoth fund and other related shipping narratives are built: Indian flagged ships will carry Indian cargoes (and also foreign stuff). And this Fund is supposed to be the balm for all shipbuilding woes.

Over the last decades of development, the financing and taxation models (for shipping and shipbuilding) have remained arcane. Also, there have been myopic to ridiculous arguments that automobiles can be towed away for non-payments and sold and costs recovered but for ships where are the mechanisms etc. In simple terms, there has been a non-favourable miasma that has prevailed for Indian shipping industry and the industry has stagnated in terms of tonnage and carriage.

The only redeeming factor is that there is a large number of Indians who still man global ships and run shipping companies (and there is still a demand). Now it has come to pass that developmental gateways are the ports and shipping is the route. Shipping cannot be seen as a secondary service.

Back to the Fund...

The sources for this MDF, unaddressed taxation patterns (personal/coastal shipping), issues in developing the capacity and capability of our yards etc.... all these require a conscious effort to ring out the old way of doing/looking at things and bring in a new way of looking at and doing things. Else, this will be another opportunity which will sail away in to the horizon.

In this issue

The Dali discussion comes first. Dr. Shantanu Paul and Dr. Patrick Donner discuss a few nuanced legal issues concerning the vessel's allision with the bridge at Baltimore port. The Authors look at the liability issues and try to answer, 'who picks the bill?'. The explanations on H&M, P&I and GA makes this an informative. Meandering through the legal lines, the section, 'Findings' connects well. An easy read.

The next article is from the WMTC 2024 collection. Comdt. Jena presents a simple study and discuss shipbuilding in India. With some nominal data, the Author presents a case for energising the shipbuilding sector by encouraging more ancillary industries, easier financing of working capital, increased productivity etc. This is another easy read.

This is followed by Part B of the Bio-inspired AI-enabled Homing Guidance System for Autonomous Underwater Vehicles. Dr. Bala Nag Jyoti et al., take us through the Stage 2 of this design development explaining the Vision based guidance system. The Deep Learning (DL) architecture, image processing is followed by Stage 3 which involves the successful demonstration. The Authors propose a Digital Twin (DT) concept at Stage 4. More field tests, fine tuning the DL algorithm and a DT follow up will mature this bio-inspired homing guidance system. The system is expected to support spatiotemporal deep-ocean mineral mapping missions.

The Technical Notes section has an informative piece on Shaft Generators and the Summary of the WMTC 2024. The MER Archives has some interesting articles and letters.

We have a good clutch of papers from WMTC and hope to run them all here in the forthcoming issues.

Here is the March issue for your reading pleasure.

Dr Rajoo Balaji
Honorary Editor
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MV DALI ALLISION: A LEGAL SNAPSHOT OF BRAHMASTRA

Shantanu Paul, Patrick Donner

Abstract: *The allision of MV Dali with Baltimore's Francis Scott Key Bridge led to its collapse and the deaths of six people, making it possibly the world's greatest shipping disaster in terms of claims value. The allegation of a vessel's 'Unseaworthiness' is akin to the mythological* ***'****Brahmastra', under which ship-owners' protection such as Limitations of Liability, General Average, have failed in numerous court cases in many jurisdictions and are being retested now under century-old US laws, are a matter of interest for the shipping industry and the public in general. The article is a discussion on various ship-owners protections and other legal provisions as applicable to this case.*

Keywords: *Seaworthiness, Brahmastra, Limitations of Liability, General Average.*

Introduction

On March 26th 2024, the allision of MV Dali, a Singapore-flagged 9971 TEU (Twenty-foot Equivalent Unit) container ship operated by Indian crew, with Baltimore's Francis Scott Key Bridge, leading to its collapse and deaths of six construction workers, shocked the whole world as well as the shipping industry. Immediately after the incident, the Mayor and City Council of Baltimore charged the Dali owner and operator with a 'Brahmastra' for putting a '*clearly unseaworthy*' vessel into the water (Cabral, 2024). In Indian mythology, Brahmastra was the most powerful weapon which could destroy all defences of an opponent and was created to uphold justice (Dharma and Satya). **The 'Brahmastra' is akin to an allegation of vessel's 'unseaworthiness', a term promoted to uphold the interest of shippers against the injustice of US ship-owners to exclude their liabilities in the 19th century before the US Harter Act 1893 but the concept of seaworthiness, as a moral duty of ship-owners, existed from the medieval time.** Over the years, failure to meet the seaworthiness obligation has become like 'Brahmastra', against all protections and immunities of ship-owners. A generally accepted test of seaworthiness is that the '*Ship must have that degree of fitness which an ordinary careful and prudent owner would require his vessel to have at the commencement of her voyage having regard to all the probable circumstances of it'* and *'if a defect existed, would a prudent owner have required that it should be made good before sending his ship to sea had he known of it'* as established in the McFadden v. Blue Star Line (1905) case.

Over the years, failure to meet the seaworthiness obligation has become like 'Brahmastra', against all protections and immunities of ship-owners

As Brahmastra changed its variant over time as used in 'Treta yuga' and 'Dvapara yuga' when the Ramayana and the Mahabharata respectively were believed to have happened, similarly the notion of seaworthiness has also changed over time and continuously evolved with the changing legal and regulatory requirements that are mandatorily applicable for international shipping today such as the International Safety Management (ISM) Code, the Standards of Training, Certification and Watchkeeping for Seafarers (STCW) Convention etc. of the International Maritime Organization (IMO). Nowadays, the concept of seaworthiness refers not only to vessel's *physical seaworthiness* but also to *human seaworthiness* as most marine accidents can be traced back to human errors. Therefore, it is the ship-owner or their operator who has to make sure that the vessel is provided with not only a sufficient number of crew but also well-trained and competent crew for the ship. Charges against the Dali owner are not limited to physical unseaworthiness but incompetence of crew, inadequate training of crew, poor maintenance of the vessel i.e. electrical and mechanical systems on the Dali were improperly maintained and configured in a way that violated safety regulations and norms for international shipping etc. (DOM, 2024). The overall cost of the incident, including hull repairs, salvage, loss of life, repairs to the bridge, business interruption etc. have been variously estimated over USD 2 billion (Gallagher,2024) and this would make it most likely the biggest maritime casualty ever in terms of claim value.

Although the Certificate of Competence (COC) is issued by the Administration, the ship-owner or his manager has to ensure that the seafarer is indeed fit to carry out his duties on board a particular vessel

The owner of the ship, Grace Ocean Private Ltd. and the operator Synergy Marine Singapore, filed a petition to the US court to limit their liability to $43.7 million. The defendant claims that the collapse of the bridge *was 'not due to any fault, neglect, or want of care'* (Steinberg & Dolmetsch, 2024) on their part. A renowned US lawyer Mr S. Yerrid, in support of the plaintiff mentioned that *'Limitation of liability is for those who sail seaworthy vessels with competent crews' (*BS, 2024). Crew competence or training on ship-specific safety issues is also a matter of 'due diligence' obligation as STCW Section A1/14 imposes responsibility on shipping companies with respect to competence in assigned duties of a seafarer (Paul, 2009).

Although the Certificate of Competence (COC) is issued by the Administration, the ship-owner or his manager has to ensure that the seafarer is indeed fit to carry out his duties on board a particular vessel (Nakaya, 2003). Hence, India being one of the top seafarers supplying nation, the training and certification system of Indian crew is not an issue here as their responsible actions, warning the US authority by 'Mayday' prior to the mishap, was highly appreciated by Mr J Biden the US President at that time, as it led to the stoppage of traffic on the bridge in busy hours and larger accident and deaths were avoided (TOI, 2024). Hence the competence of the Indian crew may not be questioned in US court over other factors of seaworthiness!

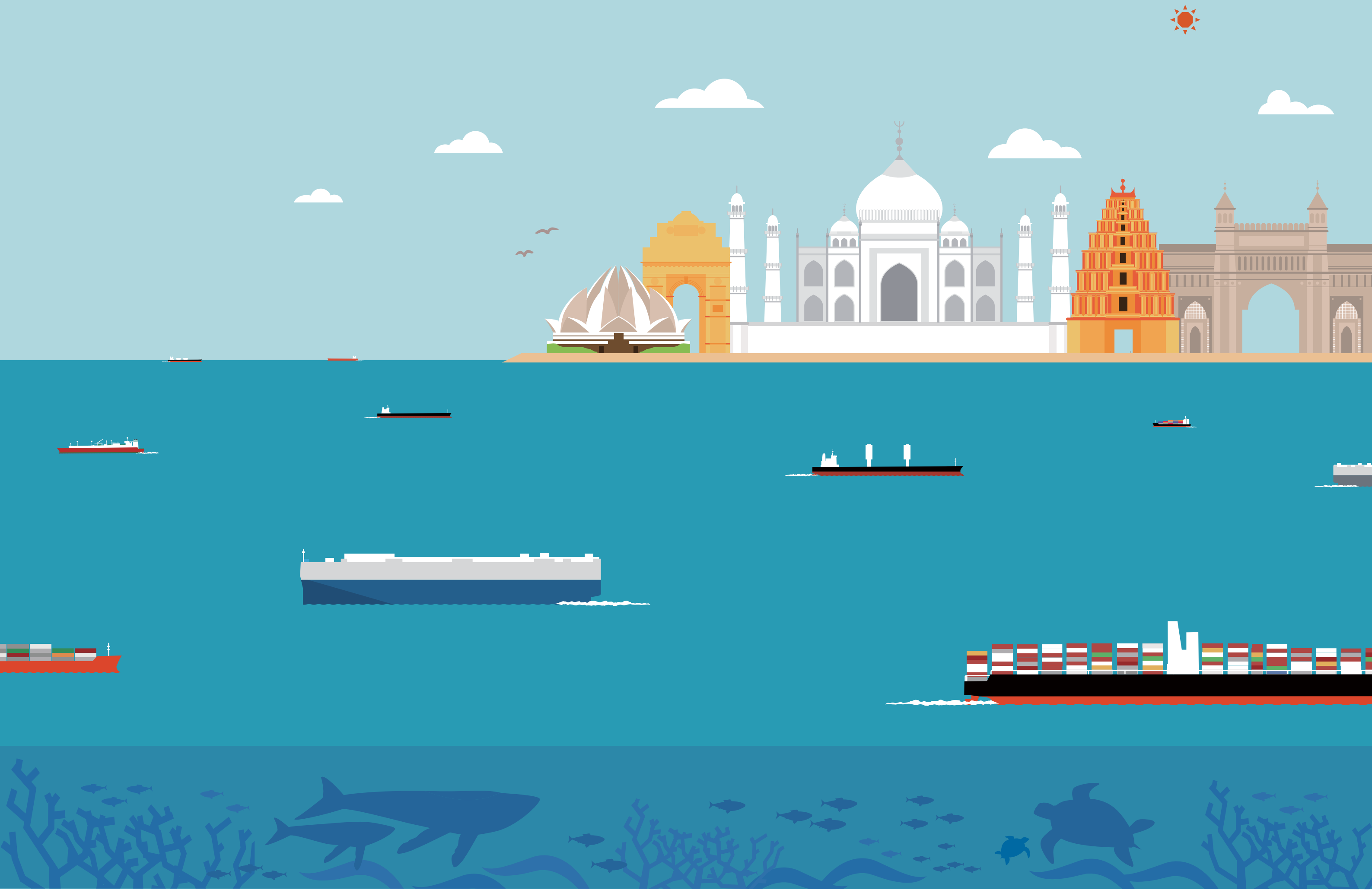
Subsequently on 12 April 2024, the ship owner of MV Dali has declared General Average (GA) (MSC, 2024) to apportion costs among cargo interests based on freight value. Nevertheless, GA contribution from cargo interests is also subject to fulfilling the shipowner's obligation of seaworthiness i.e. if the owner has failed to make the vessel seaworthy at the commencement of the voyage, as per the outcome of various court cases.

Now hundreds of questions are hovering in people's minds, including who is liable for payment of what and how much? Can the ship-owner defend against the Brahmastra and limit their liability? Can the ship-owner successfully get GA contributions from cargo interests? The case may continue for several years but irrespective of the outcome of this case, the fear of Brahmastra will surely make ships safer in the years to come. Against this backdrop, a brief discussion on the **current US limitation of liability regime and other applicable legal and insurance provisions** i.e. H&M (Hull and Machinery), P&I (Protection and Indemnity) and GA (General Average) can possibly show some directions towards the answer of our questions.

Ship-owners protection measures and Seaworthiness:

The history of ship-owners limitation of liability dates back in England to 1733, with later developments throughout the 19th Century under the Responsibility of Ship-owners Act 1813 (Gaskell, 2022). In America, it has existed since the enactment of Ship-owners Limitation of Liability Act 1851. It was apparently passed to afford American ship-owners similar advantages that the United Kingdom and other European countries granted their vessel owners and to stimulate investment in American shipping (Crais, 2022). Since then it has given ship-owners the right to limit their maximum liability for collisions and other losses such as claims for property damage, cargo damage, personal injury etc., which take place without the owner's *'privity or knowledge',* to the value of their vessel at the end of the voyage and its freight then pending (AI, 2024).

'Judicial interpretation of this term privity or knowledge means the shipowner's personal participation in, or actual knowledge of, the specific acts of negligence or conditions or unseaworthiness which caused or contributed to the casualty'



'Judicial interpretation of this term *privity or knowledge* means the shipowner's personal participation in, or actual knowledge of, the specific acts of negligence or conditions or unseaworthiness which caused or contributed to the casualty'. (BLF,2024). The owner has the burden of showing that it did not know of the condition or negligence that caused the loss. (McGlynn et.al, 2023).

The Grace Ocean and the Synergy Marine have asserted that they had no 'privity or knowledge' of faults with the vessel and claimed to limit their liability to $43.7 million based on the above (Gallagher,2024) **i.e. the value of MV Dali = US$ 90 Million, Less: Estimated repair costs of US$ 28 Million, Less Salvage costs of US$ 19.5 Million. Hence effective vessel's value= 90 - (28+19.5) = US$ 42.5 Million.** Then, by adding a freight of US$ 1.2 Million, the maximum liability equals US$ 43.7 Million (Radhakrishnan, 2024). Historically, the privilege of limitation of liability of ship-owners is closely linked with the obligation to provide a ship that is reasonably fit to withstand common perils of the sea voyage.

This ship-owners obligation was popularised by the introduction of the term '*seaworthiness'* in the American Harter Act 1893, enacted to balance the interest of ship-owners and shippers by preventing ship-owners from using exculpatory clauses in the Bill of Lading (BOL) to eliminate their liability altogether under the freedom of contract (BR,2021). Since then, ship-owners obligation to provide seaworthy ships varied with definitions but conceptually seaworthiness has remained the same and become a vital condition in many countries' national laws as well as international conventions on Limitation of Liability for cargo loss or damage under 1924 Hague Rules and its revised version 1968 Hague-Visby Rules. The obligation of seaworthiness is also applicable to ship-owners right to GA contribution from cargo interests. Moreover, when issuing an insurance policy for a vessel, the insurer(s) will assume, when estimating the premium, that the vessel is deemed to be seaworthy at the commencement of the voyage even if they did not inquire about this. Under the Marine Insurance Act 1906 (Section 39), in a voyage policy there is an implied warranty of seaworthiness at the beginning of the voyage which means that an unseaworthy vessel is not insured at all. If, however, the policy is for a period (time policy), the underwriters are not liable to cover loss or damage to the ship caused by that unseaworthiness if the owner sent the ship to sea knowing that it was not seaworthy. Also the assured is under a legal obligation to disclose all material information and circumstances known to him or that should be known by him, or his insurance contract can be void (Kassem, 2006). This insurance principle *'uberrimae fidei'* was re-established in the recent case of MV Sea Panther which sank due to collision at sea and the H&M policy underwriter repudiated ship-owner's claim for 'total loss' as the fact, **damage of the main engine crank shaft was not disclosed, also to the classification society, which would have made the vessel out of class and apparently unseaworthy**, despite ship-owner claiming that at the time of the incident the vessel was seaworthy (Krishnamurthy & Bhadoria, 2024). Then the question is how a ship-owner survives if incidentally all protections fail on the issue of seaworthiness and the liabilities that are not covered under H&M insurance.

> *H&M insurance provides physical damage protection for the vessel and its machinery, i.e. loss or damage caused by perils of the seas like fire, explosion etc*

To protect themselves, first British owners created Protection and Indemnity (P&I) Clubs, whereby they insured each other against the liabilities to which they were all exposed in the operation of their vessels, but the Marine Insurance Act 1906 applies to all marine insurance policies so the owner may lose his P&I cover as well due to lack of seaworthiness. As per P&I terms and condition, assured is under the obligation to maintain the insured ship(s) in every respect in a seaworthy and cargo-worthy condition (TMS, 2020). Therefore, relevant ship-owners protections are discussed below for general readers to appreciate events for the case of MV Dali.

H&M, P&I & GA

H&M insurance is basically the insurance of the client's vessel as its primary asset. H&M insurance provides physical damage protection for the vessel and its machinery, i.e. loss or damage caused by perils of the seas like fire, explosion etc. Loss must be fortuitous (not inevitable) and not caused by wilful misconduct. H&M may cover Salvage charges and GA contribution as agreed. It may include some cover for liabilities towards third parties depending on the type of policy and scope of cover of that policy, i.e. in case of 'collision liability'. Under standard English H&M insurance, collision liability is historically limited to 3/4th of the own ship's liability towards the other vessel in a collision. However, it excludes Fixed and Floating Objects (FFO) liability (loss or damage caused by the physical contact between the insured vessel and third-party property e.g. bridge, pier etc.) which the ship-owner will then include in the P&I insurance (Gard, 2009).

Protection and Indemnity (P&I) insurance is primarily intended to indemnify a ship-owner or operator for his liability towards third parties. It generally excludes damage to the insured's own property or direct loss of the Company. For collision liability and liability for contact damage to 3rd party property, P&I covers indemnities for liabilities that are not covered under H&M. (Gard, 2009). Today, the top 12 P&I Clubs formed the International Group of P&I Clubs (IG P&I), a not-for-profit association providing marine liability cover for about 90% of the world's tonnage by sharing the burden by a pooling mechanism.

MV Dali's H&M policy will cover the physical damage, i.e. structural damage to the ship's hull and repairs and salvage costs, i.e. expenses for the vessel's salvaging (the ship-owner's proportion of the GA) (MC, 2024) unless owner's fault would render the owner liable, i.e. owners knew that they had failed to make the ship seaworthy at the beginning of the voyage. However, if the 'Brahmastra' of alleged unseaworthiness works in the US Court then all liabilities will come on P&I and the burden of huge claims would fall on 80 reinsurers of the IG P&I, arranged under a standard risk-sharing mechanism, which is beyond the pooling within the IG P&I club. (Supra, 2024)

Protection and Indemnity (P&I) insurance is primarily intended to indemnify a ship-owner or operator for his liability towards third parties

General Average (GA) is a principle of maritime law based on ancient Rhodian law that requires all sea cargo stakeholders, both the ship-owner and the shippers, to proportionally share any damage or losses that may occur as a result of a voluntary sacrifice of part of the vessel or cargo to save the whole in an emergency. It is codified and applicable through York-Antwerp Rules 1890 (last amended in 2016) which is included in sea trade documents such as Bills of Lading and Charter Parties. GA can be declared by the ship-owner for a number of reasons including, inclement weather, when cargo is lost, fire on board the ship, machinery breakdown, stranded or grounded ships etc. In such cases, the ship-owner is entitled to a lien (legal right) over the cargo for the GA contribution due from the cargo interest. In practice, the ship-owner will forgo the lien and release cargo in return for a GA bond from cargo interests (insurers) to pay the due GA contribution. The ship-owner appoints a GA adjuster (normally from the Association of Average Adjusters, London) to assess the contribution due from cargo interests, which cargo interest and its insurer may challenge in the court or arbitrator for owners failing their obligation of due diligence to make the ship seaworthy at the beginning of the voyage. (Anderlini & Teitelbaum, 2024). The entitlement to GA contribution essentially stands and falls on whether the owner breached its carriage obligations or can otherwise escape the consequences of that fault via the terms of the contract or statute, i.e. negligent navigation of Hague-Visby Rules. Therefore, GA is not applicable for lack of owners' seaworthiness obligation; a non-delegable duty also under H&M.

Ship-owners Liability Regime - United States

It is relevant to mention that the USA is not a party to many international conventions including LLMC (Limitation of Liability for Maritime Claims) Convention 1976 and preferred to rely on their age-old national provisions, i.e. Limitation of Liability Act 1851. Harter Act 1893 is still applicable in certain parts of US sea trade and not fully supplanted by the Carriage of Goods by Sea Act (COGSA) which was passed in the US in 1936 embracing the 1924 Hague Rules, but with a package limitation of $500 and applicable from 'tackle-to-tackle' only (BR,2021). Regarding the responsibility of ship-owners, COGSA specifies that *the carrier shall be bound, before and at the beginning of the voyage, to exercise due diligence to make the ship seaworthy.* This means that the carrier is not liable for damage to the cargo resulting from the unseaworthy condition if the defective condition rendering the vessel unseaworthy is not reasonably discoverable, or it arose after the vessel's voyage commenced. Unlike the Indian COGSA 1925 and the COGSA of many other States, applicable only to export cargo from the State, the US COGSA is applicable for both import and export cargo. Similarly, unlike English law and the law of several other countries, ship-owners are not entitled to GA contribution under US law if the fault lies with the shipowner or their agents, but this is often reversed by incorporation of the New Jason Clause in the BOL and charter parties for all US import and export cargo by sea. The American law then becomes like English law and cargo interests cannot avoid contributing to GA, unless that fault would render the owner liable under the applicable rules i.e. *owners have failed to exercise due diligence to make the ship seaworthy at the beginning of the voyage* (Venezia,2021). This provision was relevant at a time when communication was not like today and owner had no control after the vessel's sailing. Today with satellite communication, the shipping company (ship-owner) is in continuous contact with the ship and the 'Privity and knowledge' of the vessel's master, superintendent or managing agent of the vessel is often imputed to the owner. If any of these individuals were at fault for the incident, ship-owner may be prevented from claiming limitation of liability under the Limitation of Liability Act 1851 or GA contribution from cargo interest. This is as per the outcome of several court cases such as MT Cape Bonny and container ship CMA CGM Libra where the ship-owner's defence for GA contribution claim failed due to the issue of seaworthiness at the beginning of the voyage, apparently known to the respective ship-owners. In the case of *Metropolitan Coal Company vs Thomas J. Howard*, the shipowner, was held fully liable for the loss of cargo despite the limitation of liability clause in the charter party. Nevertheless, the US Limitation of Liability Act 1851 was successfully invoked to limit liability of ship-owners in many cases including the sinking of the RMS Titanic (1912) and recently in the DWH (Deepwater Water Horizon) oil spill (2010) case. DWH was a floating platform, capable of navigation hence giving it legal status similar to that of a ship. As Deepwater Horizon has sunk, it has virtually no value. Therefore, the owner Transocean filed a petition for limitation of liability to US $ 26.7 million based upon a calculation of the oil then pending for sale from the oil rig (SJ, 2024). Under

this US Act, claims arising from personal injuries, deaths, fire, collisions or allisions, sinking, salvage and lost cargo are all covered. However, claims for cargo damage caused by improper deviation of the vessel have been deemed outside the Limitation Act's scope. Also, environmental claims such as those arising under the Oil Pollution Act of 1990 or the Clean Water Act 1972 are not limitable. Following the Deepwater Horizon disaster in 2010, the US initiated a bill to entirely repeal this old Limitation of Liability Act as it had lost relevance in today's context, but the bill has not made any progress to date. The USA is a common law country where 'Stare Decisis' applies, that is decisions in previous similar cases have relevance in the outcome of the current case. Now it is yet to be seen how this MV Dali case unfolds under the old US Limitation of Liability Act and the jurisprudence of US Courts if GA claims are challenged by cargo interests who are many, MV Dali being a container vessel. Some cargo may also be uninsured, often 10-15%, in which case cargo interests have to pay a deposit as per cargo value instead of depositing a security bond from cargo insurers. Also, owners of the cargo in the containers that were crushed on deck or fell overboard will have a strong case for compensation under the Hague Rules or US COGSA and the Carrier has to satisfy the court that they had 'exercised due diligence to make the vessel seaworthy before and at the beginning of the voyage' which is again questionable. So, the 'error in management of the ship and act, neglect, or default of the master, pilot, in navigation' exemption can be rebutted, but the claims might be subject to a limit of USD 500/ package. The compensation burden of the ship-owner may vary largely as the term 'package' is often disputed, if not enumerated in the BOL. The ship-owner will argue it is the container and cargo interests will claim it is the packets inside the container! The court judgements on this issue have varied widely (Mitiku, 2019) but further discussion is beyond the scope of this article.

Ship-owners Liability Regime -International Convention

As the incident happened in US waters, the US legal system is naturally the jurisdiction but the owners and operators are not US corporations and thus might also seek limitation under the LLMC in Singapore Court if required, as Singapore is a party to LLMC and especially when MV Dali is currently not in the US waters and beyond the scope of arrest 'in rem', albeit under the LLMC the limit of liability is higher. Hence the US claims against petitioners, Grace Ocean and Synergy Marine 'in-'personam', as Dali is registered under Singapore flag. The LLMC 1976 Convention of IMO is a global liability limit for a ship, for personal injury or death and loss of or damage to property. A ship-owner can limit 'total liability for claims of a single event'. Limits are different for loss of life and property as per GT (Gross Tonnage) of the vessel. The LLMC Protocol 1996 provides a considerably higher amount of compensation for maritime claims and it was further amended by the IMO in 2012 for much higher limits. However, the right to limit liability under LLMC (Article-3) does not apply to salvage claims or GA contributions. As per the IMO 2012 amendment of LLMC, liability would be limited to approximately US$ 171 mn (57 mn for property damage and 114 mn for personal injury and loss of life) (Gallagher, 2024). This option is more important because in August 2024 two U.S. House of Representatives members introduced the 'Justice for Victims of Foreign Vessel Accidents Act (Bill)', which would retroactively increase the liability for foreign-flagged vessels to up to 10 times the dollar value of the vessel and its cargo.

The Limitation of Liability Act of 1851, protects vessel owners, but the original Act was silent on whether the limitation of liability extended to foreign-flagged vessels, yet courts extended those protections to foreign-flagged vessels. The new Bill proposes that the

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14. Machinery Maintenance - Skill Enhancement - Module 4	10 - 12, 17 - 19	01 - 03, 14 - 16, 21 - 23, 28 -30

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> *Hence, necessary bearing clearance measurements should have been taken and a significant increase in clearance would necessitate a repair before the voyage could safely be undertaken*

current liability threshold for American-flagged vessels would remain unchanged (Escobar & Nolan, 2024). It is too early to predict the implications of the Bill being introduced and whether achieving passage in the US Congress in the post-election USA is a viable scenario. However, the Limitation of Liability Act of 1851 seems to make it much easier to break limitation by reference to 'privity *or knowledge*' of the owners/ managers. Claims subject to the LLMC are limitable regardless of the vessel's seaworthiness, unless it was in so bad condition that the negligence is even worse than gross negligence and reaches 'recklessness', and even then, it has to be proved that the owners / managers knew that such loss would probably result. i.e. blackout leading to an allision with the bridge. **That is highly unlikely as the right to limit has only been broken once or twice (ever)**. Arguably, it was 'reckless' not to make permanent repairs of a known blackout problem, also happened before the vessel left berth and the owner/ manager must have realised that ship's power failure was more than likely to happen again (not to say inevitable), and as the vessel had to navigate narrow channels and under the bridge. Therefore, if Singapore becomes a feasible option as jurisdiction and the LLMC is applicable, it would still be an uphill struggle for the claimant to 'break limitation', but at least the argument could be made! Undoubtedly, there will be no quick resolution to our questions about who is liable for payment of what and how much!

General Average and Limitation of Liability Cases

In 2011, MT Cape Bonny suffered a catastrophic main engine breakdown, she was towed to Yosu and cargo was transferred to another ship. Ship-owners declared GA and cargo insurers gave a GA guarantee! However, cargo interests sued the owner for the allegation of seaworthiness. The English Court ruled that the vessel was unseaworthy and neither the cargo interests nor their subrogated underwriter was liable for the cargo's proportion of GA as the ship-owner had failed to exercise due diligence to make the ship seaworthy at the commencement of the voyage. Main engine bearings were suffering from abnormal wear out in view of the crank-web deflection readings. Hence, necessary bearing clearance measurements should have been taken and a significant increase in clearance would necessitate a repair before the voyage could safely be undertaken. Also, presence of foreign particles in lubricating oil (LO) and damaged LO filters were evident from E/R records. In case GA contributions are not recoverable from cargo interest P&I has to provide cover in respect of the missing contribution from cargo (Arunachalam, 2021). In 2011, CMA CGM Libra loaded containers at Xiamen. The vessel's working chart was not updated. The second officer prepared the passage plan and the vessel ended up in shallow waters and grounded. The owner incurred salvage costs to re-float the vessel and claimed GA. Cargo interest claimed there was an actionable fault by the ship-owner with respect to IMO requirement in 1999 on passage planning for all ships on international voyages.

'*Well planned voyage is of essential importance for safety of life at sea, safety of navigation and the protection of the marine environment*', consequently, the negligence in preparation of the passage plan constituted lack of due diligence. The arguments of the ship-owner were that updating charts and preparing passage plan are matters of navigation, rather than the carrier's obligation regarding seaworthiness. However, the court held that the vessel was unseaworthy as a result of carrying defective charts and passage plan. Hence, the ship-owner was not entitled to claim GA contributions from cargo (MM, 2022). In the Metropolitan Coal Company vs Thomas J. Howard case in 1946 in the US, the court found that the vessel Thomas H. O'Leary of Haward was unseaworthy at the time it departed Edgewater, New Jersey, primarily due to overloading and inadequately thick hatch covers. The court held that ship-owner T. J. Howard failed to demonstrate due diligence in maintaining seaworthiness.

> *The arguments of the ship-owner were that updating charts and preparing passage plan are matters of navigation, rather than the carrier's obligation regarding seaworthiness*

Cargo chain turnbuckle, welded to angle iron, and wedged between the number 1 step-down transformer (left) and a steel beam (right).

Figure 1. Source Photo: United States' claim and answer to petitioners, (Civil Action No. 1:24-cv-00941) Document

Figure 2. Source Photo: Marine Investigation Preliminary Report, NTSB, May 14 ,2024.

Consequently, Howard was held fully liable for the loss of cargo, despite the limitation of liability clause in the charter party.

Findings

MV Dali lost power before veering off course and striking the bridge. As per the National Transportation Safety Board report (NTSB,2024), electrical breakers unexpectedly opened when the vessel was three ship lengths from the bridge, causing the blackout to all shipboard lighting and most equipment Dali had experienced power outages already while docked in Baltimore, which were deemed 'reportable marine casualties' and the US Coast Guard claims that these

> ***The previous captain noted heavy vibration in his handover notes and reported concerns to the ship-managers Synergy Marine Group***

incidents were not reported to the authorities. The condition of the ship's electrical systems was so poor that an independent agency halted further testing due to safety risks. The previous captain noted heavy vibration in his handover notes and reported concerns to the ship-managers Synergy Marine Group. Excessive vibrations could loosen wires and damage connections. The Ship's transformer and breakers had long suffered the effects of heavy vibrations, a well-known cause of transformer and electrical failure. As reported in the Lloyds List, instead of taking steps to eliminate the cause of excessive vibrations, the petitioners (company) jerry-rigged their ship. 'They retrofitted the transformer with anti-vibration braces, one of which had cracked over time, had been repaired with welds, and had cracked again.' Braces were welded to the bulkhead on one side and 'crudely bolted to the tops of the transformer via a steel bracket' (Miller, 2024) **(Figure-1),** a makeshift attempt to limit the vibration. Now the question is who did or didn't know? The CEO, Master or Superintendent? Can the ship-owner and operator establish their due diligence? Ship-owner may argue that the issue was not discoverable by the exercise of due diligence and try to refuse liability! In Oct 2024 the owner and manager of MV Dali agreed to pay nearly US$102 million to resolve a civil claim brought by the U.S. Department of Justice (DoJ) in Maryland under the US Rivers and Harbors Act, Oil Pollution Act, and general maritime law. The claim was intended to recoup the money the U.S. Government spent responding to the disaster and clearing the wreck of the Dali ship and bridge debris from the Port of Baltimore so the waterway could reopen (Reuter, 2024). **(Figure- 2)** The settlement does not include any damages for the reconstruction of the Francis Scott Key Bridge. The City of Baltimore as well as the families of workers who lost their lives in the bridge collapse have already filed claims in this case,. Synergy, however, has said: *'The settlement strictly covers costs related to clearing the channel, which we would have been responsible for in any case, and is not indicative of any liability, which we expressly reject for the incident that led to the collapse of the Bridge. No punitive damages* *have been imposed as part of this settlement'. (Synergy, 2024).* Some 45 other claims for damages have also been filed in U.S. courts regarding this bridge damage out of these, some 40 relate to 'Purely Economic Losses'. US law prohibits recovery of such losses, i.e. claims for business interruption related to the inability to access the Port of Baltimore or operate business that was shut down due to the collapse of the bridge, and they may not be recoverable against the ship-owner!

Conclusion

This case will take several years before a final conclusion is reached and the money actually changes hands and until that time our quest on who pays what and to what extent will continue. The effectiveness of the Brahmastra, an allegation of unseaworthiness against ship-owners, has been tried in numerous court cases in many jurisdictions over centuries, and is now being retested again under the age-old US law. The Limitation of Liability Act of 1851 still remains a vital tool in the maritime litigator's arsenal when defending ship-owners from unlimited liability. If proper steps are taken and pitfalls avoided, the Act will, given the circumstances, exonerate or limit a ship-owner's liability. The Act, despite continued criticism and efforts for its amendment or abolition, remains alive in US, and continues to generate new jurisprudence (BLF, 2024). The outcome will almost certainly be different depending on whether US law or laws based on international conventions are applied. In mythology, Brahmastra was created, not for destruction, but to protect humanity from disaster. Hence, irrespective of the outcome of the case, the fear of Brahmastra will continue to make ships safer in the future. The discussion in this article is founded on academic interest and a wild guess of the possible legal consequences on this high-profile case based on the information available in the public domain.

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Integrated Approach in Nurturing Indian Shipbuilding Ecosystem Towards India Becoming A Global Player

Pradeep Kumar Jena

Abstract

India is the fifth largest economy in the world in terms of GDP and it is expected to overtake the Germany acquire fourth position. Despite the Country's long coastline, 95% of its trade by volume and 70% by value is done through Sea, huge maritime infrastructure such as 25 - 30 Shipyards with capacity to build up to 0.4 million DWT (400,000), 12 major and 200 non major ports, the shipbuilding capabilities of our nation have not kept pace with its economic development, market demand and human resource potential. The global ship building and ship repair market remains meagre and hovering around 1-2%.

The paper aims to bring out the challenges and issues faced by the Indian shipyards and its current eco system, analysing and proposing way ahead towards India becoming a Global player. During the process of study, details are provided to generate shipbuilding demand of 45 million of CGT both overseas fleet and coastal/inland fleet, by evolving policies and addressing local factors which are entirely under India's control. In addition, ship repair and maintenance Industry segment has huge potential due to strategic location of India in international sea routes. Globally the ship repairs market is expected to reach 40 billion USD wherein India's share is presently miniscule less than 1%.

The research analysis in line with MIV 2030 and Maritime Amrit Kaal vision 2047, along with author's vast maritime experience has brought out few recommendations for integrated approach nurturing the shipbuilding ecosystem which would address the infrastructure, regulatory, fiscal issues and capability development is need to be developed.

Keywords: Global Shipbuilding, Challenges, Industrial growth, Competitiveness, manufacturing, economy, and Maritime India Vision.

Introduction

India has long standing maritime tradition, with shipbuilding activities documented as early as the Indus Valley Civilization. Coastal regions covering both eastern and western seaboards have been centres of shipbuilding for centuries. Shipbuilding industry holds strategic significance due to its role in energy security, national defence and its immense linkages with most other leading industries. The shipbuilding industry has the same impact as infrastructure sector and potential of generating mass employment in remote, coastal and rural areas. Promotion of ship building and ship repair industries therefore should be given prime importance due to their potential to strengthen the economy and Atma nirbhar Bharat mission.

Presently shipbuilding is dominated by China, Japan and Korea. Despite India's vast coastline, and with about 1200 islands, 12 major and approx. 200 non major ports, India's shipbuilding capabilities have not kept pace with its economic development, market demand and human resource potential. This offers huge scope for the development of the shipbuilding sector considering that country's potential have not been fully exploited. Government. of India through its vision documents MIV 2030 and Amrit kaal 2047 listed measures to be instituted which will guide the way ahead towards a robust maritime sector.

Problem Statement

Our country has got a long coastline of about 7,600 km, well protected by a large fleet of Indian maritime forces. 95% of the trade volume is done through Sea and there is a significant presence of Shipbuilding and repairs industries within the country. Despite this, the Indian shipbuilding capabilities have not kept pace with its economic development.

> *It is pertinent to mention that the last peak in global ship deliveries occurred in 2011, resulting in more and more ships nearing retirement age now*

Aim of the Paper

This paper seeks to bring out action areas for all stake holders in nurturing the shipbuilding ecosystem of the country by analysing the inherent challenges in shipbuilding, drivers for growth of shipbuilding and requirement of policy reforms so that India can become a global maritime player.

Distinctive Features of Shipbuilding Industry

The shipbuilding is a complex and diverse industry and its distinctive features and cyclic nature is mentioned below:

Distinctive Feature

(a) Wide variation of trade ability wherein the Builder sells the Ship first and construct later unlike other Business the manufacturer builds first and sells later.

(b) Creditability: projects completion and globally competitiveness plays a major role in winning contracts.

(c) The deliverables of the industry involve long gestation periods min 2-3 years and require high cost finance over a long period.

(d) Labour intensive Industry.

(e) Shipbuilding accelerates when expansion of seaborne trade, replacement of ship, changes of regulations and for warships depending on the geopolitics.

(f) Cyclic Feature of Shipbuilding Industry: The combination of demand-side opportunism and supply-side inflexibility tends to slow the market adjustment process, leading to some very long shipbuilding cycles. Shipbuilding cycles are, of course, close relatives of the shipping cycles wherein the shipping cycle has

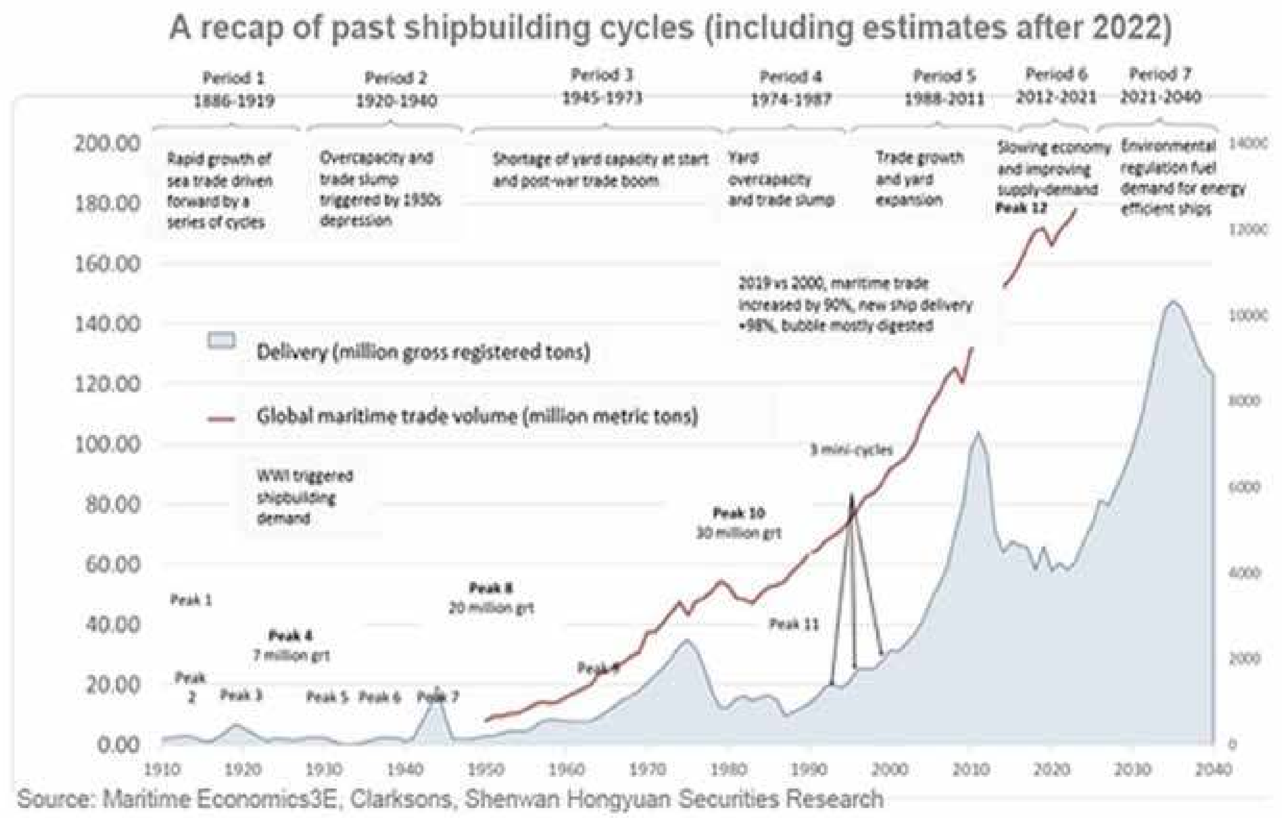

Figure 1 Shipbuilding Cycle
Source: Maritime Economics: Martin Stopford / Clarksons

four stages: trough, recovery, peak, and collapse. In the trough, freight rates fall to operating costs, forcing companies to sell ships at low prices. In recovery, freight rates rise above costs and laid up tonnage falls. At the peak, supply and demand are balanced with high freight rates and full fleet utilisation. In collapse, supply exceeds demand, causing freight rates and ship speeds to decrease again. As with the shipping cycles, these cycles were not just random fluctuations designed to make life difficult for the shipyards, but are part of the mechanism for adjusting shipbuilding capacity to the changing needs of world trade.

"Indian Shipbuilding industry is anchored around 42 Shipyards (both private and public) and has a reported capacity to build large cargo vessels up to 400,000 DWT"

Over the last century, there have been 12 separate cycles which are plotted in **Figure. 1.** The average cycle lasted 9.6 years from peak to peak, but the spread was very wide, ranging from 5 years to over 25 years. The average reduction in output from peak to trough was 52%, and the maximum peacetime reduction was 83% during the recession of the early 1930s. It is pertinent to mention that the last peak in global ship deliveries occurred in 2011, resulting in more and more ships nearing retirement age now. **Currently, roughly 53% of ships in operation are over 20 years old. By 2030, this number is expected to reach 70%.**

This trend will continue to drive the demand for fleet renewal. On the other hand, the International Maritime Organization's (IMO) 2030 carbon emission reduction target has further accelerated the replacement of older, less energy efficient ships. Leading shipping companies are aware of the tightness in shipyard capacity and have started to place orders for clean energy ships in advance to meet the environmental requirements by 2030.

Shipbuilding in India: Evaluating its current position

Indian Shipbuilding industry is anchored around 42 Shipyards (both private and public) and has a reported capacity to build large cargo vessels up to 400,000 DWT.

However, the shipbuilding industry finds itself in a position that is below its true potential. The industry today exists as a monopsonist for defence shipbuilding with a reasonably strong domestic demand and insignificant demand for commercial shipbuilding. Defence shipbuilding is dominated by DPSUs and PSUs, with a small amount of work sharing with private shipyards. However, despite efforts from the government to encourage private participation in defence shipbuilding and efforts to stimulate the supply side, the private industry has gradually declined over the last few years.

Ship building capacity is defined in terms of Dead Weight Tonnage (DWT). The Shipbuilding capacity of Indian Shipyards is shown below in Bar chart:

In addition to the Shipyards mentioned in **Table1**, other private players active in Shipbuilding/repairs are A. C. Roy & Co. Ltd.(ACRL), A.H. Wadia Boat Builders, Bristol Boats, Chowgule Lavgan Shipcare Pvt. Ltd. Ferromar Shipping Pvt. Ltd. (FSL), Mondovi Dry Docks (MDD), Patra Shipping Pvt. Ltd (PSPL) , San Marine , Sea Blue Shipyard Ltd. (SBSL), Udupi Cochin Shipyard Ltd, Titagarh Wagons Ltd. (TWL), Waterways Shipyard Pvt. Ltd.(WSPL) and Yeoman Marine Services Ltd.(YMSL).

Indian Shipyards in 2023, had orders of 433 ships with gross DWT 249.94 thousand tonnes. Out of these, the public sector shipyards had orders of 125 ships of 134.55 thousand DWT. The private sectors had orders for 308 ships of 115.39 thousand DWT. It is to be noted that Cochin Shipyard Ltd and A.H Wadia Boat Builders had the highest number of ships on order among public and private industry respectively.

Figure 3. Pie Chart for International Ships Order (1000cgt)

Figure 4. Pie Chart for International Ships Order (in, 000 cgt)

The entire shipbuilding requirements of our maritime forces are currently met through Indian shipyards largely restricted to DPSUs. The defence shipbuilding has seen an unprecedented growth in line with our maritime forces expansion. These shipyards over the years have built capability to design and deliver advanced weapon intensive platforms. However, the contribution of defence shipbuilding towards export is negligible and not encouraging. The main reason for the limited development of India's defence industrial base, is the wide variety and mission specific ships constructed in lesser numbers for IN/ICG which limits the standardisation in view of lack of volumes. In order to develop the industry base, the shipyards have to attain 'Critical Mass'.

> *Presently, China, South Korea, and Japan have dominated the shipbuilding market across the world and accounted for a global share of 41.6% (39930 in, 000cgt), 35.7% (34236 in, 000 cgt) and 10.5% (10097 in, 000 cgt) respectively in ships on order in terms of compensated gross tonnage in 2022*

India shares only 0.16% of the global new shipbuilding orders. Therefore, we need to recover from the present low performing shipbuilding status with long term vision and plan for strengthening of the Indian shipbuilding industry. The commercial shipbuilding demands efficiency and cost competitiveness of very high order. It is to be noted that among the private players the performance L&T Shipbuilding, A.H Wadia Boat Builders, AC Roy & Co. Ltd., Chowgule & Co. Ltd. And Sea Blue Shipyard Ltd. have performed well, however still lacks global competitiveness. Unfortunately, few private shipyards are plagued with dwindling order books, excessive debt, non-existent credit, falling incomes and severe cash flow constraints. Poor cash flow and failed attempts at debt restructuring & liquidation proceedings has resulted in closure of three Shipyards.

Environmental Scan : Global shipbuilding

The global shipbuilding industry has undergone profound transformations, diversifying in terms of scope, complexity, and trade impact. This study explores these shifts by analysing the evolving patterns within shipbuilding firms from Japan, Korea, and China. We embark on a historical journey, tracing the transition of industry leader - ship from Europe to Asia. As a case study, we present a detailed examination of the five stages of the Korean shipbuilding industry's transformation, spanning from domestic advantage to global prominence. To establish a comparative framework encompassing the shipbuilding industries of Japan, Korea, and China, we introduce two critical parameters: innovative value delivery capabilities and global market positioning. These parameters illuminate the distinctive evolutionary paths taken by the three Asian countries within the realm of shipbuilding. Our findings underscore that in an environment characterised by intensifying competition and shifting geopolitical dynamics, leading companies strategically leverage their national manufacturing strengths and logistical infrastructure while adeptly navigating the complexities of global politics and the industrial policies pursued by their respective nations.

This research offers invaluable insights and implications for future investigations of the global shipbuilding industry in the post-pandemic world. The global shipbuilding industry has undergone profound transformations, diversifying in terms of scope, complexity, and trade impact. This study explores these shifts by analysing the evolving patterns within shipbuilding firms from Japan, Korea, and China. We embark on a historical journey, tracing the transition of industry leader- ship from Europe to Asia. As a case study, we present a detailed examination of the five stages of the Korean shipbuilding industry's transformation, spanning from domestic advantage to global prominence. To establish a comparative framework encompassing the shipbuilding industries of Japan, Korea and China, we introduce two

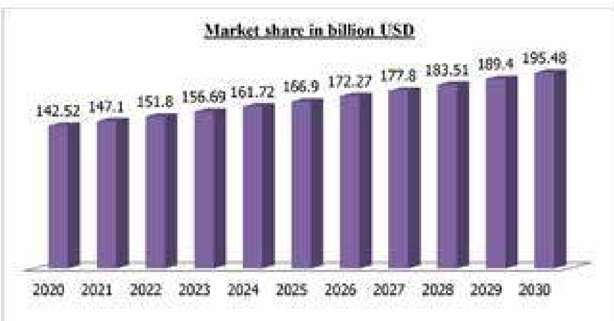

Figure 5 Statista Research Global Shipbuilding Market

Figure 6 Mordor intelligence Research Global Shipbuilding Market

critical parameters: innovative value delivery capabilities and global market positioning. These parameters illuminate the distinctive evolutionary paths taken by the three Asian countries within the realm of shipbuilding. Our findings underscore that in an environment characterised by intensifying competition and shifting geo- political dynamics, leading companies strategically leverage their national manufacturing strengths and logistical infrastructure while adeptly navigating the complexities of global politics and the industrial policies pursued by their respective nations.

Mordor Intelligence estimated the shipbuilding market at $ 148 USD billion in 2024, and is expected to reach $ 184.5 billion by 2029, growing at a CAGR of 4.84%

This research offers invaluable insights and implications for future investigations of the global shipbuilding industry in the post-pandemic world. The aim of environmental scan of global shipbuilding is to identify their efforts and strategies that have supported their growth of shipbuilding. This will help in identifying possible gaps and lessons to be drawn for Indian shipbuilding Industry. The countries are the top shipbuilding countries in the world, based on their capacity, output, and technological advancements in shipbuilding. These countries don't just build large no of Ships, also they come up with new ideas to make ships better, safer, and greener for the World.

Presently, China, South Korea, and Japan have dominated the shipbuilding market across the world and accounted for a global share of 41.6% (39930 in, 000cgt), 35.7% (34236 in, 000 cgt) and 10.5% (10097 in, 000 cgt) respectively in ships on order in terms of compensated gross tonnage in 2022. However, India stood at distant position with meagre share of 0.16% (157) out of total global order of 96050 (in, 000cgt). The share of shipbuilding nations are shown in below pie chart:

Study of Chinese Shipbuilding Ecosystem

China leads the global shipbuilding industry with their Shipyards are immensely competitive not only in Commercial Shipbuilding bagging large share of global orders but also, able to massively scale up their warships. The Chinese government has heavily invested in upgrading technology and facilities, aiming to dominate not just in quantity but also in the quality of ships produced. This strategic focus has positioned China as a go-to destination for cost-effective and technologically advanced shipbuilding solutions.

The Chinese shipbuilding industry has transformed from a 'basic ship producer' to an "Strategic infrastructure Industry" by sheer focus on technology and policy measures. They have dominated the world with 70 % of China's shipbuilding products exported. This enormous growth has been aptly achieved through following:

(a) Policy Changes These are profit-retention reform during 1979-83, tax-for-profit reform during 1983-86, adoption of the contract management system during 1987-92, eleventh five year plan 2006 – 2010 , Strategic status for Shipbuilding industry and finally large scale investment.

(b) Financial reforms These are Income Tax benefits & Export tax rebates, Fundraising reforms, Stabilisation of material costs and incentives/ Subsidies to ship owners.

(c) Development in Science and Technology & Manufacturing Industry through Technical cooperation learning and Innovation between Chinese Yards and interactions with foreign shipbuilders

(d) Shipbuilding methods including Design through developing advanced hull section construction technology and outfitting technique and mechanisation and assembly line works to reduce the shipbuilding time.

(e) Shipbuilding Industry Cluster China has emphasised on creation of maritime clusters which are vital for the growth of shipbuilding and repair industry. This clusters would cultivate the entire ecosystem for the industry.

Study of Korean Shipbuilding Industry

The Korean Government has played a played a great and crucial role in growth of Korean shipbuilding. The Government has launched the export led industrialisation policy which focused on the manufacturing sector. There was a shift in the industrial plan from light industry to technology oriented industry in the1970s wherein the aim was to boost exports and GDP within a short period of time. The Government designated shipbuilding as strategic industries and focus was made through successive five year economic development plans from 1962 to 1980. The Government has supported the shipbuilding by subsidies and loans, shipbuilding clusters were developed to encourage effective coordination between the shipbuilders, ancillary industry, associated manufactures and service providers.

Shipbuilding Market Research

A report from Statista research shares that the industry was worth $152 billion in 2022 is expected to increase by a compound annual growth rate (CAGR) of around 3.2 % up to 2030 and likely to increase to over $ 195 billion as shown below:

Another report, from Mordor Intelligence estimated the shipbuilding market at $ 148 USD billion in 2024, and is expected to reach $ 184.5 billion by 2029, growing at a CAGR of 4.84% during the forecast period as shown below:

Gap analysis

The author has carefully analysed both Indian and global shipbuilding scenario which has revealed following gaps of Indian shipbuilding industry is suffering from:

(a) **Absence of Indigenous Ancillary Industry** Development of ancillary industry is very important in shipbuilding. The shipbuilding sector in China and South Korea has received government fiscal and policy support, enabling them to develop scale as well as a cluster of ancillaries. However, in our country the ancillary industry for shipbuilding is vastly underdeveloped as major components and machinery required for shipbuilding are imported as it is cheaper and timely receipt.

(b) **Lack of Synergy between Public and Private Yards** A key gap in India's shipbuilding is lack of synergy between public and private shipyards. Both the shipyards operate separately without combining their respective strengths. It is pertinent to mention that the public sector has experience of war shipbuilding and private yards have greater flexibility and operational autonomy with vast infrastructure with them. It has been observed that PSU shipyards are sometimes not in a position to meet the warship delivery timeline and this opens a scope for partnership with private yards to reduce the build period. Also our shipyards are not successful in forming Joint Ventures among shipyards.

(c) **Low Labour productivity and Lack of skilled & efficient manpower** India has a huge disadvantage against the competing countries like China, Japan and Korea in terms of skills and labour productivity. There is a shortage of basic skills in the industry with lack of manpower with techno-economic specialisation in shipbuilding.

(d) **High Financing Costs and Working Capital** The shipbuilding activity is highly capital intensive and typically requires a working capital of around 25-35% of the cost of the ship during period of built. The interest rates on working capital in India are in the average range of 10-11%. In contrast, the interest rates presently offered to shipbuilding yards overseas are significantly low at 5-6% in Korea and 4-8% in China.

(e) **Tax Burden** The challenge has emerged is the applicability of 5% GST on the domestic materials to be utilised for shipbuilding, sale of ships, capital goods for shipbuilding and replacement of yard facilities. GST of 28% and 18% are applicable for sports/rowing boats and GST of 18% is applicable for ship breaking. These statutory tax burdens put a financial stress on the shipyards which are already starved of funds.

(f) **Cost of Bank Guarantee** The ship owners seek bank guarantees from the shipyards like performance guarantee for timely delivery of the vessel, refund guarantee for advance payment and post construction guarantee for covering defects to remain under guarantee for certain period post-delivery. Our financial institutions also do not focus on shipbuilding sector `like other major shipbuilding nations provide support to the shipyards for extending these guarantees.

(g) **Inadequate R&D Infrastructure, Technological Processes and Innovation.** The Indian Shipbuilding industries have challenges of inadequate innovation and less investment in R&D as compared to the advanced shipbuilding nations. The self-reliant capabilities in these countries were enabled through planned investments in R&D including basic research. Indian Shipyards lacks investment in R&D and future technologies such as stealth, hybrid, indigenisation, propulsion, digital twin and unmanned systems to be ready for the future.

(h) **Multiple Clearances** The present requirement to obtain multiple clearances covering land acquisition, Environmental clearance, power and water etc from various departments for new projects in shipbuilding acts as a deterrent to attracting investment into this sector.

(i) **Supportive Government Policies** The supports extended to shipbuilding industries were inadequate in the past and had severely affected the Industry particularly the private shipyards.. However, recently the Government is bringing in reforms and policies as financial assistance policy.

SWOT Analysis - Indian Shipbuilding

(a) **Strength**.

(i) India's vast coastline and proximity to major shipping routes offers a natural advantage for shipyards, reducing transportation costs and good locations for setting up shipyards.

(ii) Labour intensive industry and has high potential to generate employment vis-à-vis other manufacturing industries.

(iii) India has reputed institutes like IITs, IMU, and deemed universities producing pool naval architects and marine engineers.

(iv) Indian Shipyards has experience in both commercial and war shipbuilding.

(v) Indian skill set has proven capability of advanced software development and applications.

(b) **Weakness**.

(i) Monopsonist defence shipbuilding and poor presence in commercial shipbuilding.

(ii) Inadequate policy support, delayed decision making resulting in cost and time overrun.

(iii) Ships built period and delivery timeline is more compared international scenario.

(iv) Lacks in in-house design capability for specialised vessels.

(v) R&D in shipbuilding limited and thus not meeting the demands of the emerging market.

(vi) Absence of a dedicated government agency to integrate R&D and production in line with major shipbuilding nations.

(c) **Opportunities**

(i) 'Make in India' policy to give boost to the Indian Industry.

(ii) Labour costs in our country are on lower side even after factoring labour efficiency.

(iii) Strong domestic demand and flourishing Indian economy.

(iv) The GoI has formulated Maritime India Vision 2030 and Maritime Amrit kaal Vision 2047 with objective to propel India to the forefront of the Global Maritime.

(d) **Threats**

(i) Too much dependency on foreign vendors for supply of major machinery, propulsion equipment and weapons.

(ii) Inadequate lifecycle support for the indigenously developed systems and long delivery timeline.

(iii) Low productivity compared to Japanese, Chinese and Korean shipyards.

(iv) Conflicts like Russia & Ukraine and Israel and Palestine remain a threat to global sea borne trade.

(v) Indian naval architects and marine engineers are switching over to IT/software sector for more pay and comfort life style.

Recommendations on Nurturing Indian Shipbuilding Ecosystem

(a) **Government Support for Generating strong domestic shipbuilding demand** There is a need to channelize domestic demand for Indian-built ships, especially for inland and coastal shipping, and defence. Escalating disincentives on old, imported vessels can also boost demand for new, domestically built ships. It is important to note that targeting 15-20 % of indigenous shipping in overseas trade through indigenous shipbuilding will create a potential demand of nearly 32 million CGT over next ten years and replacement of aged commercial fleet will generate another 8 million CGT in ten years. Therefore, GoI can generate a total of 40 million of CGT for shipbuilding through evolving policies and addressing local factors. In addition, both Central and State Government should take necessary action for long term policy formulation to build Coastal, Inland Vessels and Tugs are to be mandatorily built by Indian Shipyards. Also, strict guidelines to be issued to replace Vessels of more than 25 years' service life and directives to all ports for maintaining pollution infrastructure. This policy formulation will provide the required **Critical Mass** to the shipbuilding Industry. The Shipbuilding Demand that can be generated is tabulated below:-

Ser	Demand Generation (in CGT)	Overseas Trade	Coastal Shipping & Inland Waterways
(a)	Replacement of Ageing Fleet > 25 Years	8.0	3.0
(b)	Fleet Addition	32.0	12.7
(c)	Repairs and Maintenance	4.8	2.0

(b) **Commercial Specifications for Aux/Patrol Ships for Maritime Forces** The noncombat ships of maritime forces may be made to commercial specifications to achieve more standardisation so same shipbuilding set up can be used for building both commercial and naval Vessels. Defence procurement represents the largest single shipbuilding budget and has potential for improving Indian Shipyard's commercial performance

(c) **Creation of Apex level Authority for Formulation of National Maritime Policy** The shipbuilding is an intermediate industry for the shipping sector. Growth in shipbuilding cannot be achieved in isolation, without an associated growth in the shipping industry. The government policies for shipping and shipbuilding industry are handled by multiple agencies and therefore lacks coordination.. It is recommended that an apex level authority preferably a secretary empowered with formulating policies and reforms on both the shipping and shipbuilding will strengthen India's maritime infrastructure and Shipbuilding Industry. The authority will facilitate clearance through a single window and ensure that bottlenecks for investment in the sector are removed.

(d) **Reduction of Build Period of Ships** The Shipyard operations are to be supported by process engineering and computer aided design and manufacturing. Indian Shipyards should follow integrated construction methods which are innovative mode of Ship construction wherein the Shipyard is able to design, create, install and test the outfitting elements during the correct phase of hull construction. This advanced way of construction will reduce build period of ships.

(e) **Shipyard Industry Diversification** To maintain shipyard's capability and workforce efficiency even during idle and depression period like reduced global &, domestic demands and force majeure COVID-19, it is recommended that Shipyards need to have products diversification i.e. to produce products not related to shipbuilding such as renewal energy technology, explore utilisation of excess capacity in pursuit of alternate energy technology development and production. The production of large wind turbine generators, motors, towers and specialised offshore vessels would seem to be natural fit for underemployed shipyards with large potential plants.

(f) **R&D in Ship Designing And Innovation.** For overall growth of the industry, there is a need to create an R&D base along with developing in-house design capability, infusing new technology, developing skilled workforce, adopting appropriate fiscal measures and industry friendly regulations, so that Indian shipbuilding can achieve credibility for delivering quality ships on time.

(g) **Export Promotion.** To boost the export of Indian built ships, focus should be on developing environment friendly and efficient designs. A major boost to the domestic shipbuilding industry can be given by exploring the demand for ships in emerging economies engaged in trade with India. The shipyards to create business development groups and actively pursue with Defence Attaches/Indian Embassies for exports.

(h) **Benchmarking of Shipyards**. It is recommended to bench mark business processes and the performance metrics of the company with the best-in-class. The benchmarking of Indian shipyards would enhance the competitiveness. The incentives payable to shipyards should be directly linked to benchmarking.

(i) **Right of Refusal to Indian Shipyards.** It is recommended that for acquisition/repair of any type of Vessels by Government Department including Public Sector Undertakings through global tendering process, RoFR is offered to Indian shipyards. In order to promote tonnage under Indian Flag, The revised hierarchy for RoFR Indian built & Indian flagged (Indian owned), Foreign built & Indian flagged (Indian owned), Indian built, foreign flagged (foreign owned).

(j) **Skill Initiatives of GoI.** The various Skill initiatives of the Government. of India may be extended to the Shipbuilding industry. Establishing Centres of Excellence for maritime and shipbuilding education, enhancing training programmes, and developing design capabilities will ensure a steady supply of skilled labour and improve the overall quality of shipbuilding. Initiatives to enhance the skill sets of the existing workforce.

Conclusion

It can be concluded that it is critical to support the Indian shipbuilding industry to overcome its challenges which is in the long term national interest. Though certain measures have been instituted by the government, enhancement in the prosperity of shipbuilding industry demands disruptive changes at policy level with short term focus on employment generation, self-reliance, capability development and long term focus on robust economic growth and making India a global maritime player. The analysis of various facts of Indian shipbuilding Industry clearly shows that India needs to look at multiple interventions including the Regulatory framework, Investment Policies, emphasis on infrastructure facility, R&D skill, Financing Process and Collaboration with advanced technology to nurture the thriving ecosystem of Indian shipbuilding and inching towards global maritime player.

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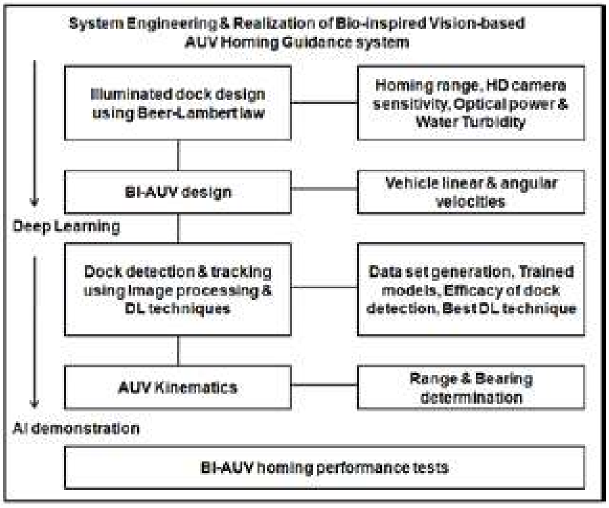
Bio-inspired AI-enabled Homing Guidance System for Autonomous Underwater Vehicles – Part B

V. Bala Naga Jyothi, A. Aryan, N. Vedachalam, S. Ramesh

Abstract

This paper describes the decade-long efforts in the development of an AI-enabled Bio-Inspired Homing Guidance System (BIHGS) for enabling long-endurance subsea missions. The inspiration is from the pigeons and passerine sea & land migrants that use a variety of olfactory clues derived from geomagnetic field and visual clues, and how they switch between them navigational strategies to navigate very-long distances. Part-A described the electromagnetic finite-element analysis-aided design and demonstration of a machine-learnt AI-enabled Electro-Magnetic Homing Guidance System (EMHGS) in which a MagHomer AUV (based on Differential Magnetometry/DM), by effecting precise attitude correction, was able to home onto a dock from a range of 7m in water surface. This part describes the development that combines the EMGHS and Vision Guidance (VG) with Kalman-filter based multi-sensor fusion, in which the BI-AUV uses DM for in-situ attitude correction and range determination, and YOLO-V5 VG algorithm to synergise DM data for precisely guiding into the 1m diameter cylindrical illuminated dock equipped with low-frequency electro-magnetic dipole generator. The deep-learnt AI-based BIHGS, which is immune to stray magnetic fields and turbid water conditions, is found to have a range of 7m and terminal homing precision of ±0.2m, with a success probability of 99.65%. The concept of the ocean-deployable, on-board Intelligent & Situation-aware Digital Twin aided BIHGS with ability to negotiate blind zones and re-course to a dynamic dock (during homing failure) under development is also described.

Stage 2: Concept and demonstration of Vision-based homing guidance



Determining dock illumination power and range

As an initial step, to conceptualise a very short-range opto-vision guidance technique in XY plane, a circular dock with white light emitting diode (LED) strip in the periphery is developed for generating the illumination up to a range of 5m. A 325mm-long, 165mm-wide prototype BI-AUV with four propellers having manoeuvrability in surge, heave and yaw degrees of freedom (DoF) is developed. A wide-angle high-definition (HD) camera is placed in front of the AUV obtains the image of the dock, as AUV progresses towards the dock. Underwater visuals captured by the camera are transmitted to the on-board computer hardware and controller for detecting the illuminated dock. The tracking algorithm determines the 2D pose of AUV relative to dock, in real-time **(Figure.1).**

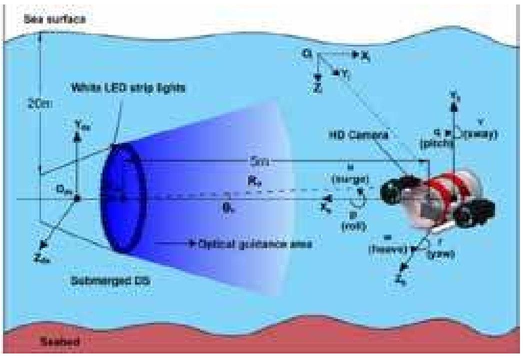


Figure 1. Concept of vision-based homing guidance

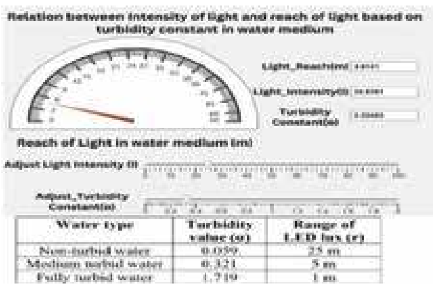


Figure 2. Software tool for estimating the power and range

The dock is fabricated to be cylindrical in shape with a circular entry having a radius of 350 mm. The white LED strip light is wound along the periphery of the dock entry and powered with a 12VDC power supply (25W) to provide an illumination of 1000 lux capable of covering a radial range of 5m. The effective range is computed considering exponential decrease in the intensity of light propagation with distance through a liquid medium (Beer-Lambert (BL) Law), which is due to the absorbing and scattering effects.

$$I = I_0 * \exp(-\alpha * r)$$

The effective range is computed considering exponential decrease in the intensity of light propagation with distance through a liquid medium (Beer-Lambert (BL) Law), which is due to the absorbing and scattering effects

Where "I" is the intensity of light at a distance "r" from the source, "I_0" is the initial intensity at r = 0, and "α" is the absorption and scattering coefficient of the water medium. A software tool based on BL law is developed using MATLAB to determine the range for the given LED light intensity, given the turbidity of sea water as the input.

Compared to the MagHomer AUV used in EMGHS that have manoeuvrability only in the surface (described in Part A), this BI-AUV has manoeuvrability in the diving plane, in addition to the XY-plane, enabling underwater homing. The image processing and control hardware **(Figure 3)** includes a real-time video processing computer featuring 128 core Nvidia Maxwell edge computing architecture graphical processor unit, quadcore Arm cortex-A57 MP core processor, 4GB dynamic RAM, video processing capability up to 30fps for HD visuals and camera interfaces. It is re-configured with the necessary libraries such as NumPy for mathematical computation, Pandas for file operation, OpenCV for image processing, and TensorFlow for DL models (YOLO) deployment.

A HD camera of 5 megapixels is placed in front of the BI-AUV and interfaced with the image processing computer, with the distance between the camera and vehicle's Centre of Gravity being 150mm. The real-time

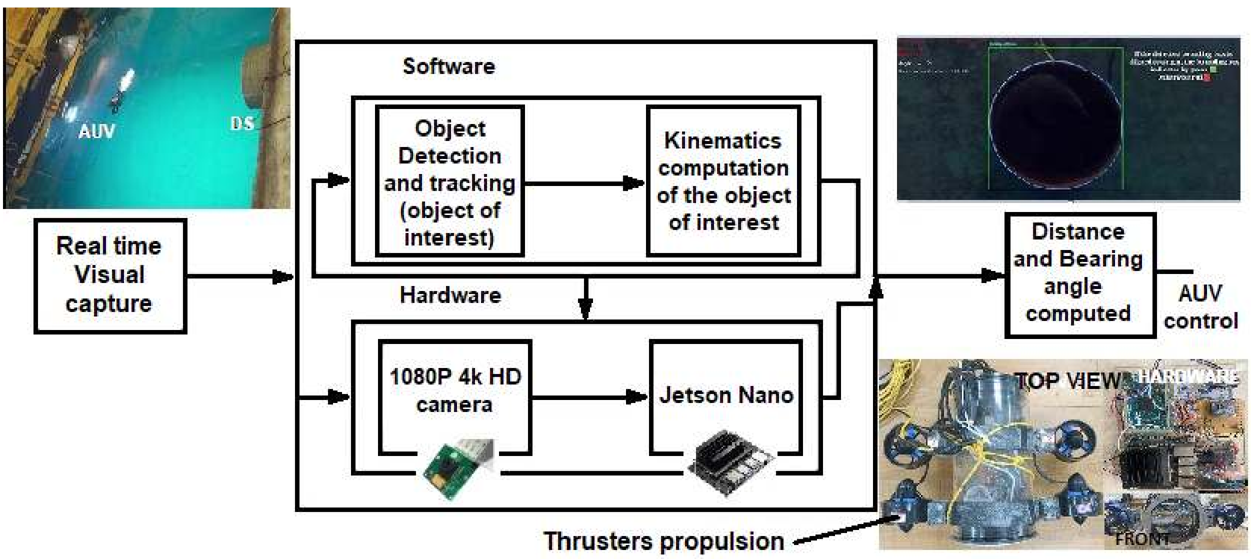


Figure 3. Image processing hardware architecture for VG

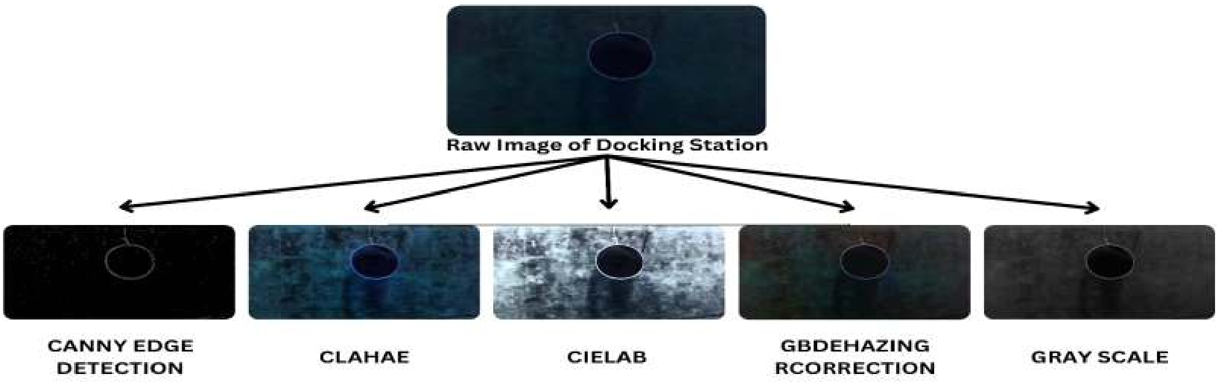


Figure 4. Different HSV techniques for dock detection

video at 25 fps acquired through the camera is converted to frames/ images every 1s, and the datasets were generated. The attitude (pose) parameters computed are transferred to the processor where the PID control algorithm is implemented to make vehicle intelligent to move towards the dock in 2D plane.

Dock detection using Image Processing & DL Techniques

For effective detection of the illuminated underwater dock, multiple image processing techniques were analysed. They include Canny edge detection, Contrast Limited Adaptive Histogram Equalization (CLAHE), and CIELAB, i.e., in CIELAB colour space, CLAHE on L is applied where GRB is converted to LAB, and the GBdehazingR correction technique is used to remove the haze, blurriness, and smoke. From **Figure 4,** it is identified that grayscale HSV is found to be qualitatively suitable for dock detection. The grayscale HSV is used to detect white light in the contrasting background. It compresses the image to its minimal pixel representation, distinguishing between shadow details and highlights in a 2D spatial dimension. The grayscale conversion is a beneficial pre-processing step in underwater imaging, as it enhances contrast, reduces noise, simplifies processing, and improves computational efficiency. Applying HSV to the grayscale converted image enables dock detection as the object of interest, even in scenarios with reflections and low-light conditions. The bounding box of the detected dock region serves as a performance metric for quantitative validation, specifically the probability of dock detection and tracking continuously.

To detect the dock, multiple deep-learning (DL) techniques were applied and validated, out of which CNN-based DL models are used for image and video processing. They extract complex features from input images through multiple layers of filters. The transfer learning is applied to pre-trained models like YOLOv5 for custom training. The pre-trained model YOLOv5 architecture is trained on large datasets with annotated images, making them effective for learning the visual features.

The pre-trained model YOLOv5 architecture is trained on large datasets with annotated images, making them effective for learning the visual features

Dataset details of the realized dock for DL techniques

The objective is to effectively detect the dock in underwater environment using a single model. The proposed methodology uses ground images to learn about object detection and tracking technique. The dock images are pre-processed using YOLO, like CNN, which requires a single forward propagation through the neural network. The CNN is used to predict various class probabilities and bounding boxes simultaneously. The model is custom-trained with underwater homing station images. Importantly, it is not one of the 80 classes given in the coco dataset. Hence, custom training was useful. **Figure 5** shows the dock illuminated with four separate LEDs (Type 1) and dock with illuminated with strip LED (Type2).

Experiments were performed to determine the performance metrics of dock detection with different YOLO

Figure 5. Dock with 4 LEDS (Type1) & circular strip LED (Type2)

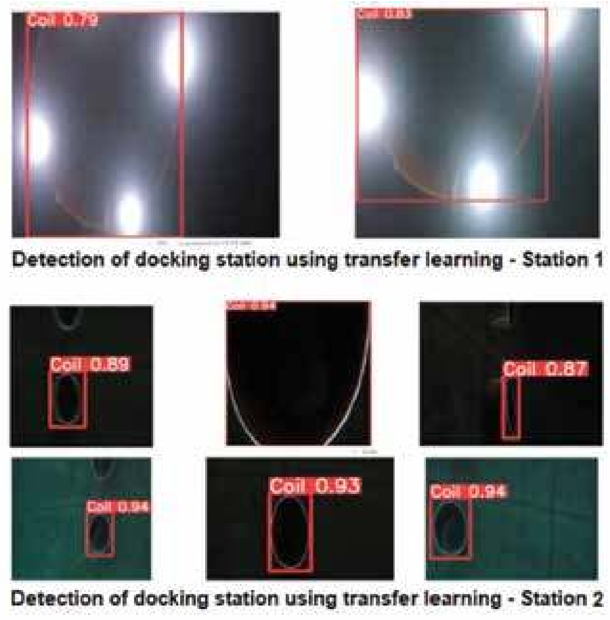


Figure 6. Different YOLO versions in detecting T1 and T2 docks

versions for the T1 and T2 illuminated docks. The wide-angle CSI camera and Type 2 dock is chosen because of its accuracy. The dataset had 7367 images, with 5200 for training, 1500 for validation, and 745 for testing.

Table 1 summarises the detection results for two dock types after training on YOLOv5 and RCNN through transfer learning. The dataset of Type2 dock is selected for further processing due to better performance, in terms of mean average precision, classification loss, object loss, and bounding box regression loss. The box loss is ~0.015 and object loss is ~0.0072. Stochastic gradient descent is used as an optimiser with a learning rate of 0.01. After training with different DL models and achieving optimal accuracy, mathematical modifications are made to extract X, Y coordinates with reference frames by de-normalising and adjusting the coordinates. The technique is deployed on the Jetson Nano, and results are saved with coordinate labels for each frame detected during the testing phase. The flowchart in **Figure 11** illustrates the process of object detection and kinematics computation for the AUV's range and bearing angle relative to the centre of the dock.

The realised dock videos are acquired in different turbid waters with different YOLO techniques and the performance metrics are compared, and the implemented YOLOv5 technique which is portable and has good performance in the available Jetson Nano board. The water turbidity is measured using the underwater multi-parameter probe supplied by M/s Idronaut Italy, Model Ocean Seven 310 (principle of scattering of light), where the turbidity meter is integrated and the range of the sensor is 0 to 2500 Nephelometric Turbidity Unit (NTU) with accuracy of 0.1 NTU and resolution of 0.025 NTU. **(Figure 7).**

The dock videos are acquired in different water types and the performance metrics is computed using different DL-based YOLO techniques **(Table 2).** The performance metrics indicates that YOLO performance degrades in waters with higher turbidity (> 25 NTU). **Figure 8** shows the dock visuals acquired in different water types and the performance of the proposed YOLOv5 technique probability of confidence.

Figure 9 a-c shows the visuals acquired in different test tanks. **Figure.9C** shows the dock visuals acquired in NIOT pond water where the dock light is scattered more and unable to identify the dock. Thus, YOLO is to be effective in less turbid waters.

Deep learning YOLO v5 architecture and control flow

The DL YOLOv5 model has a series of layers **(Figure 10)** through which the image is processed and the underwater object is identified. YOLOv5 consists of a CSP Darknet53

Figure 7. Real-time data acquisition of Turbidity value using underwater multi-probe sensor of NIOT

Table 1. Performance metrics of different YOLO versions in detecting T1 and T2 docks

Model Type	MAP Score	
	Type 1	Type 2
YOLOV5 (Resize 640x640)	98.6	99.2
YOLOV5 (Resize 416x416)	98.3	98.9
YOLOV5 (Resize 416x416 + Auto Orient)	98.5	99.5
YOLOV4 tiny	97.4	99.34
YOLOV6	96.7	98.8
YOLOV7	97.2	99.2

Table 2. Mean Average Precision metrics in different water types

Turbidity value (NTU)	MAP Performance Metrics of YOLO		
	v4	v5	v6
9.5	0.85	0.88	0.90
15	0.82	0.91	0.89
31.6	0	0	0
141.2	0	0	0

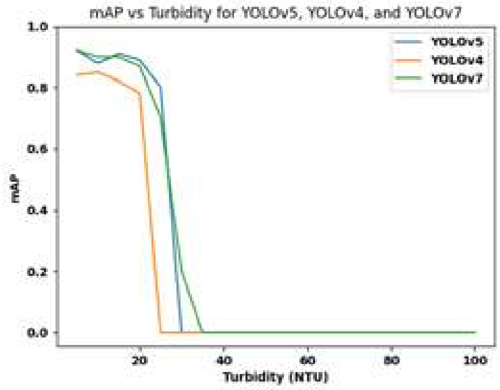


Figure 8. Performance of YOLO under various turbidity conditions

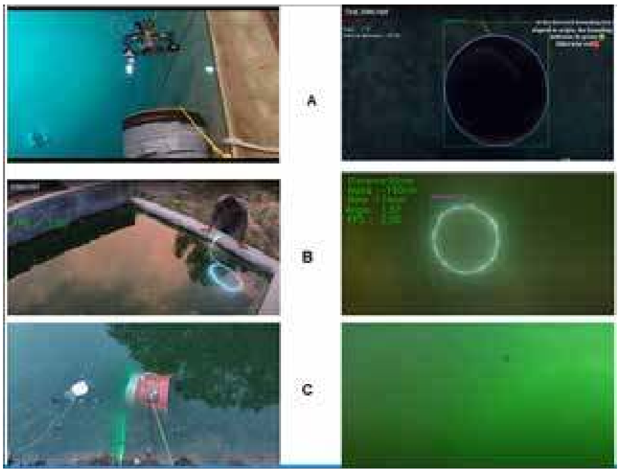


Figure 9. Dock detection using the proposed YOLO in different water types

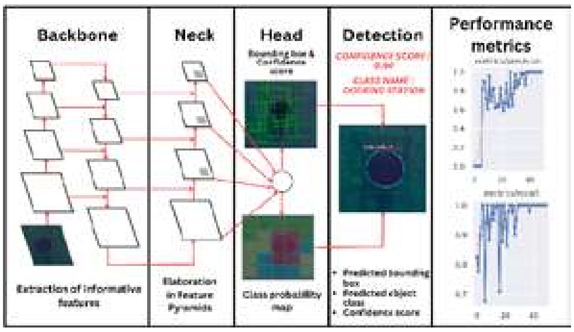


Figure 10. Identified DL architecture for dock detection & MAP metrics

architecture, which consists of a Convolutional Base Layer and Cross Stage Partial (CSP) block. The CSP block solves the vanishing gradient problem. The next set of networks consists of SPP (Spatial Pyramid Pooling) and PAN (Path Aggregation Network). They flow through the YOLOv5 architecture and Enhanced Region Proposal Network (E-RPN). The final output renders the underwater object of interest with the help of NMS (Non-Maximum Suppression) and bounding boxes. The 132-image dataset is partitioned into 79 images for training, 40 images for validation, and 13 images for testing. This configuration facilitates model evaluation and experimentation related to dock in both clear and turbid waters. The performance metrics MAP (Mean Average Precision) of the YOLOv5 is determined to be 0.95 for generated datasets are shown in **Figure 10** (right column).

BI-AUV Pose determination using image processing

Carrying out pose correction of the BI-AUV with reference to the dock is essential for ensuring a successful dock. Deep-SORT is an efficient ultra-fast-tracking algorithm commonly used in surveillance, autonomous driving & sports, which uniquely identifies and tracks objects by employing an advanced association metric that integrates both motion and appearance descriptors. Combining Deep-SORT with YOLOv5 helps to automatically detect the dock when tracking is lost or false detections occur. The algorithm utilises the ID variable, representing the number of times detections are lost and re-detected using YOLOv5. The object detection, tracking, and control algorithm **(Figure 11)** is deployed in the embedded controller for computing dock detection probability in turbid and non-turbid waters and control the BI-AUV in PID loop for enabling reliable homing. The BI-AUV's pose is determined in cartesian coordinates relative to the dock centre, using the Region-Of-Interest (ROI) mathematical computations **(Figure 17)** for consistent prediction.

Kinematics Computation of AUV Range computation

The distance "*d*," from the detected object to the camera is computed **(Figure 11),** using below equation,

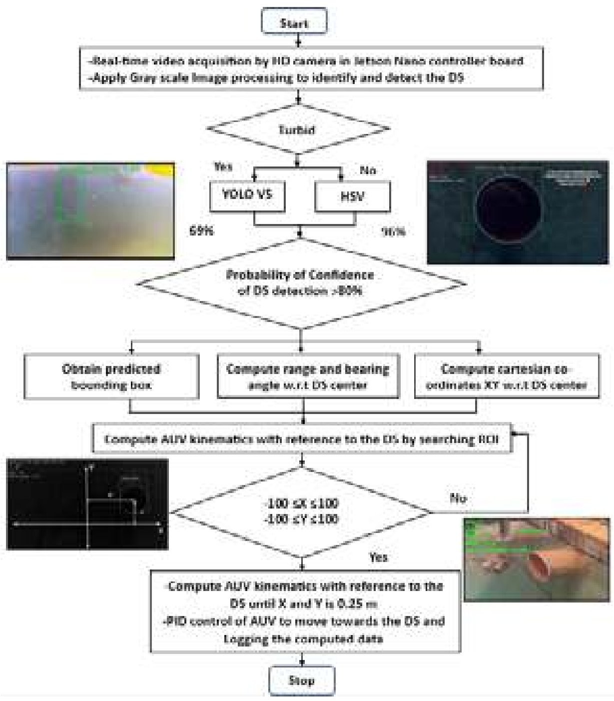


Figure 11. Decision algorithm for guidance used in VG-AUV
Bearing computation

considers the focal length of the camera lens (*f*) and the real height of the object *H* and sensor height *r* in mm.

$$d = \frac{f * H * \text{Image height (pixels)}}{r * \text{object height (pixels)}}$$

Bearing angle calculation employs trigonometric principles to identify the angle between the line linking the centre of the detected object's bounding box and the camera's reference axis.

Once the dock is identified, the centre point (x-centre, y-centre, **Figure. 12)** of its bounding box is computed, the distance from this centre point to the frame's centre is determined with hypotenuse (below relationships), to resolve both horizontal (X) and vertical (Y) coordinates.

$$\text{Distance} = \sqrt[2]{(X_{center} - \text{Frame\_width})^2 + (Y_{center} - \text{Frame\_height})^2}$$

$$\text{Calibration parameter} = \frac{\text{Reference distance}}{\text{Diagonal distance of frame}}$$

The dock is positioned at 2m water depth in the NIOT test tank and BI-AUV is deployed (in the line-of-sight) from either side of the dock, within a range of 5m **(Figure 13)** and the achieved position performances is plotted **(Figure 14).** The NMS (Non-Maximum Suppression) technique was found to be effective in reducing the distortion caused due to the reflection of the dock. However, detection could not be done effectively in turbid waters. Out of 38 runs, 36 homing operations were successful, and hence a success possibility of 95%. The position error at terminal dock was found to be < ±0.3 and ±0.15m in X and Y planes, respectively **(Figure 14).**

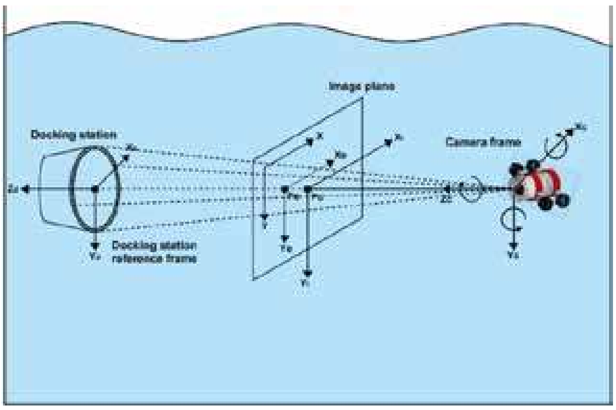


Figure 12. BI-AUV pose computation with dock in XY plane

Figure 13. Dock detection & underwater tracking with probablity of bounding box

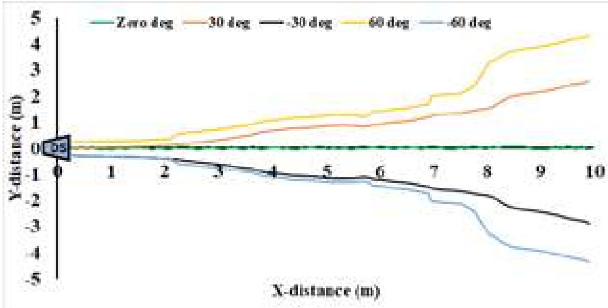


Figure 14. Terminal position accuracy during BI-AUV homing

However, two runs were unsuccessful due to a position error of 0.4m in X plane.

Stage 3: Demonstration of AI-enabled BIHGS using DM and VG aided by multi sensor fusion

Multi-Sensor Fusion (MSF) techniques combine data from multiple sensors and related information from associated databases to achieve improved accuracy, less uncertainty and derive more specific inferences than that could be achieved using a single sensor. The MSF-Kalman Filter (KF) is a recursive algorithm that estimates the state of a linear dynamic system. It was initially used for mid-course navigation and guidance for the circumlunar mission in space applications. Subsequently KF and its variants are widely used in navigation (aerospace, land, and maritime), instrumentation, demographic models, robotics, manufacturing, etc.

The KF uses the current state (Prior,) of the system and the measurement uncertainties involved to predict the next state (Posterior,) by calculating the error covariance from the prior covariance matrix **(Figure 15)** which are 0.01 and 0.1. The time and measurement update equations are iteratively updated with process, continuously in real-time for prediction and correction respectively. The

The MSF-Kalman Filter (KF) is a recursive algorithm that estimates the state of a linear dynamic system

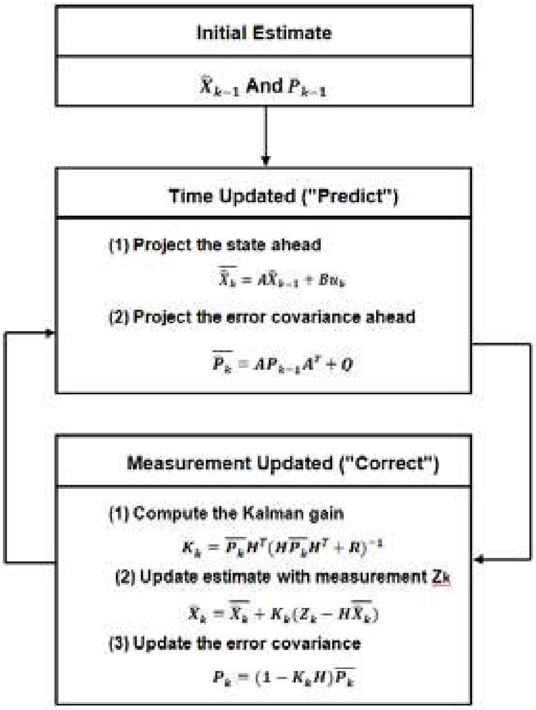


Figure 15. Principle of KF Algorithm

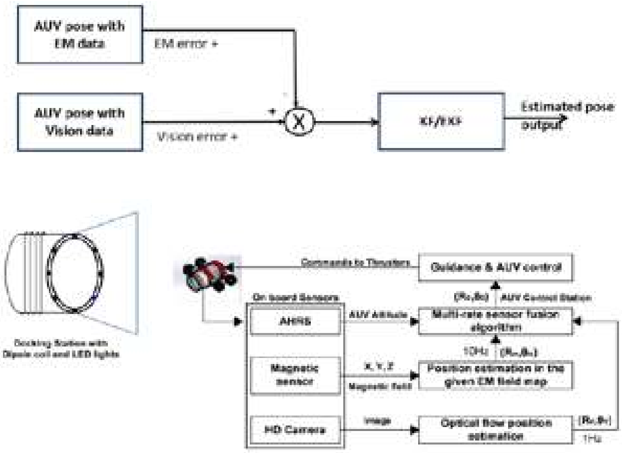


Figure 16. KF-based MSF algorithm for accurate attitude estimation

attitude information obtained from DM and VG techniques are synergised using the proven KF based MSF technique to achieve precise homing of BI-AUV **(Figure 16).**

The demonstration of the machine-learnt AI-enabled BIHGS incorporating integrated DM and VG homing capabilities with KF-based MSF algorithm **(Figure 16)** is tested for homing performance in the NIOT test tank. Out of 80 runs, all the homing operations were found to be successful. The performance metrics for 6 representative scenarios are summarised in **Table 3.** Based on the observed performance metrics of DM and VG, which were 93 and 95%, respectively, the performance of the BIHGS with integrated DM and VG techniques is expected to be (statistically) better than 99.65%, which is evident from the performance results with no failures during 80 runs.

Table 3. Performance metrics (representative) of position error with different SF techniques reaching centre of dock under different scenarios

SF technique (Angle in degree)	Position in X(m)	Position in Y(m)	Resultant error (m)
KF (0)	0.03	0.008	0.031
EKF(0)	0.03	0.007	0.030
KF (30)	0.083	0.21	0.0856
EKF(30)	0.03	0.05	0.058
KF (-30)	0.070	0.018	0.0722
EKF(-30)	0.02	0.012	0.0121

Proposed Stage 4: Concept of Digital Twin for homing guidance

While the third stage bio-inspired prototype (combing EMHGS & VBHGS using sensor fusion) ensures highest probability of precise homing on to the fixed dock in controlled environments, field application challenges (such as drift due to water currents and dynamic dock conditions) could eventually result in a homing failure. Under such conditions, the BI-AUV must be guided to execute a recourse so that the homing is re-attempted, until the homing is successful. This requires an "Intelligent Situation-Aware" (ISA) BI-AUV homing guidance system. To achieve this, the fourth stage shall incorporate an AUV on-board Digital Twin with ISA capability **(Figure 17).** The nine stages involved in the ISA configuration incorporating "recourse to dynamic dock" feature is mapped in the block diagram and matched with the pictorial description for easy understanding. The functionality of each stage (indicating the role of DT) is described in **Table 4.**

Conclusion

This paper described the 3-stage development and demonstration of the first-of-its-kind bio-inspired MSF-aided ML-based short-range homing guidance system based on differential magnetometry and vision techniques. The Differential Magnetometry based technique proved a homing success rate of 93%. The vision guidance based technique was proven with a success rate of 95%. with a range of 7m and terminal homing precision of ±0.2m from the centre of the dock. However, the Differential Magnetometry technique is sensitive to stray/regional magnetic fields, while the performance of the vision guidance is influenced by turbid water conditions. It is demonstrated that by synergising the attitude data obtained from the two techniques using Kalman-filter, the probability of homing has increased substantially, which is essential for ensuring reliable homing in hostile environments. Carrying out extensive

Table 4. Description of the stages of DT-aided BIAUV

Stage	Description
1	After locating the range and bearing of the dynamic dock (DD) from a long distance using Acoustic Positioning System, the BI-AUV progresses towards the DD.
2	Based on the priori magnetic field intensity map, AUV identifies its entry into the magnetically-lit zone. However, the magnetic field distribution is not uniform characterised with ~40% dark zone (near-zero field strengths in the areas outside the lobe). To identify the dock entry precisely inside the magnetically-lit zone, the **ML-EMHGS DT defines the extent of the "Dynamic Dock Search Circle" (DDSC).** The DDSC is transformed into AUV actuator kinematics (thruster force and control surfaces including that of fin & rudder) which is determined taking into consideration the constraints such as AUV actuator capability and other environmental conditions. The "learnt" kinematic model of the AUV under various environmental conditions forms the basis of DT-EMHGS.
3	Once the AUV enters inside the magnetically-lit zone, based on the principle of differential magnetometry (by executing a self-rotation about is axis) the AUV identifies the range and bearing (pose) of the DD.
4	Aided by the propulsion system, the AUV sets its course towards the DD, there-by looking-for the "confirmatory and aiding-input" from the optical guidance system.
5	Once AUV enters the optically-lit zone, AUV obtains the optical signature of the illuminated DD and the acquired image is sent for ML-VBHGS DT.
6	Based on the input, the **ML-VBHGS DT determines the range & bearing of the DD**. In the DT, the acquired image is compared with the "learned" pre-run scenarios.
7	The range and bearing of DD are given an input to the Kalman filter/Extended Kalman Filter, which defines the course which is heading towards the DD.
8	As the AUV progresses towards the DD, failure of DM/vison-guidance could lead to homing failure, and this will lead the AUV to enter into the optical and magnetic dark zone/s and results in a blind AUV. The decision to "recourse" shall be taken at this stage, when homing is unsuccessful and AUV turns magnetically and optically blind.
9	Guidance to recourse is once-again enabled by the incorporated **ISA feature in the DT-EMHGS**. The DT guides the AUV to the periphery of the magnetically-lit zone based on priori magnetic field information, (re)defines the extent of DDSC to enable the AUV to (re)locate and (re)enter the DD.

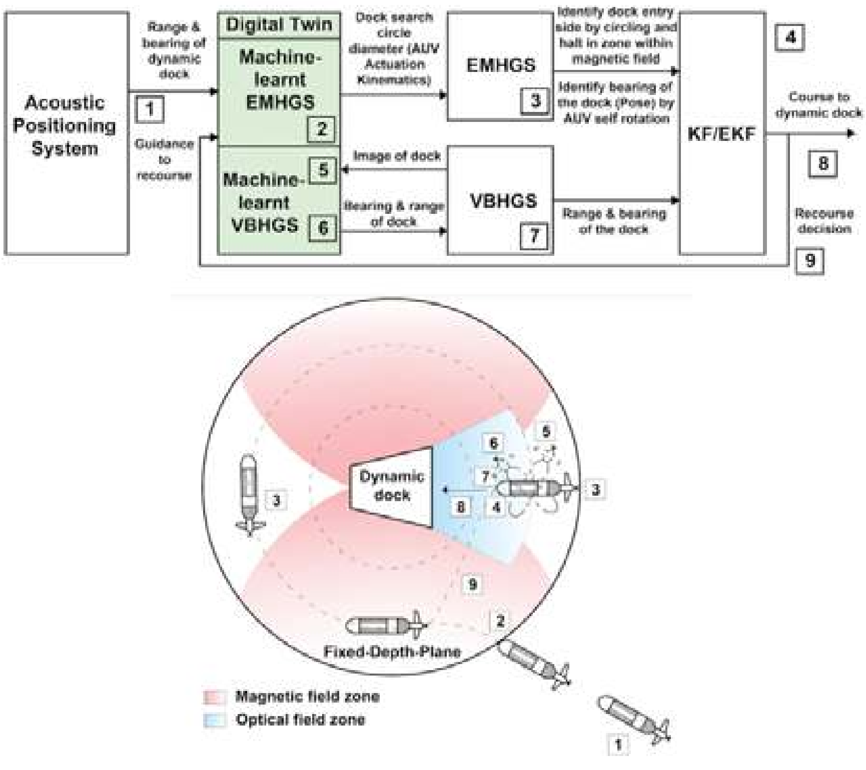


Figure 17. Concept of homing stages with the aid of DT

field testing and tuning the deep-learning algorithms and the guidance of a Digital Twin shall help to realise rugged field-implementable bio-inspired homing guidance system capable of effectively supporting increased spatiotemporal deep-ocean mineral mapping missions.

Abbreviations

AI	Artificial Intelligence
AUV	Autonomous Underwater Vehicle
BI	Bio-Inspired
BL	Beer-Lambert
BIHGS	Bio-Inspired Homing Guidance System
CIELAB	Commission Internationale de l'Eclairage
CLAHE	Contrast Limited Adaptive Histogram Equalization
CNN	Convolution neural network
CSP	Cross Stage Partial
DD	Dynamic Dock
DDSC	Dynamic Dock Search Circle
DL	Deep-Learning
DoF	Degrees of freedom
DM	Differential Magnetometry
DT	Digital Twin
EMHGS	Electro-Magnetic Homing Guidance System
E-RPN	Enhanced Region Proposal Network
HD	High-Definition
ISA	Intelligent Situation-Aware
KF	Kalman Filter
EKF	Extended Kalman Filter
LED	Light Emitting Diode
MAP	Mean Average Precision
ML	Machine Learning
MSF	Multi-Sensor Fusion
NMS	Non-Maximum Suppression
NTU	Nephelometric Turbidity Unit
PAN	Path Aggregation Network
PID	Proportional-Integral-Derivative
RCNN	Region-based Convolution Neural Network
ROI	Region-Of-Interest
SPP	Spatial Pyramid Pooling
VBHGS	Vision based Homing Guidance System
VG	Vision Guidance
YOLO	You Only Look Once

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> *The Differential Magnetometry based technique proved a homing success rate of 93%*

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TECHNICAL NOTES

Maritime Decarbonisation: The Role of Shaft Generators

Rajesh Kasaragod, Ronak B. Thakkar

Abstract/Summary:

Maritime decarbonisation has been on the agenda for a long time. It is recognised as very important, even if the contribution of ships to global warming is relatively small.

The decarbonisation process is carried out with two basic approaches, namely the increase in energy efficiency and the use of alternative fuels. A more efficient energy management system means less fuel consumption, which results in reductions in air pollutants and Green House Gasses.

Energy efficiency technologies are now being considered to gain incremental savings in fuel.

In this article, the Shaft Generator as an Energy Efficiency Technology is considered and information related to the product, its working principles and other important points are discussed. Few of the data shared in this article are taken from a capsize bulk carrier, retrofitted with 1200 kilowatt shaft generator of frequency converter type.

Keywords: Green House Gasses (GHG), Energy efficiency technologies (EETs)

The generator rotor is directly integrated on the intermediate drive shaft, eliminating the need for gearboxes and couplings and eliminating physical interfaces such as bearings between the generator and the main engine

Introduction

The Standalone Diesel Generator (Genset/Auxiliary Engine) is the most common source of electricity in a ship. Generally, it is a 4-stroke, medium/high speed, the turbocharged marine diesel engine working as a prime mover and an attached alternator which produces electricity using Faraday's law. The number of such gensets on board a ship depends on the power demand of the ship.

Electricity can also be produced by the Shaft Generator, where the alternator is directly mounted on the propeller shaft, which is driven by the Main Engine. Utilising the larger 2-stroke main engine power in this way is much more efficient than the 4-stroke engines that typically power the generators. When electric power is produced with a slow-speed main engine instead of medium- or high-speed gensets, this results in fuel savings.

Since the Generators are kept off while shaft generators driven by the main engine is in use, this results in fuel saving and thus helps in achieving the reduction in GHG emission.

History of shaft generator

Shaft generators were first introduced in 1960s. They were shaft generators without frequency converters. Hence, the functioning of these shaft generators was possible when the driving shaft RPM was stable. With the ship's speed change, the frequency of the electric current produced would fluctuate, making it unusable. And the shaft generator had to be disconnected, making way for the genset to take over.

In 1980s, frequency converters were introduced which helped in resolving the frequency issue.

It is necessary to consider the influence of the shaft generator on the flywheel end connection and inertia when doing the ME and shaft cantering calculation

There are different types of shaft generators:

a. Low speed type Shaft Generator Frequency Converter type

The generator rotor is directly integrated on the intermediate drive shaft, eliminating the need for gearboxes and couplings and eliminating physical interfaces such as bearings between the generator and the main engine. These type of shaft generators, which occupy a small space, are safe, stable, simple and reliable, are widely used in large ships. However, it is necessary to consider the weight of the generator rotor when calculating torsional vibration and alignment of the ship shafting. Refer to **Figure 1,2** and **3** below.

b. Engine Non-drive End Low Speed Direct Drive System

The scheme adopts low-speed permanent magnet direct drive generator, which is connected to the non-drive end of the propulsion main engine, without the gear box resulting in reduced losses and failure risk rate. This type of Shaft Generator is safe, stable, efficient and occupies a small space, suitable for various types of ships. It is necessary to consider the influence of the shaft generator on the

Figure 1- Split type shaft generator (courtesy – CSSC/SMDERI)

Figure 2 – Rotor and stator of Shaft generator (courtesy – CSSC/SMDERI)

Figure 3 – Schematic layout of low-speed type shaft generator - (courtesy – CSSC/SMDERI)

Figure 4 – Schematic layout of Non Drive end type shaft generator. (courtesy – CSSC/SMDERI)

flywheel end connection and inertia when doing the ME and shaft cantering calculation. Refer to **Figure 4** below.

C. Speed Increase Gear Type Shaft Generator System

The scheme adopts speed increase gear box and high-speed generator, which can be arranged in the non-drive end or drive end of the main engine. It has the characteristics of high-cost performance and strong versatility. Tunnel gear box should be used when it is arranged at the driving end of high power and low speed host, which can reduce the transmission torque and design specifications of the gear box. Refer to **Figure 5** and **6** below.

D. Medium/High Speed Machine Shaft Generator System

This scheme is suitable for ships with Medium/High-speed diesel engine as propulsion engine, and usually adopts double- shaft propulsion to achieve redundant power and fuel saving and emission reduction in various working conditions.

The shaft generator can be a series shaft type medium speed motor, or a high speed motor can be connected with the propulsion shaft through a multi-input end gear box. Refer to **Figures 7** and **8** below.

Working principle of Shaft Generator of slow speed type with frequency converter

Simple working principle of SG of the slow speed type is explained as below .

a) Main Engine: The prime mover that drives the ship's propeller and the shaft generator.

Figure 5 – Schematic layout of Gear Type Shaft Generator (courtesy – CSSC/SMDERI)

Figure 6 – Gear box view (courtesy – CSSC/SMDERI)

b) Shaft: The rotating Propeller/Tail shaft connects the main engine to both the propeller and the shaft generator mounted on it.

c) Shaft Generator: A Shaft generator is mounted on main engine shaft producing variable frequency AC power due to varying engine speeds.

d) Variable Frequency Drive (VFD) Input Rectifier: Converts the AC output of the shaft generator into DC.

e) DC Link: A smoothing capacitor or inductor to stabilise the DC power.

The excitation system transforms the three-phase AC current of the ship's grid (Main power distribution system) into DC current and the PLC in the Shaft Generator control system calculates and adjusts the output DC current (excitation current), so that the shaft generator outputs stable three-phase AC current

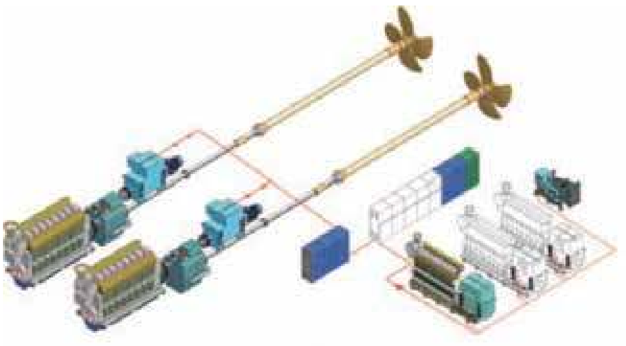


Figure 7 – Schematic layout of Medium/High speed shaft Generator (courtesy – CSSC/SMDERI)

Figure 8 – Actual Picture of Medium/High Speed shaft generator (courtesy – CSSC/SMDERI)

Figure 9 – SHAFT GENERATOR CONVERTOR PANEL (WATER COOL TYPE)

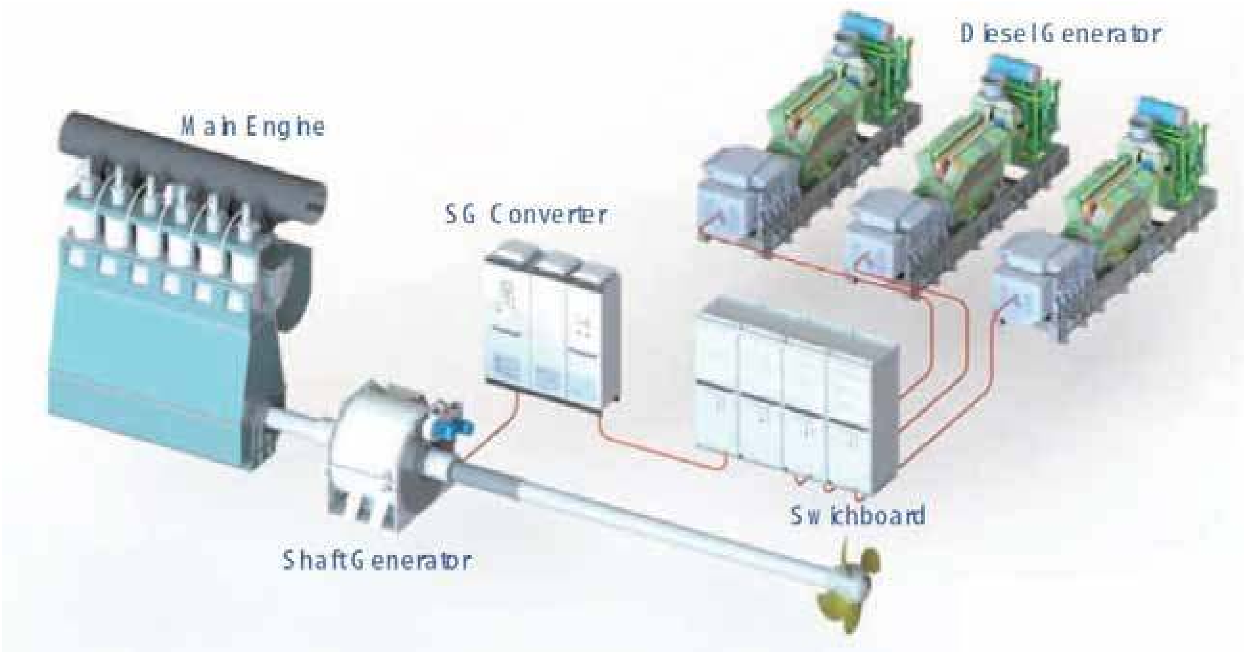


Figure 10 - LAYOUT OF SHAFT GENERATOR SYSTEM

f) Variable Frequency Drive (VFD) Inverter: Converts the stabilised DC back into AC with a controlled frequency and voltage.

g) Isolation Transformer: Adjusts the voltage level to match the ship's electrical distribution system value.

h) Ship's Electrical Distribution System: Distributes the stabilised and conditioned power throughout the ship.

i) Loads: The various electrical equipment and systems aboard the ship that use the electrical power.

The shaft generator used in this system is a shaft holding electric excitation synchronous generator. **Due to its special installation form, Auto Voltage Regulator (AVR) cannot be used for excitation, so it needs whole lot of automation/control systems inside a Shaft Generator CONVERTER PANEL (Figure 9) to stimulate the generator**. The excitation system transforms the three-phase AC current of the ship's grid (Main power distribution system) into DC current and the PLC in the Shaft Generator control system calculates and adjusts the output DC current (excitation current), so that the shaft generator outputs stable three-phase AC current.

There is a line filter between the excitation system and the AC grid (Main power distribution system) of the ship, which can suppress the harmonics generated during the operation of the thyristor rectifier, cut off the channel of its transmission to the grid, and limit the abnormal fluctuation of the grid voltage and the impact of the surge current on the thyristor. Between the thyristor rectifier and the exciting winding of the shaft generator, there is a deexcitation switch and an overvoltage protector, which deexciting the generator in case of excitation failure and prevents overvoltage from damaging the thyristor device.

A line filter installed between the rectifier and the shaft generator can suppress the harmonies generated by the IGBT operation, cut off the channel of transmission to the shaft generator, reduce the motor heat and improve the generator service life

The SG CONVERTER PANEL is installed between the shaft generator and the ship's main switchboard to adjust the output voltage and frequency of the shaft generator. Its semiconductor device is Insulated Gate Bipolar Transistor (IGBT) and modulated by Pulse Width Modulation (PWM). The SG CONVERTER PANEL is composed of a rectifier, an inverter and a transformer. The rectifier converts the three-phase AC output power of the shaft generator into DC power and the inverter converts DC power into constant voltage and constant frequency AC, then the transformer reduces the voltage from 500V to 450V.

The IGBT switching frequency of the rectifier in the drive cabinet is 3.6kHz, and the rectifier is equipped with a special controller to control the pulse width and the low-frequency three-phase AC output power of the shaft generator is rectified into stable DC power and the DC voltage between the rectifier and the inverter can be stabilised at the allowable value no matter how the ME speed changes. A line filter installed between the rectifier and the shaft generator can suppress the harmonies generated by the IGBT operation, cut off the channel of transmission to the shaft generator, reduce the motor heat and improve the generator service life.

The IGBT switching frequency of the inverter in the drive cabinet is 3.6kHz and the inverter is equipped with a special controller to control the pulse width, which converts the DC power into a stable three-phase AC power to match the frequency needs of the ship's AC grid. An LC filter is installed between the Generation Signalling Device (GSD) and the main transformer, which can sine the output voltage waveform and absorb the higher harmonics generated by the IGBT operation to prevent harmonic pollution to the AC grid of the ship.

The main transformer of the SG can reduce the high voltage output from GSD to the voltage needs of the ship's AC grid, while further isolating the drive from the AC grid, minimising the common mode voltage generated during IGBT operation.

A brake chopper is installed on the DC busbar of the SG CONVERTER PANEL and a brake resistor is installed next to the drive cabinet, which is used to absorb the DC bus overvoltage energy when the AC grid is suddenly unloaded, so that the DC bus voltage is kept within the normal range, so as to ensure the unloading ability during the normal operation of the SG.

VFD (Variable Frequency Drive)

The shaft generator output power frequency is not constant and depends on the RPM of the main engine. Since the engine speed is continuously fluctuating due to external factors such as wind, current, sea state etc., the shaft generator output needs to be processed to get a stable frequency, prior connecting it to the Main power Distribution system. This function is carried out by the SG CONVERTER PANEL through variable frequency drive (VFD). Below we discuss more on Variable Frequency Drive (VFD).

Understanding VFD (Variable Frequency Drive)

VFD stands for **Variable Frequency Drive**. As its name suggests it is an adjustable frequency drive that varies the frequency of the AC supply. Since the speed of an induction motor depends on the supply frequency, the VFD can be used to vary its speed.

VFD is made of four blocks or sections where each section has its own function. The four blocks or sections of a VFD are **Rectifier**, **DC bus/filter**, **Inverter** and **Control Unit**.

The Rectifier

The input AC supply is connected to the Rectifier section of the VFD. It is a full-wave rectifier that converts the AC power into unfiltered DC.

The DC Bus and Filter

This intermediate section is used for filtering and storing the DC power that is retrieved by the inverter. Its main function is to remove the ripples from the pulsating DC output of the rectifier.

The Inverter

The inverter or switching section converts the steady DC into AC with adjustable frequency.

The Control Unit

Control unit is responsible for controlling the switching operation, output frequency, output power. It is integrated with the user interface and sensors to acquire the necessary data. It also monitors fault conditions.

Benefits of Variable Frequency Control - **Advantages of VFD**

VFD not only provides variable speed control but also offers energy saving with improved efficiency and simple control. Here are some of the advantages or benefits of VFD

- **Improved Efficiency:** The conventional speed control using the variable voltage method wastes a lot of energy as compared to the variable frequency method.
- **Precise Control:** A VFD allows smoother and precise control of the speed where required, using a sensor.
- **Limits Inrush Current:** Inrush current is the huge starting current drawn by an induction motor during its startup. It is 5 to 8 times greater than its rated current. It can damage the windings of the motor. The VFD can safely limit the starting current and it is used in one of the methods for induction motor starting.
- **Extend Mechanical Life:** It can safely start and stop a motor with a gradual change in speed without any mechanical jerks. It extends the mechanical life of the motor.
- **Reduced Maintenance:** Smooth operation of motors reduces the mechanical stress and eliminates the jerks that eventually reduce the maintenance required for such a motor, thus reducing the long-term cost.
- **Power Factor:** A poor power factor causes reactive power loss that is the energy wasted in the form of heat. Induction motor usually has a low power factor. A VFD improves the power factor to utilise the power more efficiently.
- **Protection:** A VFD can also provide protection against overload, over-voltage and phase loss. It immediately stops the supply current in case of such faults to protect the load connected from damage.

IMPORTANT POINTS TO BE CONSIDERED WHILE PLANNING FOR RETROFITTING SHAFT GENERATOR

While considering shaft generator retrofitting on existing vessels, careful study of engineering, space considerations, alignment with the ships power distribution and management system are to be carried out to get the maximum benefits.

While considering shaft generator retrofitting on existing vessels, careful study of engineering, space considerations, alignment with the ships power distribution and management system are to be carried out

Data such as Ship activity to know sea going days, frequency of port calls and the duration of port stay, the pattern of power demand, the weather pattern in the trading area of the ship, 3D Scanning of fitting area, ME critical RPM etc., will help in determining the optimal rating of the shaft generator, maximum benefits and best ROI (Return on Investment).

One of the makers from China (SMDERI) makes split type shaft generator for slow speed engines, which comes in two halves. This type of shaft generator can be retrofitted on the existing propeller shaft without disturbing the shafting and its alignment and hence, helps in saving time in the drydock and shaft removal, refit and alignment related matters.

The Shaft generator is generally made to order and hence the buyers initial specification plays an important role in getting the right equipment delivered. Specification related to the range of RPM where the shaft generator is to work, and the power output VS RPM are very critical for getting maximum benefit from the Shaft Generator.

Power Management System (PMS) and Alarm Monitoring System (AMS) are to be modified to incorporate SG into the ship system in a retrofit of Shaft Generator project. The modification to PMS ensures uninterrupted supply of power by the system taking into consideration the power availability from Shaft Generator and Diesel Gensets, complying with all applicable class rules. The AMS system modification ensures the audio and visual signal, when there is abnormality in the system. An HMI (Human Machinery Interface) Panel for Shaft Generator provides information display, alarms, necessary parameter setting and controls.

During the retrofit projects, Main Switch Board Modification may be required to incorporate the Shaft Generator breakers and connections to the Main Switch Board and the bus bars.

Due to the additional weight of the shaft generator on the propeller shaft, there is a need to carryout analysis of bearing load to ensure that all the shafting related bearings are loaded within the limits. Hot and cold jack up tests is carried out under class supervision to ensure this.

Sea trial is to be carried out to confirm the Shaft Generator retrofit compliance to the class requirements.

Benefits of fitting a shaft generator

Below are few of the benefits of fitting a Shaft Generator on board a ship.

- Fuel consumption reduction and hence improved Carbon Intensity Index (CII).
- Reduced manpower requirement by reducing the number of engine crew.
- Reduced spare part consumption on Aux Engines, due to reduced running hours.
- Reduced noise in the engine room due to Aux Engine not running when Shaft Generator is in use.
- Reduced lube oil consumption due to reduced running hour of Aux Engines.
- Reduced maintenance cost due to reduced running hour of Aux Engines.
- Availability of additional power and redundancy.
- Cost savings
- Reduction in emission
- The Converter Panel fitted with the Shaft Generator can also help in easily accommodating the future requirements such as Alternate Marine Power(AMP) or Shore power. The power management system and other such control systems can manage the shore power with little modification.

- ❍ Data from a recent cape size retrofit of shaft generator.
- ❍ Genset running hour reduced by 40%
- ❍ Fuel saving per annum is 500 MT
- ❍ Carbon emission reduction 1500 mt/year.
- ❍ Lube oil consumption reduced by 48%
- ❍ Aux. Engine spare expense reduced by 54%
- ❍ Manning expense reduced by 2%

Conclusion

In conclusion, shaft generator systems offer numerous benefits, including enhanced fuel efficiency, reduced operational costs and significant environmental advantages. By utilising the ship's main engine to generate electricity, these systems reduce the need for auxiliary generators, resulting in lower fuel consumption and emissions. This not only helps ship operators comply with increasingly strict environmental regulations but also promotes a more sustainable and cost-effective maritime industry. As the demand for greener solutions grows, shaft generators stand out as an effective way to optimise energy use and minimise environmental impact.

Acknowledgements

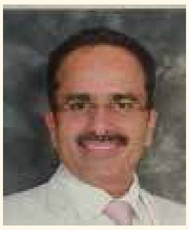
https://www.marineinsight.com

https://maritimehub.co.uk

https://www.marinelink.com

Shaft Generator control system user manual by SMDERI.

About the Authors



Rajesh Kasaragod has 33 years of experience in the Maritime Industries. He is a mechanical engineer and also holds MEO Class I certificate. He is a fellow of the Institute of Marine Engineers India. He is presently working as Head, Adani Shipping India Pvt. Ltd. He has decades of experience in drydocking of various types of ships in China, Dubai, Oman, Bahrain and in executing ESD projects.

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TECHNICAL NOTES

World Maritime Technology Conference 2024: A Glimpse into the Future of Global Shipping

WMTC Technical Committee

The World Maritime Technology Conference (WMTC) 2024, held from 4 to 6 December at The Leela Palace in Chennai, India, served as a key platform for maritime professionals, scholars and experts to engage in discussions about the future of global shipping. With the theme "Global Shipping - A Battle for Survival or a Torchbearer for Hope?" the conference explored the challenges, technological advancements, and opportunities facing the maritime industry in a rapidly evolving world. The conference saw an overwhelming response, with 155 abstracts submitted from nine countries, covering 15 diverse themes. This level of global engagement reflected the shared interest in addressing the pressing issues that shape the future of the maritime sector.

Global Participation and Themes

The conference attracted participation from various countries, including India, China, the United Kingdom, Singapore, the United States, Denmark, Belgium, Norway, and Sweden. The extensive range of themes covered in the conference illustrated the depth and breadth of contemporary maritime concerns. The key themes addressed included Navigating the Future, Shipbuilding and Repairs, Duty of Care, Classification of Society, Sustainable Development, Powering Academic Research, Managing Learning and more.

Among the 155 abstracts submitted, 108 full manuscripts were received and reviewed by 25 experts. Additionally, the conference featured contributions from students, with 47 abstracts and 28 full manuscripts submitted by students from ten Indian maritime institutions, highlighting the future talent in the field.

57 papers were presented over the course of the three-day conference, addressing critical issues ranging from technological innovations and digital transformation to sustainability and risk management. In addition to academic papers, the conference featured panel discussions and keynote speeches that provided valuable insights into the future of global shipping and maritime policy.

Day 1 Highlights: Exploring the Future of Maritime Education and Digitalisation

The first day of the conference opened with a keynote speech addressing the future of maritime education. The focus was on enhancing the quality of learning, improving cognitive skills, and aligning curricula with industry needs. Emphasising the importance of using artificial intelligence (AI) and digital tools in education, the keynote explored how these tools can enhance teaching methods and create more interactive and immersive learning experiences for students.

> *The conference attracted participation from various countries, including India, China, the United Kingdom, Singapore, the United States, Denmark, Belgium, Norway and Sweden*

One presentation discussed the role of counselling in bridging the gap between maritime education and industry expectations, emphasising the importance of career awareness and guidance for students

The day's sessions featured a series of presentations that delved into the intersection of education and industry. One presentation discussed the role of counselling in bridging the gap between maritime education and industry expectations, emphasizing the importance of career awareness and guidance for students. Another presentation examined how AI could be leveraged to improve operational efficiency in maritime operations, focusing on areas such as fuel consumption reduction, operational safety, and minimizing human error.

Another key session focused on the welfare of seafarers, discussing the importance of mental health and safety management

Further presentations explored pedagogical strategies designed to enhance knowledge acquisition, particularly for students with learning disabilities. There was also a focus on the potential of AI and machine learning (ML) in shaping the future of maritime education, from the creation of lesson plans to the integration of virtual reality (VR) and augmented reality (AR) for immersive learning.

As the global maritime industry works towards meeting the IMO's decarbonisation targets, another session addressed the challenges of achieving low-emission shipping. Presentations covered alternative fuels, digital tools for fuel optimisation, and AI-assisted optimisation techniques to support decarbonisation efforts. Additionally, there was a focus on improving operational processes, from AI-based optimisation in offshore platforms to advanced smart pumping systems for tankers.

Presentations addressed the urgent need for alternative energy production, CO_2 sequestration, and the role of ocean governance in tackling climate change

The day concluded with a session on improving connectivity between rivers, ports, and railways. The importance of intermodal transport in enhancing logistics efficiency and supply chain resilience was discussed, with AI identified as a key enabler in optimizing port and transport connections.

Day 2 Highlights: Examining the Shipping, Innovation & Sustainability Futures

The second day began with a discussion on the role of classification societies, highlighting their critical function in ensuring the safety, security, and environmental compliance of maritime operations. Presentations focused on the evolving responsibilities of classification societies and their collaboration with the International Maritime Organization (IMO), particularly in the context of regulations like MARPOL and SOLAS. The discussion also included an analysis of the societal influence of classification societies and their alignment with the United Nations Sustainable Development Goals (UN-SDGs).

In a separate session, the changing landscape of the shipping markets was explored, with particular attention paid to the unpredictability of the markets due to geopolitical uncertainties, pandemics, and natural disasters. Presentations covered topics such as the impact of energy transitions on the maritime industry, the resilience of dry bulk shipping, and the influence of digital tools in balancing supply and demand in the shipping market.

Another key session focused on the welfare of seafarers, discussing the importance of mental health and safety management. Presentations addressed the psychological impact of industry changes, such as decarbonisation, and the increasing focus on crew welfare, with an emphasis on support systems and training to enhance safety and well-being on-board ships. Various safety protocols and new approaches to determining safe manning levels were also discussed, along with measures to address motion sickness and improve the working environment for seafarers.

> *Presentations discussed digital twin technologies, waste heat recovery systems, and propeller cavitation reduction as key methods for enhancing vessel performance and reducing fuel consumption*

Day 2 concluded with a session focused on shipbuilding and repairs, particularly in the context of India's potential to capture a share of the global shipbuilding market. Discussions covered the strategic advantages and challenges facing India's shipbuilding industry, including labour laws, cost competition, and infrastructure limitations. Key topics included the need for legislative action, policy reforms, and innovation in research and development to enhance India's position in the global maritime market.

Day 3 Highlights: Ocean Governance, Innovation & Research

Day 3 of the conference featured a keynote on ocean governance, with a focus on the importance of cleaner transport and hybrid offshore support vessels (OSVs). Presentations addressed the urgent need for alternative energy production, CO_2 sequestration and the role of ocean governance in tackling climate change. The session explored the latest developments in sustainable maritime technologies, such as solar power integration into ship power systems, and the use of scrubbers to comply with sulphur cap regulations.

The conference also addressed advancements in product technologies, including alternative fuels such as LNG, LPG, methanol, and ammonia, as well as renewable biofuels. Presentations explored the technical readiness of these fuels and their challenges for marine applications, providing insights into the future of fuel alternatives in the maritime sector. One presentation focused on the role of desiccant evaporative cooling systems as an energy-efficient alternative to traditional HVAC systems aboard ships.

A final session on maintenance practices explored cost-cutting strategies in maritime operations, with a focus on improving vessel efficiency. Presentations discussed digital twin technologies, waste heat recovery systems, and propeller cavitation reduction as key methods for enhancing vessel performance and reducing fuel consumption.

The conference concluded with discussions on the critical role of academic research in shaping the future of maritime technologies. Presentations highlighted advancements in hull design, marine propulsion systems, and the importance of simulations and digital tools in optimizing maritime operations for sustainability and efficiency.

Conclusion

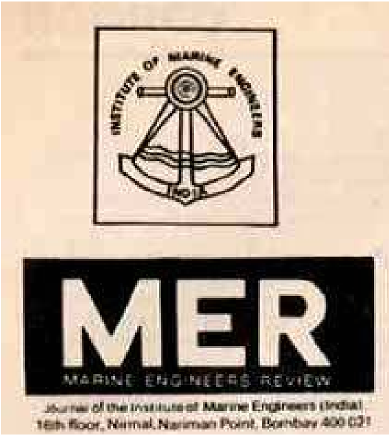
The WMTC 2024 provided a comprehensive and thought-provoking overview of the challenges and opportunities facing the global maritime industry. With a focus on digital transformation, sustainability, and the evolving role of maritime education, the conference highlighted the importance of innovation and collaboration in navigating the future of shipping. The discussions underscored the need for continued research, technological advancements, and policy reforms to ensure that the maritime industry not only survives but thrives in the face of future challenges.

Future Outlook

To ensure the continued relevance and growth of the World Maritime Technology Conference, future editions could benefit from the inclusion of emerging themes such as the integration of renewable energy technologies and advancements in cybersecurity within maritime operations. Additionally, increasing participation from countries in Africa, the Middle East and Latin America could provide valuable insights and foster a more diverse, global discussion. A strategic outreach plan, including partnerships with regional maritime organizations and universities, could help attract a wider international audience and encourage cross-border collaboration.

[This Technical Note was prepared by Sukanya Rajalakshmi, Junior Research Fellow, Indian Maritime University, Chennai & Dr. Rajoo Balaji, Head, Technical Committee, WMTC]

Going Astern into MER Archives...

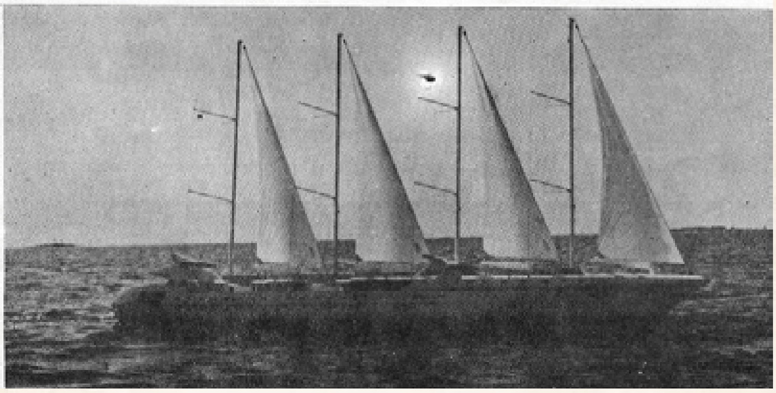


The editorial fires up on lack of firefighting training and the STCW 78 laying emphasis on the same. The write-up lists all the elements that are to be covered in such training and impresses India should gear up to impart this training to an estimated 60000-70000 seafarers. Well, are we well equipped as of today to in terms of facilities and updated content and refreshed faculty ?

OPINION carries two interesting thoughts: one is a casual comparison of a 'Briton' employee to a Japanese one, in terms of loyalty; the other one is on self-polishing copolymers' lifespan being only for 2 years whereas a vessels' average docking period is 2.5 years. Did the engineers of this era face damaging problems due to this or extended drydocking? It would be interesting to hear about the hull and anti-fouling paints of the eighties when the technologies were still maturing.

Moving to the articles, the first one discusses 'hybrid' vessels, with the focus on cargo handling and ro-ro options. It talks about Lakers (vessels which can operate in Great Lakes and outside) and barge carriers, heavy lifts, reefers and SWATH (Small Waterplane Area Twin/ Triple Hulled) Vessels etc. There is section on how wind energy can be harnessed by fitting sails. Have we come around a full circle or yet to?

Fig 7: Ships of the future: the Wärtsilä designed "Windcruiser" — a cruise liner with the attraction of sailing.



Then there is one on an expo where the maritime products are to be showcased in London. Do we not have more than enough of them today?

The next article is on coal firing on a fluidised bed (FB) boiler. The heat transfer efficiencies were the major merit for these designs. Would welcome some discussions on these from engineers who have worked on FB boilers.

This is followed by an interview with the Chairman of the H&W Yard. An interesting feature is the talk on using CAD/CAM and the references to MAN B&W (MAN had bought out B&W by then) and Sulzer jostling for space in the engines market.

This is followed by an interesting article on the marine engineer and the law. The article emphasises that the engineer ought to be familiar with many maritime laws.

There is one Transaction on the 'Naval Engineering Achievements in the Liberation of Falklands' (read at Feb 1983). The discussion section appears more interesting than the main paper.

The POSTBAG section ahs some interesting reads on slow steaming effect on stern bearings and LBd ratios and ship vibrations. This apart, I have inserted two letters (Letters to the Editor column). They are self-explanatory. We would invite your thoughts juxtaposing the present status of the marine engineering curriculum.

There is one technical note on connecting rod bearing bolt design after the letters. This would be of interest to engineers appearing for examinations.

Improving coal-fired plant

Sir,
As reported in MER December '84 Dr Derdini of Italcantieri has drawn further attention toward coal-fired ships. He mentioned improvements with regard to efficiency. Modern coal-fired ships with mechanical stokers cannot burn coal as efficiently as steam ships can burn oil, but the stoker was preferred to alternative means on account of reliability and available experience.

More efficient propulsion plant will become possible. As regards the burning of raw coal the two available alternatives are the fluidised bed combustor and pulverised coal firing. Experience with the former is growing rapidly and it offers the shipowner fewer restrictions on types of coal suitable for bunkers. It is unlikely to contribute much to improved efficiency, although some savings in weight and space may be possible.

For improved efficiency pulverised coal should not be ignored. Although there would be practical difficulties the best prospect for a flexible marine system would be an adaptation of the bin and feeder system. With this, raw lump coal is bunkered and reduced on board by a central milling plant at a steady rate and deposited in a buffer store of modest capacity local to the boilers.

As Dr Derdini rightly remarked, the best and simplest improvement in efficiency is obtained by raising the steam temperature. It is something of a mystery why modern ships were ever fitted with steam plant operating with temperatures as low as 490°C at the superheater outlet. It has nothing to do with burning coal, since many coal-fired boilers ashore consistently provide a steam temperature in excess of 525°C. Nor, clearly, is it anything to do with steam turbines which are capable of taking steam at this temperature.

The conclusion can only be that the particular boilers used are in some way responsible. The coal-fired marine radiant boiler offered by my company certainly has no inhibitions in this respect and offers the advantage of an all-welded construction suitable for use with mechanical stokers, fluidised beds or pulverised coal.

A F Hodgkin
Chief Design Engineer
Babcock Power Ltd

Lubrication problems at slow revs

Sir,
With reference to your excellent report on the *Pacific Guardian* in the January MER, I would like to draw you attention to a very important aspect of this ship design which has relevance to the latest direct-drive slow-speed diesel installations.

The vessel, being a cable laying vessel, has to operate at very reduced rev/min simply to hold position against wind and tide. The design of a single-screw fixed pitch propeller with a whitemetal-lined sterntube bearing required a system which would ensure sufficient lubrication to the bearing at revolutions as low as 5 rev/min. The normal hydrodynamic oil film is not fully generated at shaft speeds less than about 25 rev/min.

To ensure normal operation at lower speeds we designed a hydrostatic jack oil system into the sterntube bearing which automatically cuts in and out at preselected propeller revolutions.

Incidentally, *Pacific Guardian* is also fitted with a Universal/Glacier Coastguard sterntube seal system which allows the condition of the aft seal to be monitored at any time and also precludes oil pollution from the seal lubrication system.

The purpose of drawing your attention to the slow revolution aspect is that the latest long stroke B & W and Sulzer diesel engines of 600 mm bore upwards all have manoeuvring speeds in the critical under 30 rev/min zone and, therefore, the normal hydrodynamic oil film may not be generated, creating potential severe wear between the shaft and bearing and consequently misalignment and vibration problems.

As the survey authorities are introducing extended time between tailshaft and sterntube bearing surveys, this aspect of the sterntube bearing design has to be taken into account at a very early stage in the shafting design programme.

H M Macleod
Chief Designer
Universal Metallic Packing Co
Bradford

Reducing shipboard vibrations

Sir,
I read with great interest the article by Mr Hans Meyer on 'Reduction of shipboard vibrations' (MER Nov 84). As an owners' consultant, I was directly involved in the case history referred to.

In fact, at an earlier stage, in the ballast condition, it was noted that the hull girder, even on a slight swell from forward, would strongly vibrate.

I recall that on my first visit to the first ship (of a series of three), which was already trading, I noted her unconventional L:B:d ratio, which was due to the builder's efforts in maximising bale and container capacity at a limited loaded draught.

Furthermore, whilst the ship was in ballast at sea, with the excessive trim of 2.8 m forward and 5.7 m aft, the induced wave pattern would cause slam on an appreciable area of the flat bottom just aft of the bulbous bow. This led to my preliminary opinion that the unusual trim combined with the hull form was the cause of vibrations.

A further discovery was that although the builder had provided an adequate forepeak to obtain a suitable forward draught, this could only be used to about a third of its capacity due to excessive bending.

It has remained a mystery to me how this passed unnoticed by all those originally concerned with design and approval.

In parallel to the vibration investigations done by Mr Meyer, detailed calculations were carried out by me which led to the elimination of those fore-peak problems.

The solution recommended was to add side tanks, of about 800 t capacity, in way of No 3 hold. This resulted in lengthy discussions with the builder and in the owner claiming for carrying capacity losses. Arbitration was called for and, finally, the recommendation regarding the side tanks, plus the recommendations which ensued from the vibration tests, were all implemented by the shipyard.

At this stage I would like to note that at the original trials of the first vessel delivered, certain vibrations were accepted as present, but they were not qualified.

It should further be noted that the anticipated contract trial draughts were theoretical and not representative of the trading draughts.

Thus, it should be emphasised that original designs should be carefully produced and approved, whilst bearing in mind the conditions a vessel may encounter during her trading life. Also, specifications of trials should be determined realistically and their results properly analysed.

C Philippou
Marine Technical Consultancy
& Design, Piraeus

Underwriters take over

Sir,
We have been drawn particularly to your Opinion 'Underwriters take over.'(Nov 84 MER).

As is customary with your fine publication, this is an interesting and informative piece.

Nevertheless, perhaps your readers might like to know that the American Bureau of Shipping has been most willingly cooperating with insurance groups on the matter of providing information relative to maintenance of class. In fact, several months ago it was ABS that suggested to the Swedish Club and others that our Society would be glad to oblige should they choose to make a condition of coverage that owners permit us to send pertinent survey reports to them; a proposal which, as you report, has recently been implemented.

You also indicated that 'unfortunately the classification societies will see this as undermining their credibility.' However, from the foregoing, I believe you can see that this is not true of ABS. We are pleased to work with the insurance industry as we are with other industries in furthering the goal of promoting safety of life at sea.

L J Bates
Executive Vice President,
ABS

Letters to the Editor

Dear Sir,

This is in appreciation of the excellent technical publication being made available to marine engineers in India.

I have left the seas and I am far from it, presently being attached as Chief Engineer (Designate) to a new 5-Star deluxe hotel which is under construction and likely to be commissioned next year under the management of East India Hotels Ltd. (Oberoi Group). It is a great consolation for me that the architectural structure of the building if when looked at closely resembles a "Super Tanker" with "cat walk & all" and the vast spreading Hussain Sagar lake ahead, I must say inspires me to go "Full Ahead".

I would much appreciate if Technical bulletins/papers are made available as was done earlier from London especially after a Technical symposium; these could be made available on a quarterly basis.

In the section "Data Base" mention is made of various publications, but the time factor is the criteria, when corresponding directly with the London. It would be much appreciated if these publications are made available to members at various branch offices.

N. Sumant Bayanker
B-57, Sainik Puri,
Secunderabad - 500 594

(Thank you for your appreciation. The transactions now appear in MER in the Centre of the journal and can be easily removed and preserved separately, if required. We are afraid the 'date-base service " is only available to readers in the U.K. for the present. - **Editor**).

Dear Sir,

Marine Engineering College (usually known as Directorate of Marine Engineering Training, in short form D.M.E.T.) was established in 1949 to meet the requirements of Indian Merchant Navy. In the last 3 1/2 decades, this institution has become an institution of international repute.

Marine Engineers educated at this institution have been internationally appreciated and praised. This has been possible mainly due to high standard of education and training imparted by this institution.

At present students are admitted to this college through the joint entrance examination conducted by Indian Institute of Technology. After an intensive, comprehensive and thorough education for 4 years, they are awarded a degree, which is accepted by the Ministry of Education as 1st degree of Marine Engineering.

Also this passing out certificate is equivalent to Section-A and Section-B of Institution of Engineers (India), which is also recognised equivalent to a Bachelors' Degree in Engineering by Govt. of India.

These all have been possible because of exceptionally high academic standard and continuous modification of practical professionally oriented subjects like Management, Sea-manship, Inter-Governmental Maritime Organisation (IMO) regulations etc. along with standard technical subjects like Mathematics, Applied-Mechanics, Thermodynamics, Heat-Engines, Internal Combustion Engines, Electro-technology, Electronics, Naval-Architecture etc.

cont...

Apart from this we have been imparting a crash course of one year duration to Graduate Engieers in Mechanical and Electrical Engineering recruited from different recognised universities of India selected by an expert selection board.

It can be noticed from above that minimum qualification for admission to Marine Engineering course in our country is quite high compared to U.K. where it is only 'O' level.

A DMET cadet after passing out from this college after 4 years course is awarded a certificate signed by Director General of Shipping. Under the same D.G. of Shipping, a sister organisation, MMD, conducts certain examinations which are known as 2nd class Part 'A' and 'B' and 1st. class Part 'A' and 'B'.

2nd class part A examination comprises of 3 papers - (i) Appl. Mech. (ii) Heat & Heat-Engines (iii) Mathematics, all of 3 hours' duration and One paper of Drawing of 6 hours' duration.

2nd class part 'B' consists of 4 papers of 3 hours' duration each (i) Engineering knowledge (Motor), (ii) Engineering knowledge (General), (iii) Electrotechnology and (iv) Naval Architecture.

1st class part 'A' consists of 2 papers (i) Heat & Heat-Engines (ii) Applied Mechanics each of 3 hours' duration.

1st class part 'B' comprises of 4 papers of 3 hours' duration each (i) E.K. (Motor) (ii) E.K. (General) (iii) Electrotechnology (iv) Naval Architecture.

A cadet passing out of DMET is fully exempted from 2nd class part 'A'. He is also exempted from 1st class part 'A' provided he gets 60% aggregate marks and at least 50% marks in individual papers in the final passing out examination.

Though the cadets of DMET in their 4 years course are taken through a course which entitles them to get an equivalent 1st level degree in Marine Engineering and though they covfr more than the curricula content of Electrotechnology and Naval Architecture of 2nd and 1st class standard of MMD, still they have to reappear in those subjects for no reason. This sort of double examination is a mere wastage of time, energy, youth and money. Moreover this is being done in the two sister departments under same Head of the Department, the Director General of Shipping.

It will not be out of place to mention here that in other countries like U.K., Hongkong, Singapore, Bangladesh etc. where the entry qualification for such marine training institute is only 'O' level and the duration of course is only 3 years the cadets are exempted from Electrotechnology and Naval Architecture for 2nd class and 1st class Engineers' examination after they pass out from those similar institutions.

It has also been brought to our notice by ex-students of this institution that though we have introduced use of scientific calculaters for examintions for the last 8 years in all technical institutes the above mentioned MMD authorities do not allow candidates to sue calculator for their examination. Although our present Prime Minister has laid specific stress in using computers even in school level and some of the central schools have already started using them.

We strongly feel that the grievances arising out of this injustice among past and present students of this institute should be immediately looked into and necessary steps taken to avoid complicacy of matters in near future.

J.P. Majumdar
and
B.N. Bera

Hon. Jt. Secretaries
DMET Group 'A' Teaching Staff Associatic
P-19, Taratala Road,
Calcutta - 700 088.

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

IME (I) GOVERNING COUNCIL, BRANCH, AND CHAPTER COMMITTEE ELECTIONS 2025-27

As the elections for The Institute of Marine Engineers (India) approach, we wish to notify all Corporate Members of the following procedures:

SCHEDULE

Soft Copy of Nomination Papers:

- The entire election process will be communicated exclusively through electronic media.
- Nomination forms will be sent via mass email and can also be downloaded from the IME(I) website. Completed forms must be returned to the Election Officer.
- Nomination papers for Council elections will be emailed by **15th May 2025** to the registered email ID.
- The Institute's office must receive the completed nomination papers by **15th June** 2025.
- The last date for withdrawing nominations is **30th June 2025**.
- The Election Committee will complete the scrutiny of nomination papers by **5th July 2025**.
- After scrutiny, the Election Officer will publish the CVs of eligible candidates on the IME(I) website.

E-VOTING

As a Corporate Member (on the Roll as of **15th May 2025**), you can cast your vote in the upcoming IME(I) elections using the **e-Voting** system exclusively.

- Two voting options will be available:
  - o **Head Office (HO) Elections**
  - o **Branch Level Elections** (if applicable)
- Overseas Members will have the option to vote **only for the HO level elections**.
- If your email address has changed, you must update it by emailing **electionofficer@imare.in** no later than **15th June 2025**.
- Members will receive the e-Voting link **only** at their registered email addresses as per IME(I) records on **1st June 2025**.
- To update your email ID or contact details, write to **membership@imare.in** by **10th May 2025**.
- E-Voting will commence on **15th July 2025** and remain open until **1700 hrs on 31st August 2025**.

ELIGIBILITY TO STAND FOR ELECTION

- All office bearers of the **Council and Council Members** must be **Fellow Members** from branches or chapters only.
- Office bearers and Council Members must have been Corporate Members for at least four years at the time of filing their nomination and must have served at least one full term on the executive committee of a local branch or chapter before being eligible to stand for election from that branch.

USE OF WORKPLACE / OFFICIAL EMAIL IDS

- In the past, mass emails have been blocked by certain organization domains, flagged as spam, or led to the blacklisting of the IME(I) domain. To avoid this, we **strongly recommend using personal email IDs only**.
- Using your personal email ensures you receive all important election-related communications.

For any queries, please contact: **Election Officer**
electionofficer@imare.in

"Reg. No. MCS/090/2018-20"
RNI No. MAHENG/2006/19917
W.P.P. Licence No.:
MR/Tech/WPP-336/ South/2018-20

IME(I) House, Nerul, Navi Mumbai