JME
"The Prime Mover"

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'INDIGENOUS CAPABILITIES OF MAIN PROPULSION SYSTEM ONBOARD SHIPS'

GENERAL MARINE ENGINEERING / NOTES FROM SEA

LETTERS TO THE EDITOR

1. Thank you for forwarding me the 74th edition of the Journal of Marine Engineering 'The prime mover' vide your DO letter 242/KPA dated 14 Aug 17

2. This edition is indeed interesting and informative. I am sanguine that the theme of this issue '*Onboard Energy Management and Environment Protection'* will surely help enhance awareness on the best practices for energy management and contribute towards conservation of our environment.

3. I take this opportunity to congratulate the editorial team and you for bringing out a highly informative edition

Admiral Sunil Lanba, PVSM, AVSM, ADC
Chief of the Naval Staff
Integrated Headquarters
Ministry of Defence (Navy)
New Delhi 110011

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1. Refer to your letter DO – 242/KPA dated 14 Aug 17 forwarding me a copy of the 74th edition of "The Prime Mover.

2. The theme "Onboard Energy Management and Environment Protection" is indeed in keeping with the times and the various issues discussed under this theme merit further progression towards discharge of the 'Green' responsibility of the Indian Navy. The articles on defect rectification and those by practicing engineers at sea were also very informative.

3. Please convey my appreciation to the editorial team for their efforts in compiling an eminently readable Journal. I also take this opportunity to wish you and all personnel at INS Shivaji the very best for the times ahead.

Vice Admiral HCS Bisht, PVSM, AVSM, ADC
Flag Officer Commanding-in-Chief
Headquarters
Eastern Naval Command
Visakhapatnam 530014

1. Please refer to your letter DO:242/KPA dated 14 Aug 17.

2. At the outset, let me thank you for forwarding a very interesting and informative copy of the 74th edition of the Journal of Marine Engineering "The Prime Mover". The Journal and its articles are of relevance to the Navy and make an excellent read.

3. The article on "Energy Saving through Optimizing Machinery Load and Exploitation" provide useful insight for undertaking major studies towards energy conservation. The coverage of "Knowledge Enabler Bay at GTTT (Mbi)" is highly commendable, as the facility would entail reduction in downtime for defect rectification, to ensure optimal availability of Fleet ships at sea.

4. I would like to congratulate the Editorial Team for preparing a well written Journal and take this opportunity to wish Team Shivaji all the success in future endeavours.

Vice Admiral AK Saxena, AVSM, VSM
Director General Naval Projects (Mumbai)
Office of the DGNP (MBI)
Naval Dockyard
Mumbai – 400023

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1. Thank you very much for forwarding the 74th Edition of the Journal of Marine Engineering "The Prime Mover".

2. I appreciate the efforts put in by the editorial team for preparation of such a wonderful and informative compilation. The articles on "Green Fuel" and "Energy Savings through Optimizing Machinery Load and Exploitation" were an interesting read and were apt to the theme of the Journal, "Onboard Energy Management and Environment Protection".

3. I wish you and Team Shivaji all success in future endeavors.

Vice Admiral DM Deshpande AVSM. VSM
Controller of Warship Production & Acquisition
126 C- Wing
Sena Bhawan
IHQ MOD (Navy), New Delhi- 110011

1. Please refer to your DO letter 242/KPA dated 14 Aug 17.

2. At the outset I would like to thank you for forwarding a very interesting, informative and enriching journal. The theme of the present edition "Onboard Energy Management and Environment Protection" is indeed a worthy topic in the present day scenario.

3. Congratulations to you and your team on this commendable work. Wishing you success in all future endeavours.

Vice Admiral Atul Kumar Jain, AVSM, VSM
Chief of Staff
Headquarters
Eastern Naval Command
Visakhapatnam – 530014

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1. Accept my sincere thanks for the copy of 74th edition of the Journal of Marine Engineering "The Prime Mover".

2. The theme of the present edition based on **'Onboard Energy Management and Environment Protection'** is indeed very informative, focusing on enhancement of technical efficiency. The publication will certainly find a place in the reference material held in my office.

Vice Admiral G Ashok Kumar, AVSM VSM
Deputy Chief of Naval Staff
187, South Block
IHQ of MoD (Navy)
New Delhi 110011

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1. Refer to your DO Letter DO: 242/KPA dated 14 Aug 17.

2. At the outset, let me thank you for sending the College copy of the 74th edition of the Journal of Marine Engineering "The Prime Mover".

3. I extend my sincere compliments to the entire Editorial Team for compiling a high quality and informative journal. The theme topic "Onboard Energy Management and Environment Protection" is very contemporary and relevant in the field of Marine Engineering and would play a significant role in selection, operation and maintenance of future generation systems. The sections on MESC Projects and Training Activities continue to endorse that Shivaji is one of the premier training establishments of the Indian Navy.

4. We would place the Journal in CDM Library to ensure greater circulation amongst the HDMC/ other course participants.

Rear Admiral Dushyant Singh Chouhan, NM
Commandant
College of Defence Management
Sainikpuri Post
Secunderabad – 500094

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1. Please accept my sincere thanks for the 74th edition of the journal of Marine Engineering "The Prime Mover".

2. The contents of the Journal, based on the theme "*Onboard Energy Management and Environment Protection"* makes an interesting read. It was exciting to learn about substantial reduction in green house gases observed during the trials of Bio-Diesel on a Marine Diesel Engine. The innovative repair of SMC CAC at sea onboard INS Tir is a fine example of both professional competence and devotion to duty. The note on the effect of diesel transients on onboard power supply system explains the concept aptly and is a must read for any young operator and maintainer.

3. The efforts of editorial team of the JME for regularly publishing such insightful journals are highly commendable and it also reflects the high ethos and dynamism of the institution itself. I wish INS Shivaji greater success in the years ahead.

Rear Admiral Chandra Shekhar Rao, NM
Director General Naval Design(SDG)
West Block-5
RK Puram
New Delhi-110066

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1. It's been an immense pleasure to glance through the covetous 'The Prime Mover' 74th edition of the Journal of Marine Engineering. The articles covered in the book are very informative and well presented which are worth reading.

2. It is indeed a matter of great honour, pride and privilege for me to extend warm wished and congrats to you and your team for such wonderful edition and wish many laurels in the future.

Rear Admiral Narayan Prasad, NM
Admiral Superintendent
Naval Dockyard
Visakhapatnam-530014

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1. Thanks for a copy of the 74th edition of the Journal of Marine Engineering 'The Prime Mover'.

2. I have perused the journal and was highly impressed with the content and presentation. Both of which are very high quality.

3. I would like to congratulate you and your editorial team for the excellent work.

Rear Admiral SN Alamanda, VSM
Admiral Superintendent
Naval Ship Repair Yard
Naval Base
Kochi-682004

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1. Refer to your DO: 242/KPA dated 14 Aug 17.

2. It is a delight to receive the 74th edition of the Journal of Marine Engineering 'The Prime Mover'. The contents of the journal, based on the theme "Onboard Energy Management and Environment Protection" are very informative. I am very pleased and grateful for inclusion of the articles "CFD analysis of plane and Circular Couette Flow" and "Experimental Investigation and Analysis of Friction Stir Welding" written by INA cadets under supervision of officers from ME Faculty. This should provide necessary impetus to cadets to showcase their ideas by undertaking technical Term paper study, Minor Project and Major Project relevant to Marine Engineering and motivate the young Mechanical Engineering cadets.

3. My appreciation and congratulations to the editorial team for a well written Journal. I wish the entire team of Shivaji the very best in all future endeavours.

Rear Admiral Amit Vikram
Principal
Indian Naval Academy
Naval Academy PO
Dist Kannur, Kerala-670310

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RESTRICTED

1. I thank you for sending me a copy of 'Journal of Marine Engineering' (Vol. 74 Edition). It gave me immense pleasure to of through the Journal and I am highly impresses with the content and presentation.

2. I am sure that the present JME journal based on 'Onboard Energy Management and Environment Protection' will be of great help in the field of energy management. The articles are thought provoking and speak volumes of the various topics of energy usage, fuel and ballast water management and marine pollution, etc. These articles with colour photographs will enhance the level of technical know-how and definitely inspire our young generation. I welcome this in future with more marine engineering related topics with modern technology usage.

3. I compliment editorial teams for evolution of the JME into a high quality professional journal over the years. Wish you success in all of your future endeavors.

Rear Admiral K Srinivas, NM, VSM
Director and Station Commander (Navy)
MoD- Department of Defence (R&D)
DMD Establishment
Post Box No. 2043
Secunderabad-500003

FROM THE CHIEF EDITOR'S DESK

1. It gives me immense pleasure to bring out the platinum edition of Journal of Marine Engineering.

2. As the Navy is ever expanding with its presence around the globe, there is a need to enhance our indigenous capabilities for marine propulsion system and its integration so as to acquire self-sustenance on the *'to float, to move'* category. Since Naval ships are highly technical and dynamic platforms, constantly pioneering innovative cutting edge technology, the requirement to develop indigenous systems to acquire self reliance has become 'need of the hour'. To ensure successful implementation of the concept, it is essential to find and ascertain potential players in the field and encourage them to develop the skill and expertise to suit the ever changing horizons. And as enterprising and ambitious engineers, we need to understand this rapid change in transformation and advancement of technology in the field of marine propulsion system, propulsion system integration, maintenance methodology and advanced health monitoring techniques. In addition, it is our responsibility to indoctrinate the young and budding minds by imparting knowledge and sharing ideas on continual update of technology and to provide them with adequate training.

3. The theme of this edition of JME "*Indigenous Capabilities for Main Propulsion System*" is apropos and congruous with 'Make in India' initiative launched by Hon'ble Prime Minister Shri Narendra Modi. The recently concluded Technical Seminar – 2017 in coincidence with release of Platinum edition of Journal of Marine Engineering has provided an ideal platform to share our thoughts and ideas on technical advancements in the field of Marine Propulsion. The present edition of Journal of Marine Engineering consists of papers and articles selected from the contributions received from Engineer Officers serving at ships and shore establishments and some of the technical papers forwarded for the Technical Seminar conducted at INS Shivaji from 13-14 Nov 17.

4. The response to the Platinum edition of Journal of Marine Engineering has been overwhelming and we are not only encouraged but also humbled by the appreciation. I request our

readers for their continued support and contributions by way of technical papers, anecdotes and experiences which are essential to further enrich the quality of the Journal of Marine Engineering. I also take this opportunity to compliment and thank the editorial team for their relentless efforts in publishing this journal. The experience had been enriching and educative and I once again thank everyone involved in making the Journal a success.

(Sumeet V Shidore)
Captain
Chief Editor

INDIGENOUS MARINE GAS TURBINE ENGINE DEVELOPMENT

Capt Azmathulla Khan

1. The paper aims to propose a methodology for indigenization of Marine Gas Turbine Engine through a consortium between Indian Firms/DRDO and foreign collaborator with close monitoring and on fast track.

2. **Background**. During the past 50 years the Gas Turbine engine has evolved into the world's most complex product, which has made an astoundingly positive impact on mankind. The fighter aircraft's gravity defying maneuvers, quick reaction of Naval platforms, large turbofan powered transport and commercial aircrafts spanning the Globe, making the world much smaller, clean burning gas turbines used worldwide for power generation have "Gas Turbine Engine" as a single most entity for such unparalleled performance of any mechanical engineering machine. Lessons learned and design innovations developed for gas turbines have also been transitioned to rocket engines including the oxygen and hydrogen pumps for the space shuttle main engines.

3. **Need for Indigenous Gas Turbine Engine Development**. Indian Navy has been operating gas turbine propelled ships for the last four decades, due to their inherent advantage of being the most compact power packs and rapid transient handlings capabilities, the warships are expected to continue with gas turbines for both propulsion and power generation aspects. M/s Zorya-Mashproekt, Ukraine and M/s GE USA are the two suppliers of the gas turbine engines for ship propulsion and Indian Navy has gained certain level of maturity in both exploitation and maintenance upto capital repairs.

4. Indian Navy presently is dependent on these both foreign OEMs for supply of necessary hardware for service and operational aspects, denial of the services/spares by these OEMs during critical times would be a major limiting factor. Further, requirement of land based gas turbine in India for various applications is on rise. Considering that the gas turbines presently installed onboard Indian Naval Ships have also found

successful application with minor modifications for land based applications due to their nature of duty cycle, significance of indigenous development of marine gas turbine engine needs no further emphasis. This would address, self reliance, OEMs engine supply unwillingness, poor after sales service due to long lead times, autonomy of application of engines and export of these engines to friendly navies.

5. **Indian Gas Turbine Design Experience**. GTRE under the aegis of DRDO was established in 1959 with a specific task for research in gas turbine engine development for various defence applications, other premier institutes associated with Gas turbine research are National Aerospace laboratory, Bangalore, Indian Institute of Science Bangalore (Associated for development of Kaveri jet nozzle design), Jadahavpur University (Control System Design) and Indian Institute of Technology Bombay (Independent Validation and Verification of Gas Turbine Simulation and Control System Design). The backbone of Metallurgical aspects has been addressed by Defense Metallurgical Research Laboratory, Hyderabad and MIDHANI. The control system, most critical gas turbine fuel pump design was provided by HAL Lucknow division and the online vibration/engine health monitoring was developed in collaboration with IIT Kharagpur.

6. There has been no feedback on the overall short falls of the last indigenous Kaveri gas turbine engine development programme. It is understood that in both Kaveri Aero and Marine Gas Turbine Programmes, the aero dynamic and gas dynamic aspects, which are the critical aspects of individual engine component design/performance and integrated functionality as a single composite gas turbine unit, were the shortfalls.

7. Notwithstanding the above, GTRE over past five decades has generated considerable knowledge/ expertise in all design aspects of Gas turbine utilizing the wide spread infrastructure facilities and huge pool of qualified scientific manpower held with the establishment. It is prudent to task the unit for further development in liaison with suitable foreign partner capable and willing to participate in co-development through a joint venture. However, the modalities through a Memorandum of Understanding (MOU) need to be worked out in this regard.

8. **Consortium Approach**. Therefore a consortium approach as was implemented in some of the successful projects such as Brahmos needs a consideration. A consortium with GTRE, Indian Industry, Academia and the foreign collaborator needs to be formed for design development, prototype manufacturing and testing and serial production of the Gas Turbine. Indian Navy as end user needs to formulate the SOTR based on the need and the frozen SOTR will form the baseline for the development by the consortium. Further, the Indian Navy could propel the consortium under the aegis of INS Eksila in a time bound manner to meet the project objectives of indigenization of Gas Turbines. The project can be funded through DRDO under Mission Mode Project.

9. **Issues Involved**. The various issues involved in such a complex project are as follows. These need to be addressed by a captive team at INS Eksila for the duration of the project.

(a) Partnership for TOT/ Development.
(b) Industry / Academic involvement.
(c) Financing Model.
(d) Risk Mitigation.
(e) Integration.
(f) Indian Navy's involvement through Nodal agency.

10. **Partnership for ToT/ Development**. Considering the past experience with Kaveri Marine GT development through GTRE, the long lead timelines with degree of uncertainty, it is very essential to partner the program with renewed foreign firm with Gas Turbine design capability. Some of the foreign firms having the capabilities are M/s Pratt Whitney, M/s Rolls Royce, M/s GE and M/s Zorya-Mashproekt. However willingness of the firms to joins hands with India in such a program needs deliberation. It is pertinent to mention that M/s Zorya-Mashproekt, Ukraine during deliberations at various levels in the past have shown their interest in their participation even with Kaveri Engine Development and same needs to be addressed at appropriate level. M/s Zorya-Mashproekt is a known reliable partner with Indian in supplying and supporting Gas Turbines for Indian Navy during the last four decades.

11. Brahmos development as joint venture between Indian DRDO and Russian Firms is a success story. Also, Eurojet EJ 200 is one of the most successful collaborations in recent times for Defence applications and in Indian context, the agreement with Russia for development of “Fifth Generation Fighter Aircraft (FGFA)”, which is expected to roll out the first prototype by 2017.

Industry/ Academia Participation

12. Both HAL and BHEL have expertise in license in manufacturing industrial Gas Turbine engines of a various rating with TOT/ production license agreement with the foreign OEMs and combining their expertise with experience that GTRE has acquired while developing the Kaveri Engine would be a move in right direction for development of Gas turbine engine technologies for both Military and civilian applications. As indicated at Para above, joint collaboration with a proven marine gas turbine developer like M/s Zorya – Mashproekt, Ukrains is the way ahead for development of indigenous marine gas turbine engine, as this would minimize the design uncertainty risks, reduce the long lead time of design considering the limited gas turbine design capabilities within the country.

13. Considerable advancements have been made by various Indian firms in handling the complex, high end materials both in terms of castings, precise machining and thermal barrier coatings which are the key aerospace technologies. The following Indian firms have gained access to some of the aerospace technologies and they can be sub-contracted for indigenous engine development programs with certain amount of risk passed on to these partners in development of compressor, combustion chamber and turbine sections etc:-

(a) **M/s BHEL**. Has considerable experience in handling various gas turbine engine based power generation plants both within country and abroad.

(b) **Bharat Forge**. The aerospace business unit is a leading supplier of various components like airframe, structural and engine parts for the aviation sector.

(c) **M/s Larsen & Toubro**. The firm has good design and manufacturing facilities and experience. The base frame for Kaveri marine gas turbine prototype engine was developed by the firm.

(d) **M/s Godrej**. Has one of the best welding facilities in the country, can be partner for combustion chamber component manufacturing.

(e) **M/s Mahindra**. Has a very good base of mechanical engineering based design.

(f) **M/s HoneyWell**. Has experience in control system design.

(g) **Academia**. In addition, large number of high end institutions like IITs, NITs can also be involved in specific topic based on their expertise level, and DRDO may take a lead role in interactions. As indicated at Para 5 above, Indian Institute of Science, Bangalore, National Aerospace Laboratory, Bangalore, Jadhavpur University, Indian Institute of Technology Bombay, Kharagpur are some of the prominent institutes who had been involved with the Indigenous gas turbine engine development program.

14. **Financial Considerations**. Another major aspect of the project is financial estimates and fund sharing by various stake holders. The project being complex in nature for realistic assessment and workout a business model amicable to all stake holders, a suitable committee with all stake holders needs to be formulated at appropriate level. The committee needs to elaborate various hold points with respect to each of the sub-assemblies and major assemblies, linking the financial outflow with specific target achievement. This would prevent budget overruns and tight control over the project timelines. The project is to be funded through DRDO under mission mode project with appropriate deliberations by Cabinet Committee on Security (CCS).

15. **Risk Mitigation**. The initial developmental cost involved with such technological challenging projects is quite high. In order to mitigate/ share the risks of the same and to bear the uncertainty inherent in the industry, various aero space majors have formed collaborations for technical experience sharing and

spread of risk/ loss due to failure. There are risk-sharing agreements where partners commit to financing some share of the project in the development process. A list of such known collaborations is appended below:-

Ser	**Partnership**	**Engine**	**Aircraft Application**
(a)	International Am Engines (IAE) Pratt & Whitney *(33%).* Rolls Royce **(25%).** Fiat (8%). *MTU* (11%). W(13.8%), KHI (5.8%), MHI (3.5%)	V2500	*Airbus A319, A320, and A321 as well* as *McDonnell Douglas MD90*
(b)	Pratt& Whitney, MI-II (lO%), KHI (1%)	PW4000	*Airbus A300 and A31 0, McDonnell Douglas MD1 I, and Boeing 747 and 767*
(c)	Pratt & Whitney, M-i-U (12.5%), MI-II (5%). KHI (1%)	PW4084	*Boeing 777*
(d)	Pratt 62 Whitney, h4TU (12%), MHI (2.8%)	PW JT8D-*200*	*McDonnell Douglas MD80*
(e)	CFM International GE (50%) and SNECMA (50%)	CFM56	*Powers the Airbus A319. A320, A321 and A340 as well as Boeing 737*
(f)	GE (59%), SNECMA (25%). W (9%). Fiat (7%)	GE-90	*Powers the Boeing 777*

16. **Integrator**. Considering the complexity in development of various modules and number of stake holders involved in the process, a design integrator with adequate experience and expertise is very vital. Having gained considerable experience in integrating the various gas turbine engine based power plant systems, M/s BHEL / M/s HAL, a public sector unit, would be a natural choice of integrator with a role to integrate efforts of public-private industries from India and Ukraine as consortium.

17. **Nodal Agency**. Also, to ensure close liaison and monitoring the project for efficient project management, including adhering to the strict timelines, as end user, the Indian Navy should lead the program as nodal agency. In this context, INS Eksila being the only marine gas turbine engine overhauling Naval establishment of ***IN*** would be an ideal choice to spear head the indigenous development programme. Also, INS Eksila holds the domain expertise of Gas Turbines and possesses GT testing facilities which would facilitate smooth progress. Accordingly, the role of Eksila in day to day functioning needs to be redefined to act as a more professional body. Nodal agency would be reviving the project at various levels at regular intervals with specific focus on time and cost overruns.

18. **Summary**. There is an urgent need for indigenous development of Marine Gas Turbine engine as a step towards for self reliance. The current infrastructure of the gas turbines spread across the country is to be brought under single umbrella with Eksila in conjunction with GTRE as the project drivers. The various spin offs like land based gas turbine generators for power generation and gas turbine engines for gas pumping stations would meet the requirements of ever growing power sector.

19. **Way Ahead**. As has been brought out above, there's an urgent need to take upon the indigenous gas turbine engine development programme on a fast track with M/s Zorya-Mashproekt as design partner and Indian Navy / Eksila as a nodal agency for project monitoring with tight timelines (broad flow chart placed at Appendix "Á"), the funding of the project is to be from DRDO with appropriate sanction from Cabinet Committee on Security. The following way ahead is recommended:-

(a) Constitute of captive team in a progressive manner at INS Eksila. To begin with two officers for one year and progressively increased to four officers over two years.

(b) Consultation with consortium partners by the captive team.

(c) Formation of consortium with Gas turbine design house and Indian industry for development of various components of the engine. A combined project proposal with due inputs from all the partners is to be formulated and taken with Ministry of Defence through DRDO/ GTRE.

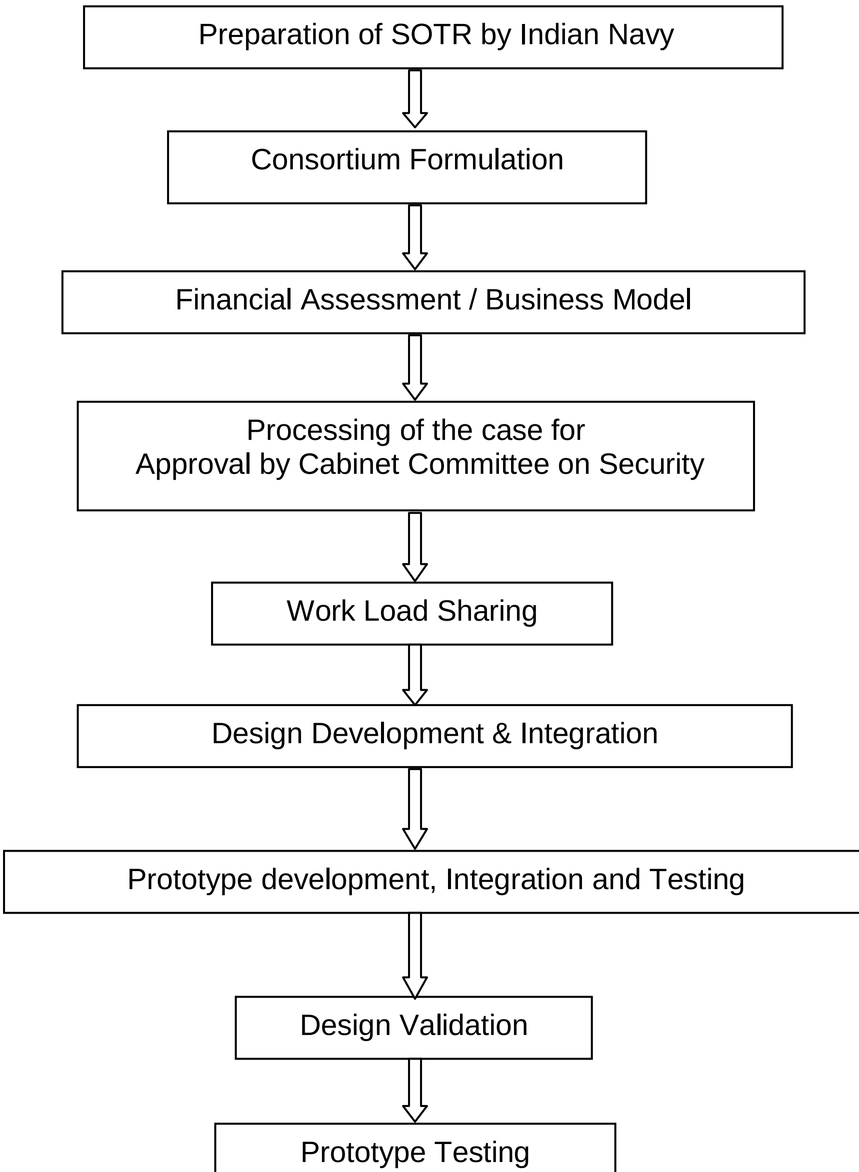
(d) Indian Navy to formulate the SOTRs based on the future force projections.

(e) Design and develop prototype Marine Gas Turbine Engine through consortium and M/s Zorya-Mashproekt, Ukraine as Engine design partner.

(f) ToT for serial production of the Marine Gas Turbine Engines, post proving of the prototype engine with extensive testing.

Appendix ‘A’
(Refers to Para 19)

INDIGENOUS MARINE GAS TURBINE ENGINE DEVELOPMENT FLOW CHART



MODELS FOR ACHIEVING SELF RELIANCE IN MAIN PROPULSION PLANT

Capt Vinay G Ankalgi and Cdr Manish Singh

"A strong Indian defence industry will not only make India more secure. It will also make India more prosperous."
- *Prime Minister Narendra Modi*

Introduction

1. The history of the marine propulsion systems can be identified with paddles and ores, used primarily to propel small boats and crafts. Later, these were replaced by sails, which remained the source of propulsion for a long time until about end of 19th century, when coal-fired steam engines created a revolution in the field of propulsion systems, followed closely by induction of reciprocating diesel engines. Since then, the last century has seen a quantum leap in the propulsion technology, including gas turbines, nuclear propulsion, electric propulsion and high speed water jet propulsions.

2. When India attained Independence, the Royal Indian Navy consisted of 32 ageing vessels suitable only for coastal patrol[1]. It was then that Indian Navy's foray into indigenisation began, over five decades ago with the design and construction of warships in the country. The goal of self-reliance has been pursued with most major warship construction programmes being progressed within the country.

3. Today, forty eight of its state-of-the-art ships and submarines are under construction in Indian shipyards, both public and private, a clear reflection of the Indian Navy's enduring support to India's indigenous warship building endeavour. While much has been achieved in our pursuit of ship building over the past decades, our dependence on foreign OEMs for importing of Marine Propulsion packages continues. The time is now ripe for launching into a new phase of self-reliance by manufacturing technologically advanced equipment within India, in pursuance of the Government of India's vision of

[1] "Genesis of Indian Navy", Accessed on June 10, 2016, www.indiannavy.nic.in

'Make in India'. However, considering the fact that only 50-60% indigenisation has been achieved in the MOVE (propulsion system and power generation diesel/ gas/ steam turbine engines, alternators and associated control systems) category in the *IN.*[2] The need of the hour is identification of the key technologies in the field of Marine Propulsion where the *IN* faces capability gap and suggest measures for mitigating the capability gap for building Self-Reliance in the field.

Aim

4. The aim of this paper is to study the existing indigenised capabilities with respect to Naval Marine Propulsion and identify models for building self-reliance in Main Propulsion Plant.

The Need for "Self Reliance" in Defence Manufacturing

5. Post major liberalisation in 2001 with 100% private sector participation,[3] Defence manufacturing came out of the stranglehold of Public Sector Undertakings-Ordnance Factories (PSU-OF) monopoly. The subsequent policy footprints have created a level playing field for the private sector. The Defence industry can be considered as a subset of a nation's concern to ramp up manufacturing capability. Therefore, the capability of our defence industry in terms of value addition, self-reliance in critical technology and policy initiatives so far and their impact needs to be examined and a possible synergy between "Make in India" policy and defence industry capability needs to be brought about.

6. India has the third largest armed forces with eighth largest defence budget in the world, accounting for almost 3 per cent of global defence expenditures. However, India has also emerged as the largest defence importer, accounting for nearly 10 per cent of global defence imports. About 60% of its defence requirements are presently being met through imports and it

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[2] Indian Naval Indigenization Plan (INIP) 2015-2030, IHQ MoD(N) / DoI [online]. Accessed June 10, 2016, http://indiannavy.nic.in/..../INIP_2015-2030.pdf.

[3] Laxman K Behera, January 08, 2008, http://www.idsa.in/idsastrategiccomments/ PrivateSectorParticipationinIndianDefenceIndustry_LKBehera_080108

spends about 31.5% of its total defence budget on capital acquisitions.[4]

7. Historically, India has been availing technology through licence agreements from Russia and a smattering of Western countries. The exceptions are some of the missile systems, small arms and their ammunition and tanks where technology has been indigenously developed by the Defence Research and Development Organisation (DRDO). The Prime minister of India, Shri Narendra Modi has emphasized, "If India has to be self-reliant in the area of security according to our armed forces needs, we have to make our own weapons," [5]

Present Trends in Self-Reliance

8. The Self Reliance Index (the percentage share of indigenous content in total procurement expenditure) of India has remained stagnant at around 30 per cent over the years.[6] Therefore, there is a requirement to develop design capability in critical technologies for defence, with thrust on adequate investment in R&D and developing ability to manufacture major sub-systems and components. Considering the Indian Naval Shipbuilding building domain, it is seen that the Indian Shipyards import more than 80% ship systems and equipment from abroad[7]. The Chinese took around 15 years to increase the use of domestic components in its shipyards from 25% in early 1990s to 60-65% presently. The Japanese, who sourced the 30-40% domestic component in mid-1950s, have achieved almost 100% self-reliance now. Similarly, Korean shipbuilders, who sourced 20-25% domestic components in 1970s, now source about 88-90% components from in-house industry[8].

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[4] Retrieved from http://avinav.org/aerospaceanddefence.php

[5] PTI " Indigenous Defence Production must for India's self-reliance", The Economic Times , January 03, 2016

[6] Ibid, 5.

[7] Indian Shipyard imports 80% of Components, 18 Dec 12, retrieved from http://www.thehindubusinessline.com/industry-and-economy/logistics/indian-shipyardsimport-80-of-components/article4214179.ece.

[8] Encourage Shipbuilding and Ancillaries will Follow, 20 Oct 2008, retrieved from http://www.thehindubusinessline.com/todays-paper/tp-logistics/encourage-shipbuilding-andancillaries-will-follow-industry/article1639385.ece.

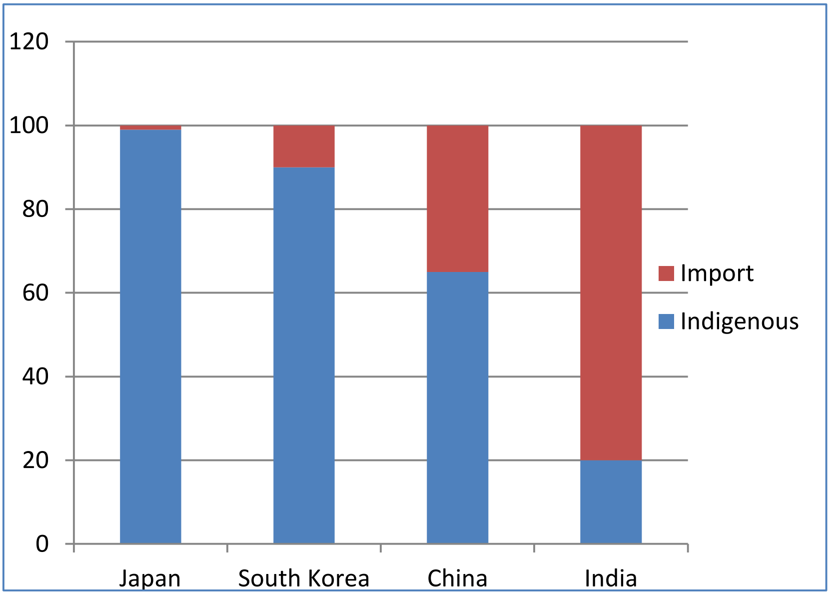

Fig. 1 Comparison of Indigenous component in Asian Navies

Why Self-Reliance in Marine Propulsion?

9. Twenty five years after it gave itself the target of "Made in India," the navy has come a long way. During the commissioning ceremony of INS Sumitra on 04 Sep 2014 at Chennai the former Chief of Naval Staff Admiral R K Dhowan said, "We have transformed from a buyer's navy to a builder's navy." The Navy no longer has to order platforms from abroad and has built up the capability to build from aircraft carriers to submarines and over 48 platforms are on order in India at various shipyards. While *IN* has been able to achieve about 90% indigenisation in the 'FLOAT' category in the 'MOVE' category it is around 60%, restricted only to low end auxiliaries of Main Propulsion Plants [9].

10. In the foreseeable future, the role of *IN* would continue to extend across the entire spectrum of security of the nation; from protection of Sea Lanes of Communications to peace keeping, and a greater role in the Indian Ocean Region (IOR) and beyond,

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[9] Indian Naval Indigenization Plan (INIP) 2015-2030, IHQ MoD(N) / DoI [online]. Accessed June 10, 2016, http://indiannavy.nic.in/..../INIP_2015-2030.pdf.

in pursuit of national interests. Thus, warships would require longer deployment capabilities with reliable niche technology to make them more lethal platforms and would also require state-of-art marine propulsion systems, whether it is gas turbines, nuclear, electric or hybrid propulsion systems. The dependence on the foreign OEMs for Marine Propulsion equipment shall be an impediment in case of adversities. Therefore, it is of paramount importance for the *IN* to have a robust manufacturing base in the country to become a self-reliant regional force with minimal foreign dependencies. The road for building Self-Reliance shall begin with increasing the Indian participation in the manufacturing and gradually achieving higher indigenous content in the equipment and services.

11. **Systemic issues in Marine Propulsion**. Some systemic issues that are attributable for low levels of indigenous capability in the Marine Propulsion are as follows: -

(a) High developmental costs with long lead time.
(b) Higher equipment performance standards to meet *IN* requirements.
(c) Economy of scale view requirements of limited numbers.
(d) Slow movement in the Research and Development project of marine Gas Turbines.
(e) Stringent emission and noise level norms considering stealth requirement.

12. **Main Areas of 'Move' Where *IN* is Facing Capability Gaps**. Indian Navy currently employs three conventional propulsion modes i.e. steam plants, diesel engines and gas turbines. Sufficient developments have been made in respect to steam propulsion plants and small diesel engines. Indigenously manufactured steam turbines of M/s BHEL and main propulsion diesels of Kirloskar Oil Engines Limited are already in use onboard ships. Nuclear propulsion and Integrated Electric Propulsion are also envisaged for future ships & submarines. However, the major items in respect of Main Propulsion in the ship-building programme that are still being imported are as follows:-

(a) Gas Turbines (11-15 MW and 20-25 MW).
(b) High Power Main Propulsion Diesel Engines.

(c) Marine Gearboxes (1-50 MW).

Models of Indigenisation that can be adopted

13. The various indigenisation models that can be adopted in marine application are elaborated below :-

(a) **Development through Private Defence Industry**. In this model the onus of development rests on the private firm. The United States follows this model and defence manufacturing has become a U.S. specialty, with 47 American companies filling the top 100 grossing slots in the world.[10]

(b) **Creative Adaptation**. The philosophy of *Acquire* followed by *Reverse Engineering* leading to indigenisation has largely been the Chinese approach. It has been highlighted as a process of "creative adaptation"[11]. The classic example for this is from the fact that since 1985, China acquired four retired aircraft carriers for study, the Australian HMAS *Melbourne* and the ex-Soviet carriers *Minsk*, *Kiev* and *Varyag.*[12] On 25 September 2012, China's first aircraft carrier, *Liaoning*, was commissioned. On 31 December 2015 it was reported by several news sources that China was building a second aircraft carrier using entirely indigenous design.

(c) **Development through Government Agencies**. In this model the complete indigenisation and manufacturing responsibilities rests solely with the Government PSUs and Ordinance Factories. This model was largely followed in India till the recent past; however this mode of indigenisation has its limitations due to efficiency and productivity concerns.

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[10] Eloise Lee and Robert Johnson, "The 25 Biggest Defense Companies In America", Bussiness Insider, March 13,2012

[11] Ajai Shukla, "China' defence industry offers lesson to India", July 18,2011, www.bussiness-standard.com

[12] PTI " Chinas first aircraft carrier to be commissioned in august", The Economic Times, March 09, 2012

(d) **JV Model**. The Joint Venture (JV) by Defence Public Sector Units (DPSUs) to build complementary capacities, infrastructure, technology or capability available with the partners. Further, the technology can be absorbed to initiate and sustain indigenisation efforts.

(e) **Consortia of Indian firm and the OEM**. Considering the present scenario of improvements in ease to do business in the country, it is felt that the environment is just conducive for the Indian firms to engage with foreign OEMs dealing in the key technologies of marine propulsion system as *consortia*. These consortia can work as a single entity, to deliver complex and state-of-art propulsion systems, by entering into a work share agreement, under which technology / design is provided by one firm and the manufacturing is undertaken by other in India. This will have tremendous advantages both in delivering the latest in technology and reducing the cost of development & production. The model would ensure that both the collaborators gain from the expertise / technical know-how of each other, through sharing of technology, procedures and work force can share the technology and manufacturing capabilities to supply the equipment.

Defence Procurement Procedure (DPP) 2016 – Salient Aspects towards building Self-Reliance.

14. The DPP-2016 has considered Self-Reliance as a major corner-stone on which the military capability of any nation must rest. Also considering the immense potential of the manpower and engineering capability within the country for attaining self-reliance in design, development, and manufacturing in defence sector. The DPP-2016 has considered the concept of 'Make in India' as the focal point of the defence acquisition policy/procedure. The emphasis of DPP-2016 is on 'Buy (IDDM)'[13] for outright purchases and funding of 'Make'[14] category

[13] Page 3, Chapter I - Operational Context, Acquisition , Categories and Acquisition Plans, Defence Procurement Procedures-2016, MoD, GoI
[14] Page 2, Chapter III – Procedure for 'Make' category of Acquisition, Defence Procurement Procedures-2016, MoD, GoI

for building indigenous long term capability. The order of priorities for acquisitions and salient features of 'Make' category are placed at **Appendix 'A'**.

Proposed Road Map for building Self Reliance in Marine Propulsion

15. It is considered that no single model as discussed at para 13 above directly applies to the Indian industrial setup and procedural requirements vis-à-vis varied technological needs foreseen for Marine Propulsion in *IN*. The building of Self-Reliance in Marine Propulsion has to be seen as incremental building of Indigenisation in a time bound manner without compromising the niche technology requirement of the future *IN* platforms. It is understood that *IN* has envisioned and its future plans for induction of large number of ship by year 2027. The same shall be executed based on 15 year Long Term Integrated Perspective Plan (LTIPP) and 5 years Services Capital Acquisition Plan (SCAP). Synergising these plans with the ecosystem in the country for encouraging and building Indigenisation quotient in Marine Propulsion can be the key. Therefore, *IN* needs to adopt a two pronged approach towards this, by suitably harnessing the potential of DRDO establishment and Indian industries and through JV by the Government or Consortia of Indian firm with foreign OEMs, based on availability of equipment with ToT in short term or through R&D in long term. As a guiding factor the duration can be aligned as per SCAP. The models can thus be classified as follows:-

(a) **Short Term Route (2 to 5 years) – Manufacturing through Transfer of Technology (ToT)**. This would include equipment that are commercially available in world market and can be manufactured in the country through ToT route. The manufacturing of the equipment can be undertaken through JV between Government and the OEM, JV between Government, OEM and Indian firm or SPV/Consortia of Indian firm and foreign OEM.

(b) **Long Term Route (5 to 10 years) - Design and Manufacturing based on R&D**. This would primarily include critical technology equipment that are not available through ToT route. The R&D and Creative

Adaptation in such cases can be undertaken by DRDO or Indian firm independently or in consonance with 'Make' category of DPP-2016.

16. The economic viability of the above model can be achieved by undertaking suitable measures as mentioned below:-

(a) **Freedom of Exports**. By allowing manufacturers to manufacture equipment in India and export it to other upcoming navies in the IOR and also the commercial vessels across the world will provide economic viability for Business firms.

(b) **Life Cycle Maintenance Support**. The suppliers can further engage in providing life cycle and maintenance support to the equipment in *IN*. In general, the maintenance cost (cost mainly consists of maintenance labor cost, maintenance equipment cost and spare parts cost for complete life cycle) forms twenty five percentage of the total life cycle cost of a typical marine diesel engine. This shall prove to be a win-win situation for the suppliers and the *IN*. The suppliers can reap the economic benefit while the same would reduce pressure of maintaining infrastructure and facility for the *IN*.

17. **Envisaged Advantage of the Proposed Model**. The various advantages envisaged with the above model are as follows:-

(a) **Respite from Inordinate Delays in Supply of Equipment**. The time bound initiation and in-house availability shall help reduce inordinate delays in supply of equipment.

(b) **Building of Technical Base in the Country**. The utilization of Indian Engineers and academia viz IITs and NITs through projects shall enhance the R&D work in the field of marine propulsion technology. The development of technology in the country has to be brought about by providing special incentives to the firm engaging with academia for R&D work in the field of defence technology. This process shall not only encourage the R&D atmosphere in the country but shall also help in building the technical base for defence technology.

(c) **Skill Development**. The engagement of the Indian firms shall ensure skill development within the country that shall be a step towards building total self-reliance apart from creating jobs in manufacturing and services sector.

Marine Propulsion Technology – Focus Areas and Proposed Way Ahead for Self-Reliance

18. The major Marine Propulsion equipment conventional and futuristic where there is shortfall in indigenous capability and are paramount for self-reliance drive of *IN* is covered in the succeeding paragraphs.

Gas Turbine (GT)

19. Presently all gas turbines, fitted in Naval ships are of foreign origin and mostly Russian. For the indigenously designed P-17 and Vikrant, the General Electric LM2500 engines have been supplied by Hindustan Aeronautical Limited (HAL), Bangalore, which undertakes licensed production of the General Electric engine from OEM knock down kits. HAL also has necessary infrastructure to support the engines in service. However, it is understood that no component of LM2500 engines is locally procured/ manufactured and only assembly of complete knock down kits is being undertaken. Indigenisation initiatives taken in this regard include development of a fully indigenous Kaveri Marine Gas Turbine (KMGT) is being pursued at GTRE, Bangalore.[15]

20. **Thrust Areas**. Following are the thrust areas wherein Gas Turbines manufacturing can be explored:-

[15] Dr V Bhujanga Rao (VBR), Director General, Naval Systems and Materials, Defence Research and Development Organisation (DRDO), Ministry of Defence, interview with India Strategic (IS).Published: December 2013, Accessed July 12, 2016. http://www.indiastrategic.in

(a) There is a need to develop gas turbines in the range of 11-15 MW and 20-25 MW for fitment on future ships as main propulsion units.

(b) Development of GTs with low Specific Fuel Consumption (SFC) at part loads viz. Inter-cooled Recuperated WR 21 Gas turbine developed by Rolls Royce and Northrop Grumman that offers a 30% reduction in fuel consumption and a flat specific fuel consumption curve over entire operating range, when compared to contemporary gas turbines.

21. **Proposed Way Ahead for building Self-Reliance in GT**. It is evident from the above paragraphs that apart from direct procurement of GTs from foreign OEMs, HAL is engaged in JV for assembling of LM 2500 GTs in the country to meet the current requirement. Also, R&D for KMGT is being undertaken by DRDO the programme already fraught with delays. The same can continue through Short Term Route (2 - 5 years). However, to avail latest technology for future platforms, it is felt that a parallel program for Design and Development by Creative Adaptation of low SFC GTs through Long Term Route (5-10 years) through Indian Industry and BHEL be encouraged. The Make category of DPP-2016 can be explored in this case with a view to achieve Self-Reliance in new technology of GTs.

Diesel Engines (DE)

22. Primary requirement for the diesel engines is to have low noise levels and high availability/ reliability. M/s Kirloskar Oil Engines Limited (KOEL), M/s MAN, GRSE/ MTU and M/s Cummins India have all been involved in licenced production of marine Diesel Engines in India. Although a great degree of self-reliance in lower power range has been achieved, the high power diesel engines are largely imported or assembled in India.

23. **Thrust Areas in DE**. The capability of indigenous design, metallurgy, control systems and manufacturing of critical components like fuel ignition pumps, governors, turbo-chargers, rotating components, non-magnetic engines, etc, are still in nascent stages and need substantial boost. Another critical field is adherence to stringent environmental regulations, which requires technological advancements for reduction of emissions,

as well as improving combustion efficiency.

24. **Way Ahead for building Self-Reliance-DE**. Considering the fact that high power diesel engine has a market for commercial application as well, the *IN* needs can be met by firms ready to invest through manufacturing in India. It is felt that same can explored by Indian Firms with ToT and manufacturing in India by forming SPV/Consortia with OEM. This shall fall under Short term (2-4 years)- Manufacturing with ToT route. The *IN* can further look for procurement through Buy and Make (Indian) route. Creative Adaptation through Long Term Route (5-10 years) through Indian Industry can be encouraged.

Reduction Gear (RG)

25. In designing a warship gearbox, special attention is required to be paid to all the parameters that could influence the noise and vibration performance of the gearbox. These design aspects, such as tooth corrections, tooth loading, gear layout, balance, lubrication and resilient mounting, requires to be taken into consideration. Presently some gearboxes of ships are being manufactured in India by M/s Elecon, under joint ventures with foreign firms such as M/s MAAG Switzerland & M/s Renk Germany.

26. **Thrust Areas in RG**. For efficient power transmission to the propeller, marine gearboxes should possess the features viz. higher hardness of pinion and gear materials to cater higher gear tooth loadings, high efficiency by ensuring lower transmission losses and reliability, long life and low noise levels and vibration. There is a requirement of Low-noise gearboxes with greater indigenous content in the range of 1-50 MW for the new construction ships.

27. **Way Ahead for building Self-Reliance-RG**. In case of RGs there is a need to gainfully engage the global leaders to enhance own expertise, infrastructure and production facilities to be self-reliant and self-confident in the field of marine gear box manufacturing. The involvement of Indian Private firm through Short term (2-4 years) - Manufacturing with ToT route is considered as viable.

Future Marine Propulsion Technology

28. The future Marine Propulsion Technology viz. Nuclear and Electric have already made inroads into the IN, the recommendations for building Self-Reliance for the same is placed at **Appendix 'B'**.

Conclusion

29. Although, the competence of the Indian Industry in the Marine Propulsion has shown tremendous growth in the last decade, there exists a large void in the field of design, production, manufacturing and technology know-how in the domain, to meet the requirements of future new construction projects. The paper has suggested certain key areas of Marine Propulsion that faces capability voids within the country. The requirement of plugging the same shall be a step towards incremental indigenisation leading to Self-Reliance in the field. Thus, to leverage the present scenario of improvements in ease of doing business in India and favourable government policies the requirement of ToT and sharing of resource pool between the Indian industry and global players to utilise, what each is best capable of, along with encouraging indigenous R&D is the need of the hour. For the *IN*, that has envisioned and clearly laid down its future plans for induction of large number of ship by year 2027, the requirement of niche indigenous Marine Propulsion Technology can be achieved using the two pronged approach of synergising its time based plans with Indigenous capabilities in the country. The future plans of *IN* for Marine Propulsion Equipment emanating from LTIPP and SCAP can be synchronised with indigenous capabilities for building Self-Reliance through Short Term(2-5 years)- ToT and long Term(5-10 yaers)- R&D route. The same has to be backed by the government and steered by the Indian firms for attaining Self-Reliance in the longer run. The JV of the government PSUs with foreign OEMs and the collaboration of the Indian private firms with foreign OEMs through formulation of Consortia can be pivotal for building Self-Reliance in Marine propulsion domain in the country.

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Appendix ‘A’
(Refers to Para 14)

SALIENT FEATURES OF DPP-2016

Order of Priority for Acquisitions.

1. As per DPP-2016, in decreasing order of priority the procurement of defence equipment, under Capital Acquisitions are categorized as follows:-

(a) Buy [Indian – Indigenously Designed, Developed and Manufactured equipment (IDDM)]
(b) Buy (Indian)
(c) Buy and Make (Indian)
(d) Buy and Make
(e) Buy (Global)

Make Category of Acquisition

2. In addition to the above listed categorization, there is the ‘Make’ categorization, which aims at developing long-term indigenous defence capabilities. Depending upon factors such as Indian industry’s capability, access to technology, time frame required and available for development, the ‘Make’ category of procurement would be pursued in isolation, in sequence or in tandem with any of the five categories under ‘Buy’ or ‘Buy and Make’ Classifications. The sub-category under ‘Make’ category are further sub-divided into the following :-

(a) **Make-I (Government Funded)**. Projects under ‘Make-I’ sub-category will involve Government funding of 90%, released in a phased manner, and based on the progress of the scheme, as per terms agreed between MoD and the vendor.

(b) **Make-II (Industry Funded)**. Projects under Make-II category will involve prototype development of equipment/system/ platform or their upgrades, or their sub-systems/sub-assembly/assemblies/components with a focus on import substitution, for which no Government funding will be provided for prototype development purposes.

Appendix 'B'
(Refers to Para 28)

RECOMMENDATIONS FOR FUTURE MARINE PROPULSION

1. **Nuclear Power Propulsion**. Nuclear power presents the ultimate AIP solution affording high speed, mobility, autonomy and submerged endurance limited only by stores capacity and crew fatigue. Development of nuclear power propulsion plants may be considered for the surface ships viz. IAC 2 of the *IN*.

2. **Way Ahead for building Self-Reliance-Nuclear Propulsion**. Having developed Arihant, India can proudly proclaim capability in the field of Nuclear Submarine construction. However the Need of the hour is to consolidate on this technology through proliferation and following the model of introspection and lessons learnt. India can further develop this technology through proliferation and consolidation of **indigenous capabilities of DRDO and BARC** for future platforms.

3. **Electrical Propulsion**. Electrical propulsion technology is maturing at a fast pace for marine applications. This technology provides considerable advantages in terms of higher efficiency, increased flexibility in installation, improved survivability, lower noise signatures, reduced maintenance and manning requirements and considerable savings in through-life ownership costs. Advanced navies like the US Navy, Royal Navy and French Navy already have in place major programmes for adoption of this technology.

4. The Indian Navy has floated a domestic tender for construction of four landing platform docks (LPDs) and bids were sent to domestic shipyards, Larsen & Toubro (L&T), Pipavav Defence and Offshore Engineering, and ABG Shipyard[16].The ship will be powered by electric propulsion systems. Hindustan Shipyard Ltd. (HSL) will be building the two LPDs.

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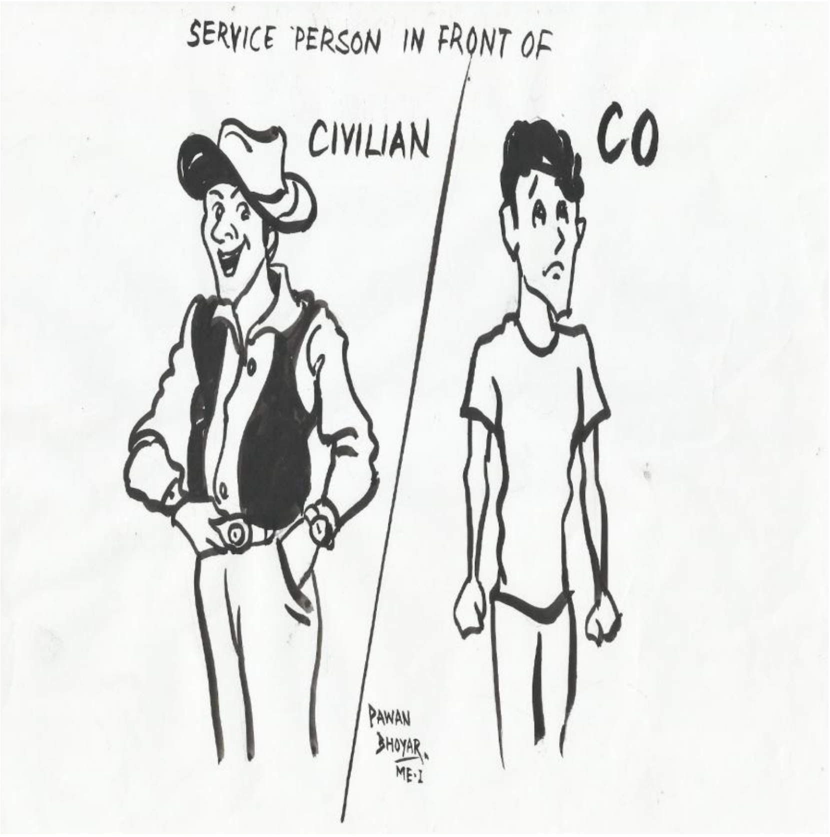
[16] "ABG Shipyard May Lose in Race for Rs 20,000-Cr Warships for Indian Navy", Published on 20 Feb 2016, Accessed on June 10, 2016, www.indiandefensenews.in

5. **Way Ahead for building Self-Reliance-Electric Propulsion**. The technology of developing, integrating and managing high end electric components viz. Propulsion Motors, Converters and Transformers provides an opportunity for Indian firms to participate by engagement with foreign OEMs. The indigenous development in this field can also be achieved through Make route of DPP-2016 by also involving Micro, Small and Medium Enterprises (MSMEs). BHEL can be involved for Propulsion Motors through Short term Route (2-4 years).



AN ASPIRING BLUE WATER NAVY MUST NOT STRUGGLE WITH CENTRIFUGAL PUMPS – A SUGGESTED WAY AHEAD FROM THE GROUND ZERO TO HARNESS INDIGENOUS TECHNOLOGY ON INDIAN NAVAL SHIPS

Capt Mohit Goel, NM

Synopsis

Pumps constitute the majority of mechanical equipment fitted on- board Naval ships and submarines. They handle a variety of mediums like sea water, fresh water, feed water, distilled water, chilled water, hydraulic fluids, fuel oils, bilges, sewage water etc. Amongst all the pumps on-board, water pumps constitute the biggest single group. A majority of these are centrifugal pumps. The aim of this paper is to consider the variety of applications of centrifugal water pumps on-board Naval Vessels and suggest standardisation in their types giving due consideration to maintenance aspects, and recommend rationalisation of their design with a view to reduce inventory and enhance operational availability. The scope of this paper is limited to all independent centrifugal water pumps used for sea water, bilge, ballast, fresh water, feed water, chilled water and various other domestic applications on- board ships and submarines. Engine driven pumps, others integral to the machinery and portable pumps are excluded from this study. The paper aims to propose a time-bound workable solution to the issue of non- availability of ABER replacement MD Pumps on IN ships. The paper also advocates use of Composites and Advanced Repair Techniques to enhance the operational availability of this vital but often neglected equipment onboard. The paper is written from the practical work undertaken recently by Naval Dockyard with a proactive assistance from IU(West) and IU(East) , Mumbai where a large number of challenges were faced recently in this area.

Background

1. **Introduction**. Indian Navy has been grappling with the issue of non availability of pumps as ABER replacement for some time. Large ranges coupled with limited number of suppliers have added to the complexity of the problem. Further, closing down of the two major pump suppliers namely M/s BE

Pumps & M/s Best and Crompton has added yet another dimension to the issue. Considering that the Delhi and Talwar class of ships are now going through the Medium Refits, there is an urgent need to evolve a workable solution in a time bound fashion.

Sl	**Firm Name**	**Approximate no. of Pumps**	**No. Of Models**	**Status of Firm**
(a)	M/s BE Pumps, Kolkata	607	61	Closed
(b)	M/s Best and Crompton Pumps, Chennai	380	27	Closed
(c)	M/s SPX flow, Ahmedabad	958	71	Poor Response
(d)	Russian origin	500	19	Indigenized
(e)	Miscellaneous (M/s KBL, Pune, M/s CRI, Desmi, Sehra, GRSE)	300	45	Satisfactory Response

Table 1 IN Inventory of MD Pumps at a Glance

2. **Aim**. The paper aims to propose a time-bound workable solution to the issue of non-availability of ABER replacement MD Pumps on *IN* ships. The paper also advocates use of Composites and Advanced Repair Techniques to enhance the operational availability of this vital but often neglected equipment onboard.

3. ***IN* Inventory**. The *IN* inventory has approximately 2,700 pumps of 210 different models manufactured by different

vendors. This is in stark contrast to the philosophy adopted by the Russian Navy which has only minimal types of pumps across various classes of ships. Study of the Russian pumps design indicates that only few different models can replace the entire range of water pumps in IN inventory. Analysis of the present *IN* inventory indicates that the past induction practices have resulted in large inventory of pumps on *IN* platforms with many duty points procured from various sources. There are many cases where pumps of different designs have been accepted from different manufacturers for the same duty point applications. There are also cases where different types of pumps have been installed for seemingly minor difference in duty points. In specific cases, some design features of these pumps have added to their maintenance problems. The data with respect to major pump suppliers along with type and number of pumps is enumerated below:-

4. **Scope**. In order to find an optimized solution, the firemain and fresh water pumps fitted onboard Delhi and Talwar class of ship were considered for this study.

5. **Prominent Designs**. Majority of general duty centrifugal water pumps in the Navy belong to one of the following designs:-

(a) **Stool Mounted and Coupled Pumps with Water Lubricated Bush**. Most of the vertical pumps, namely cooling water pumps, fire pumps manufactured by erstwhile M/s Best and Crompton and M/s Beacon Weir fall in this category.

(b) **Stool Mounted and Coupled Pumps without a Bush**. Most of the vertical pumps manufactured by M/s BE Pumps are of this design.

(c) **Worthington Design**. These axial split casing pumps with grease lubricated multiple bushes are the most reliable pumps if maintained and operated with due care. However, they are very large with very high weight to capacity ratio and require elaborate overhaul procedures involving extensive machining.

(d) **Monobloc Pumps**. Most of the Russian pumps are of mono-bloc design. This versatile design with no bushes and one sturdy intermediate plate obviates most of the problems discussed earlier. Moreover, monobloc pumps are smaller and have less number of rotating parts. The mean time between failures of these pumps is relatively very high and overhaul procedure is very simple

6. **Disadvantages of Stool Mounted Pumps**. Major disadvantages of these pumps are as under:-

(a) **Large Size**. These pumps are large due to the extra height of the stool.

(b) **Failure of Bush**. Premature failure of water lubricated bush calls for additional maintenance. Presence of fine harbor silt in the pumped medium and excessive radial thrust on the rotor due to low-pressure operation of the pump (Operation to the right of Best Operating Point (BOP)) are the primary reasons for premature failure of bushes.

(c) **Distortion of Stool**. The stool acts like a support member between the pump and motor with the upper surface supporting the motor and the lower surface supporting the pump. A major disadvantage of these pumps is distortion of the stool. Though the pump casing is made of a rigid casting, the stool is generally fabricated with 6 to 8 mm steel plate. Affected by the rigours of seawater corrosion and being the weakest link between the pump and the motor, the stool gets thinned down and distorted after a few years. Distortion of the stool disturbs the axis of the pump and the motor and causes misalignment. Continued operation of a misaligned pump results in excessive vibrations and premature failure of antifriction bearings and rotors.

7. **Monobloc Pump Design for the Navy**. In the light of the above findings, it is opined that the basic monoblock design is the most versatile for our applications. These pumps are smaller, have less number of rotating parts and have a high MTBF with simple maintenance requirements. They have no bushes, no stools and only one sturdy intermediate plate. Such

monobloc pumps of the Russian type have proved most reliable and maintainable, and should therefore be adopted as the standard design for the Navy. No stool mounted pumps should henceforth be introduced. All future designs of water pumps should only be vertical or horizontal mono-block pumps.

8. **Sea Water Pumps (Firemain Pumps)**. Delhi class of ships is presently fitted with nine fire pumps of M/s B.E make, of capacity 150 TPH at 10 bar. The driving motor is 93 KW, 2950 RPM of M/s GEC Alsthom. The starter panels operate on Star-Delta principle. Analysis of firemain pumps of Talwar and Delhi class indicate that duty points and performance curves of these pumps are similar. The pumps used onboard Talwar class and Delhi class is of similar capacity and working pressure. Further the Talwar class firemain pumps have been indigenised recently through reverse engineering. This paves a way for inducting the recently indigenized Talwar class firemain pumps from M/s Balaji Tech both on Talwar / Delhi class without changing the motor and associated starter.

9. **Issue of Fresh Water Pumps**. Only two models of fresh water pumps are used onboard the Russian origin ships ranging from the erstwhile Missile boats Petyas to the Aircraft Carrier. They are classified as UBC 4/40 and UBC 10/40. These pumps are identical in construction and the major difference is in the motor and small modification to the casing. The flow rate of the pump can be varied from 3 cum/hr to 14 cum/hr with corresponding changes to the prime mover by adjusting the depth A and radius T of the inner channels (Refer Figure 1). It is opined that such a design significantly standardises the parts of the pumps throughout various flow rates. It is also pertinent to mention that the fresh water pump has been indigenised by IU(East) through M/s Balaji Tech. This makes the indigenised pump the most suitable candidate for use as replacement of fresh water pumps onboard Delhi class in particular and across the *IN* in general.

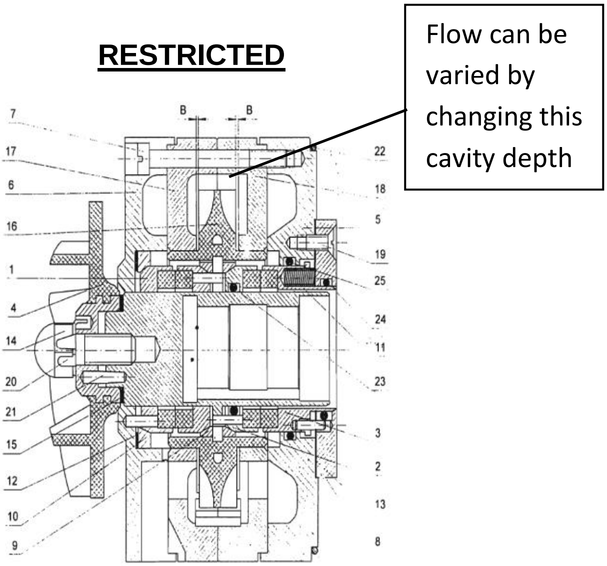


Fig. 1 Variation of Flow by Minor Modification

10. **Proposed Way Ahead**. Considering the above facts, following way ahead is proposed:-

Short Term

11. **Modification to the Motor**. The pump is the most susceptible part of an MD pump as it is most affected by wear & tear. On the other hand, the motors are rugged and can be rewound / repaired with relative ease and do not add significantly to the range and scale of inventory. Further, as the motors of the existing pumps have been type tested, their continued use as part of the short term solution is prudent. Notwithstanding as a long term measure there is a need to look at ways and means to optimize the motor size employing contemporary design modifications.

12. **Delhi Class Firemain Pumps**. As the process of Type Testing process is long drawn, as an immediate step, only the pumps both for firemain and fresh water can be replaced with the indigenized pump keeping the same motor. This will do away the requirement of type testing of motor and starter. The complete solution will entail only a minor modification to the piping along with extension to the existing motor shafts. Considering short time and the ease with which the solution can be implemented, it is intended to use this solution on four out of nine INS Delhi firemain pumps and exploit them during the

current refit. As the ship is in Medium Refit, it will offer adequate field testing opportunity. Based on the onboard exploitation results, the way ahead for the balance pumps can be progressed.

13. **Fresh Water Pumps**. The one model with different variants of the fresh water pump discussed in the preceding paragraphs, meets all the freshwater, refrigeration cooling, sanitary and sewage pumping requirements of all classes of Russian ships. The population of these pumps in the Navy is about 300 numbers. On the contrary, the indigenously built ships have about 30 different models performing the same duties with a population of about thousand pumps. Assuming an inventory of 40 distinct parts for each pump, the Russians have 40 ILMS entries for the three hundred pumps, while the indigenous inventory has about 1200 ILMS entries making the inventory unmanageable by any measure. To mitigate this issue it is prudent to replace all the pumps in these duty ranges with the indigenously developed Russian pump.

Long Term

14. **Balance Pumps On Delhi Class**. Upon successful completion of the trials of the firemain pump, it is intended to undertake a similar study for the ships cooling and AC pumps to make them compatible with the similar application pumps of the Talwar/ Russian inventory to make replacements in a plug and play mode, thereby making pumps easily replaceable and to cross platform compatibility.

15. **Development of Light Weight Motors**. Motors remain an integral part of the problem as well as solution towards reliable performance of centrifugal pumps. The pace of induction of modern technology has not been in sync with the technological innovations in the industry. It is strongly felt that present firemain motors are too bulky and need reduction both in size and weight. Naval Dockyard, Mumbai has taken up a feasibility study to replace the existing motors with light weight modern motors meeting all the Naval Specifications. As a long term measure, there will be a need to replace the existing motors with lightweight contemporary motors. This can be done progressively over the next 2-3 years.

16. **Use of Composite Impellers**. The harsh and highly corrosive seawater in Tropical Waters is one of the primary source of erosion and corrosion of non- ferrous moving components inside a firemain pump. Composites are an emerging technology with demonstrated, exceptional performance characteristics. It can substitute alloys with higher performance, lighter in weight, faster to manufacture and greatly increasing corrosion resistance. Minimised running clearances are possible due to non-galling and non-seizing nature of reinforced plastics. Composites can withstand hard contact with little or no damage and can also handle intermittent dry run spells. In cases where dry run is quite extensive, the composite will suffer surface melt but will not damage extensive metal parts which happen with a traditional non-ferrous metallic impeller. Modern composites hold a promise of obviating this problem as they are highly corrosion resistant and also lighter thus reducing the wattage requirement of the motor. Initial trials of using a composite impeller in a Talwar class firemain pump have been very satisfactory. Endurance trials have been successfully undertaken for more than 500 hours and all the parameters (including noise and vibrations) were found to be satisfactory. Significant drop in running current was observed indicating lower power consumption which can be very beneficial onboard Submarines.

17. **Re-Building/ Retrieving of Pump Casings through Metal Buildup Using Modern Epoxy Compounds**. Pump casings and impellers of various ships landed at Dockyard for overhauling are found to be heavily corroded and deep pitting was observed throughout their surface. The efforts to retrieve the casings and impellers by carrying out hot welding and brazing were unsuccessful due to extremely poor material state especially for Russian origin pumps. These pumps were observed to have scattered deep pitting upto 10 mm and general thinning of material. As the new casings and impellers were not readily available, an attempt was made to recover components of these pumps through cold weld repairs by using Polyceramic Rebuilding and Resurfacing Compounds. These adaptable cost-effective products are a good choice for engineering repair and protection on all types of mechanical equipment and machine components. The work was undertaken for Seawater

pumps of Talwar Class, 'B' Class and Delhi Class. These pumps have undergone onboard usage exceeding six months. The performance of the retrieved pumps was found to be satisfactory during test bed and onboard trials. A marked improvement in the condition of impellers and casings was observed as further deterioration was arrested due to application of the putty. It has also enhanced the proactive support provided by Naval Dockyard to afloat units. A brief pictorial compilation highlighting the '*Before*' & '*After*' condition of pumps is placed at enclosure.

Conclusion

18. The Navy's experiment with stool mounted back pull out model pumps for water application has been a resounding failure. Besides closure of firms that supplied them, there have been repeated failures of these pumps due to distortion of the stools, bearing and bush due to shaft whip. Considering the experience till date *IN* must migrate back to the time tested rugged Russian model of monoblock pumps and the closure of the firms must be viewed as an opportunity. The study indicates that about ten Russian pumps that can replace all the pumps listed in this paper excluding the ones for special applications such as the turbo driven feed pumps of steam ships. More importantly, all these monoblock pumps of Russian design have already been indigenised and are in various stages of trials with the material specifications conforming to the latest DME specs for water applications. This reduces the existing inventory of pumps to about a tenth where more of these pumps would be interchangeable between various classes of ships.

19. The case study amply proves that there is an adequate scope for rationalisation of pumps fitted onboard ships in commission and on new commission ships. The solution offered in the paper is being implemented onboard INS Delhi during the current MR and would rapidly eliminate the problem faced during due to non availability of pumps as ABER replacement.

20. Modern epoxy coatings have a wide range of applications in the marine field. Recovery of casings and impellers has given a major boost towards ensuring a better performance and enhanced reliability of seawater pumps fitted onboard IN Ships and Submarines. It is recommended that these compounds be added in the Naval Inventory and be used

during overhauls and repairs to engineering components.

21. Composite impeller offer significant advantage vis a vis metallic impellers for use onboard Ships and Submarines. The trials undertaken at STH and onboard have revalidated the theoretical calculations. It is therefore recommended that we may consider induction of this technology in Indian Navy at a larger scale.

22. The standardisation of centrifugal pumps and rationalisation of their design as suggested will evolve a standard family of pumps in the Navy which will eventually lead to the following benefits:-

(a) Better reliability and greater maintainability of pumps due to operator familiarity with the standard range.

(b) Maximum inter-changeability of components and sub-assemblies resulting in reduced inventory and consequently greater availability of spares

Enclosure 1 to Paper

1. **Recovery of INS Talwar (Fire Main Pump)**

Fig. 2 Condition of Pump Received from Ship **Fig. 3 Post Surface Preparation and Internal Coating**

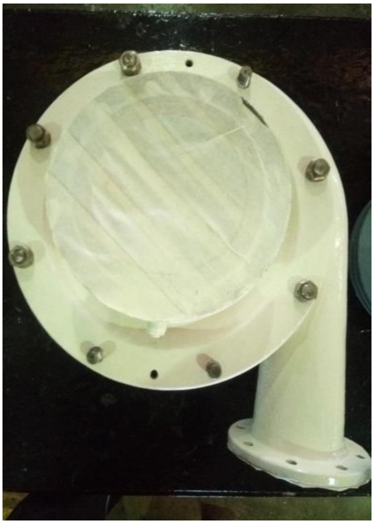


Fig. 4 Condition of Pump Post **Fig. 5 Pump Post Recovery and**

External and Internal Coating	**Overhaul before Being Installed**

2. Recovery of INS Betwa Fire Main Pump Stool

Fig. 6 Stool Received From Ship

Fig. 7 Stools Recovered after Application of Ceramic Coatings

3. Recovery of INS Beas Brine Pump

Fig. 8 Condition of Pump Received from Ship

Fig. 9 Condition of Pump Post Surface Preparation and Internal Coating

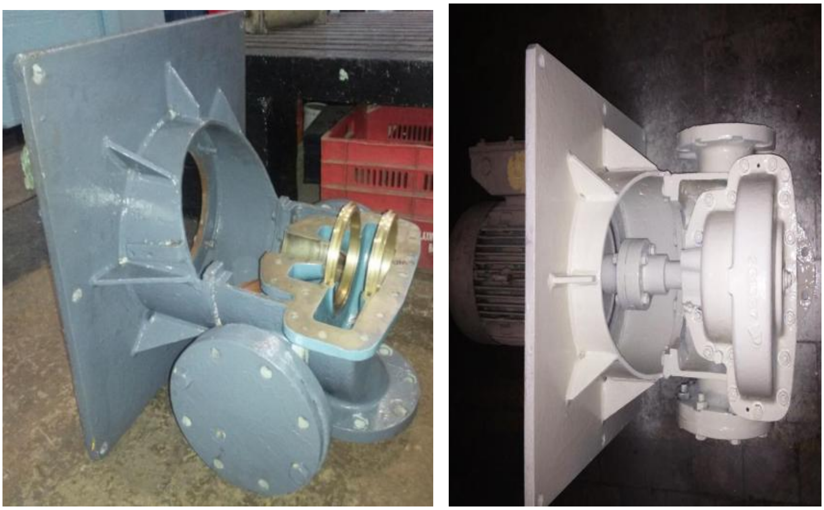


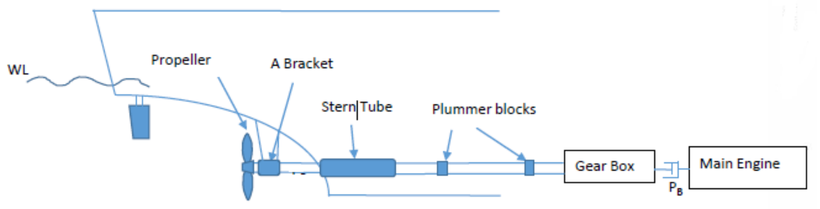
Fig. 10 Recovered Pump after Cold Weld Repairs

DEVELOPMENT OF INDIGENOUS PROPULSION SYSTEM INTEGRATION (PSI) CAPABILITY

Cdr Vikas Sood, Cdr Bala Senthil D

Introduction of Propulsion System Integration (PSI)

1. Naval ships are powered with suitable propulsion plants to meet the specified targets of speed, endurance, and maneuverability as per their envisaged roles. The propulsion plant could consist of a Diesel Engine, Gas or Steam Turbine or combination of these. In-depth studies are required for selection and integration of the Prime Mover, Gearbox and shafting arrangement for evolving an effective propulsion system to match ship's hull and tonnage. PSI, as a process is the key link in mapping of the requirement of a designer into the functionalities as demanded by the customer. This function ensures the completion of all the tenets of FLOAT, MOVE and Fight Capability of a man of war (Ship or submarine).



Fig, 1 Main Propulsion Plant Aggregate[1]

2. **Type of Naval Application's**.[2] The Naval applications can be categorised into the following:-

(a) Combatants

(i) Aircrafts carriers
(ii) Destroyers, frigates and Corvettes

(b) Submarines

(c) Specialised ships (Mine warfare, Research, Training...)

(d) Patrol Forces (Coast Guard)

Important Factors to be Considered during Propulsion System Integration

3. The Naval Staff requirements specifications defines or sets the initial input for the Propulsion System Integrator and some of the important terminologies pertaining to Naval Applications which needs to be completely understood by the PSI. The degree to which the Defined and Specified Threat Effects mentioned below will degrade sea or mission capability:-

(a) **Susceptibility**. The degree to which a ship, equipment or weapon system is open to effective attack from a threat or threats.

(b) **Threats**. Those hostile elements of a combat environment which could reduce the ability of a ship, its systems, and crew, to perform its mission.

(c) **Threat Effect**. The definition of a threat in terms of those physical characteristics which affect ship design.

(d) **Sortie**. Operational sea going by one ship.

(e) **Mission**. The task to be performed during a sortie.

(f) **Battle Damage Repair**. The best repair that can be done to make the ship mission worthy after suffering battle damage, taking into account the time and resources available and the operational requirements.

4. All these aspects mentioned above would make the reality of a naval platform the most complex project.

5. Ship Design is a complex Project; PSI/ System Engineer, Amalgamates all the processes from conceptualization to design to construction and powering. The complete propulsion system design and integration process may broadly comprise of the following [3]:-

(a) Feasibility Studies.
(b) Concept and Basic Design.
(c) Preliminary Design.

(d) Procurement.
(e) Special studies and Detailed Design.
(f) Post design, Production and Test.

Introduction to Design Process

6. Design phase of a Naval Platform is the most complex phase as it encapsulates all the requirements of the customer and creates a map with the available tools and means to formulate a design. Evans (1959) introduced the concept of design spiral, which represents the sequential and iterative aspects of the process.

7. Design is an iterative process, which is very difficult to capture in a model. Design spiral is well known traditional way of capturing the ship design process. As the design progresses, it converges to a single point. Each Baseline is the new iteration of the design. The limitation is that the design spiral does not show the interaction between the domain areas as the iteration progresses.

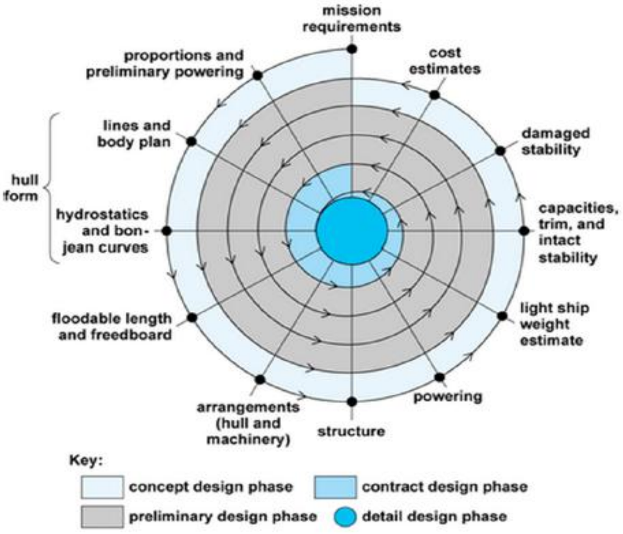


Fig. 2 Role of PSI in Design Reviews

8. The existing system of naval platform (ship or submarine) design involves various iterations and stages with comprehensive inbuilt checks and balances in the entire design

process. The specifications, drawings and mock-ups are all approved with due consultations so that there are no issues later during the exploitation and integration of the platform in the fleet. The decisions are taken considering the views of all who are concerned during the life cycle of the ship or submarine. It is recommended that the design reviews be conducted at each specific milestone reached during the design process so that timely corrections are concurrently taken as the design progresses.

9. The involvement of PSI in the design reviews is considered critical/ essential in order to ensure the essence of the design review are system reliability by achieving increased awareness of safety, overcoming interface and integration problems, suitable application of technology and resolution of grey areas.

10. **Design Reviews during Naval Platform Design**[4]. The birth of a naval ship starts with issue of staff requirements. The design process involves various iterations. Design reviews are conducted appropriately when the projects reach defined milestones in their design cycle. In consonance with the milestones which are applicable to warship design evaluation process, the following stages qualify for design review and these are categorized accordingly:-

(a) Staff requirements — design review.

(b) Concept design — design review.

(c) Weapons, sensors, machinery, equipment selection — design review.

(d) Preliminary/Sketch design — design review.

(e) Detailed/ Technical design — design review.

(f) Workshop design drawing — design review.

(g) Equipment inspection test schedules — design review.

(h) Quality review during ship construction.

(j) Final design review post launching and prior to commencement of sea trials.

11. It may therefore be appreciated that design reviews after each of the above milestones are essential for the smooth success of the complete design process. In each of the design reviews the elements of the design review, i.e. objective, review team, input data, output data etc., will need to be specifically defined and worked upon. It is also recommended that the final design review prior yield tremendous benefits when experts are drawn from reputed design community, national and international, and transfuse their talent and wisdom into the design process.

Propulsion System Integration (PSI)

12. The modern warships have become more complex comprising number of heterogeneous interdependent subsystems. The process of Propulsion System Integration (PSI) plays an important role in shipbuilding which involves various iterations and interaction between PSI agencies with ship designer right from the preliminary staff requirement stage to delivery of ship to the Indian Navy.

13. Let us first break down the PSI concept into its constituents:-

(a) Develop a technical package in sufficient detail to provide necessary information, data and guidelines required by the Shipbuilder for installation of the propulsion machinery and to enable adequate placement of procurement orders for the main propulsion equipment and associated auxiliary/ components.

(b) Through the execution of the specified engineering functions and relevant tasks, achieve the correct integration of the various components of the propulsion system, their interfaces with each other and with the ship structure, in order to perform as per the ‘agreed objectives’ assigned to the considered system.

(c) Provide adequate procedures for successful alignment and installation of the propulsion plant, Setting to Work, HAT and SAT.

14. In PSI, the role of each Party to be identified and respective perimeter to be defined. Scope of Work (SOW) in the process of PSI is the assistance to a designated designer and it ensures the Project Organisations are clearly defined.

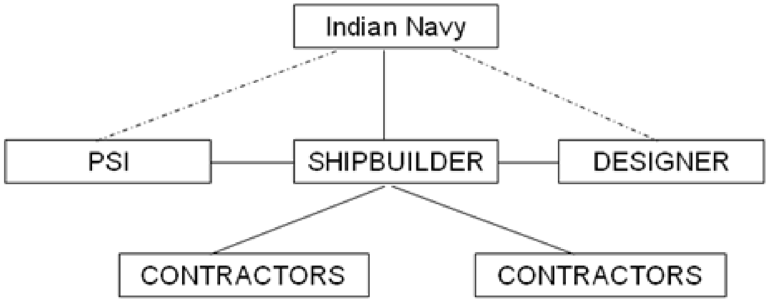


Fig. 3 Organization Chart

15. **Scope of Work (SOW) of Engineering Functions**. Engineering tasks are performed through a number of tasks and services, detailed within the PSI specification. The list of tasks of the integration works shall be arranged through a ***Work* Breakdown List** (WBL) and the tasks are numbered according to a reputed Ship Work Breakdown Structure (SWBS). For a given task, each of the involved parties is assigned a particular responsibility, as per the following code:-

(a) Execute (E) : To perform the task.

(b) Review (R) : To review the tasks performed by others.

(c) Information (I) : The results of the tasks are transmitted for information.

(d) Treatment (T) : The results of the tasks are transmitted for further action.

16. The important role of Propulsion System Integrator includes "Continued Iterations". The following other services are included in the PSI SOW:-

(a) **Coordination Management**. Assistance to the Shipbuilder/ Designer for coordination management is provided by the PSI. Such coordination is mainly achieved through the *interface meetings*.

(b) **Interface Meeting**. The system integrator will prepare the meeting agenda, interface specification/ data and memorandum of agreement.

(c) Technical Assistance during propulsion erection & setting to work.

(d) Technical Assistance during propulsion harbour and sea trials.

(e) Phasing and scheduling.

17. Therefore, in warship building, the supplier will be fully responsible as a single point authority for the integration and assistance for installation and commissioning of the propulsion plant. The supplier will ensure that the specified performance (including interface with the ship) is achieved by the propulsion system as a whole and also for the individual components of the propulsion system provided individual equipment meet their critical contracted specifications. All this is the primary responsibility of the PSI to provide.

Need for Development of Indigenous PSI Capability

18. The propulsion system design and integration studies are presently being sub-contracted to foreign ship designers and vendors. With a large number of indigenous shipbuilding programmes envisaged in the future, there is a need for the Indian industry to acquire adequate expertise and in house competence in propulsion system machinery selection, design and integration studies. By developing an indigenous PSI, we can also refrain from sharing the critical parameters like speed, displacement etc with foreign agencies.

19. **Capability Envisaged**. Identifying and developing the capabilities required by the Armed Forces to maintain the decisive edge will be the cornerstone of future defence planning. Achieving self-reliance will be possible only with proper planning and ensuring that a clear and coherent way ahead is understood by all stakeholders to achieve optimum utilisation of scarce resources. Synergy between the Ministry of Defence, including the *IN*, the DRDO and industry is essential to identify and achieve the desired results. The ability to achieve this through indigenous means should be a national endeavor.

Conclusion

20. Propulsion System Integration (PSI) is a process, which is required to be involved/ consulted right from Preliminary Staff Requirement Stage. PSI will not give one solution such as exact combination of machineries/ aggregate, it gives optimal range of equipment. Some of the points pertaining to development of indigenous PSI capability are discussed in the succeeding paragraphs:-

(a) It is also pertinent to mention that in the past *IN* has been a “Buyer’s Navy” and not “Designer’s Navy”. Since we were buying the ship’s/ propulsion systems from other countries, we were not focussing on integration part i.e. PSI. Although, *IN* had started building indigenous ships, we still offload the job of propulsion system integrator. Further, one of the PSI agency working for *IN*, M/s DCNS, France is a shipbuilder, who undertakes PSI services. Therefore, Indian Shipyards are required to be trained in the field of PSI and ensure that the PSI should be an integral part of shipbuilding process.

(b) The effective harnessing of the scientific and technologically trained pool of manpower, the R&D skills and the technological expertise available with the public and private sector would be the key to achieving self-reliance in the field of PSI.

(c) Expertise in the field of PSI is required to be developed among the research institutes which have narrow specialization through MoUs/ offloaded jobs/

outsourcing. These institutes are required to be hired and given the role of consultant on a case to case basis, which in turn would create pool of trained people in the field of PSI among the *IN* technical fraternity and shipbuilders.

References

[1] CEP No.709, Opportunities in System Engg & its application in Marine Propulsion System Integration

[2] Jane's Publications

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[4] Design Review of Naval Platforms, By Vice Adm Rajeshwer Nath Issue: Vol 25.1 Jan-Mar 2010 | Date: 04 March, 2011

ELECTRIC PROPULSION AND INDIAN NAVY – A PERSPECTIVE

Cdr Subrat Panda and Lt Cdr Karanjit Singh

Introduction.

1. Integrated Electric Propulsion (IEP) is an arrangement of marine propulsion systems in which gas turbines or diesel generators or both generate three phase electricity which is then used to power electric motors turning either propellers or water-jet impellors and also provides power for the ships load. It is a modification of the combined diesel-electric and gas turbine propulsion system for ships which eliminates the need for clutches and gearboxes by using electrical transmission rather than mechanical transmission of energy. This also significantly reduces the length of shaft (or eliminates it altogether).

2. In *Indian Navy*, electric propulsion system is used only in diesel electric submarines, where diesel generators are used to charge the onboard batteries and these batteries are connected with main motor and auxiliary motors. The motors are connected to main and auxiliary propellers for propulsion of the submarines. Electrical propulsion have many advantages over mechanical propulsion system, however having this system onboard Indian Naval ships is still a distant vision. Advantages accrued in having an IEP and various components of an IEP System are brought out in the paper. Also, various challenges required to be addressed prior designing an IEP system are discussed in brief. The paper concludes by recommending the most optimal option available in IEP for *Indian Navy*.

3. **Integrated Electrical Propulsion System**. Electrical propulsion has been around since the early 1900s. In the 1990s, electric propulsion received an enormous boost in the cruise ship industry and in capital Naval ships. A typical architecture of an electric propulsion system has multiple diesel generator sets, feed a fixed frequency high voltage electrical bus. This bus feeds the electrical propulsion motor drive and the auxiliary load, in most cases through a transformer. The electric propulsion motor drive consists of a power electronic converter used to control shaft line speed and thus ship speed.

4. **Basic Architecture of IEP**.

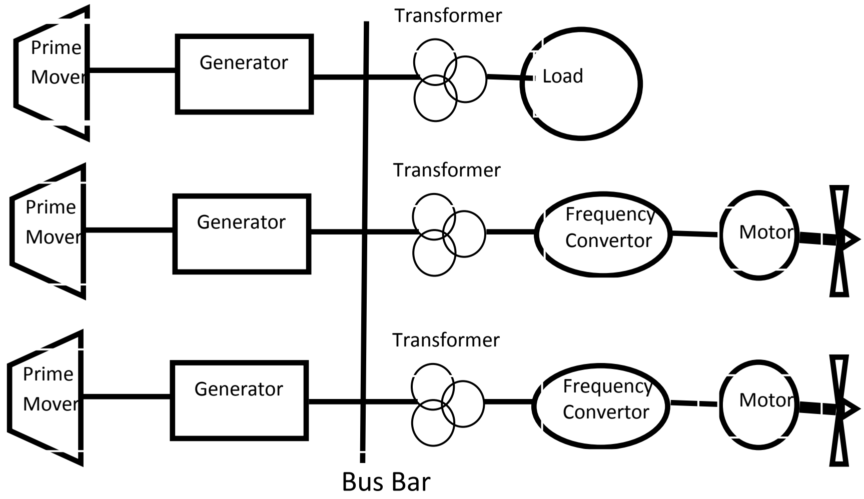

Fig. 1 - Basic Architecture for IEP

5. **Advantages.** Advantages of electric propulsion system are as follows:-

(a) **Fuel Efficiency**. Electric propulsion is a fuel-efficient propulsion solution when the auxiliary load is a significant fraction of the propulsion power requirement, since the generator power can be used for both propulsion, through the electric motors, and auxiliary systems. To achieve this, a Power Management System (PMS) matches the amount of running engines with the required combined propulsion and ships load. This control strategy ensures engines do not run inefficiently in part load and is often referred to as the power station concept.

(b) **Reduced NOx Emissions**. NOx emissions of electric propulsion are likely to be less than those of mechanical propulsion. In electrical propulsion, the diesel generators run closer to their design point, at which they typically produce less NOx emissions due to less fuel-consumption increasing. Furthermore, they always run at rated speed, as opposed to mechanical propulsion engines, which run at reduced speed in part load, producing more NOx.

(c) **Reduced Maintenance**. Electrical propulsion reduces maintenance load, as engines are shared between propulsion and auxiliary load and are switched off when they are not required.

(d) **Reduced Radiated Noise**. Electric propulsion can achieve reduced radiated noise due to the absence of a mechanical transmission path from the engine to the propeller. To achieve this, the design of motor and power converter has to be optimised for minimal torque fluctuation.

(e) **High Operational Availability**. Electric propulsion has potentially high operational availability, at least if the power and propulsion plant has been designed for this purpose.

6. **Propulsion Options for IEP**. Currently, there can be two methods of electric propulsion possible for use in a future ship design. The first method uses direct-drive podded propulsors similar to those found in commercial shipping and in cruise liners. The second method uses a prime mover and shaft configuration, similar to the mechanical drives found in nearly all surface ships known as in-hull propulsion.

(a) **Podded Propulsion**. This propulsion method involves the use of Podded Propulsors (Pods). Pods are widespread in the cruise liner industry and in commercial shipping. Pods can be directly driven or indirectly driven. In a direct driven pod, the prime mover is located outside of the ship's hull inside an enclosure or pod. This allows the propeller to be mounted directly to the prime mover, eliminating the need for an in-hull shaft. Indirectly driven propulsors, also known as azimuthing thrusters, usually have their prime mover located inside the ship. In this configuration, a gearing mechanism connects the prime mover to the propulsor. The direct driven propulsors have great advantage view increased noise level associated with the gearing in the indirect method. Direct drive pods eliminate the need for a shaft and overcome the problems associated with hull penetrations. Since, the propulsion pod is mounted to the ship's hull, steering control can be obtained simply by allowing the pod to rotate through 360°. This capability eliminates the need for a rudder. Changing the prime mover's direction of rotation provides forward and reverse thrust. Although, it cannot be considered for immediate use in *IN*, view limited technology development in this field for warships however, this method has great potential to be used in future ship designs.

(b) **In-Hull Propulsion**. In this configuration, the prime mover is located inside the hull of the ship. Rotational torque is transferred to the propeller by using a shaft that extends aft from the motor and penetrates the hull of the ship. The propeller is connected to the end of the shaft and converts rotational torque into forward and reverse thrust. This method of propulsion requires additional equipment such as shaft bearings at bulkhead penetrations, shaft seals at hull penetrations, and a rudder to provide steering control for the vessel. Although this method still requires the use of a shaft, significant reductions in shaft length are possible due to increased flexibility in locating the prime mover within the ship. This method is presently used in *IN* submarines and warships of many advanced Navies across the globe. This method of propulsion is deliberated upon in this paper for implementation in *IN*.

7. **Electric Motors for IEP.** The propulsion motors required for a warship can be of two type i.e AC Motor or DC motor. There are various types of AC and DC motors that are available in propulsion industry. In order to find most suitable option for fitment onboard *IN* ships each type of motor is discussed in brief.

(a) **DC Motors.** Superconducting DC Homopolar Motors (SDCHM) was successfully demonstrated on the test craft *Jupiter II of US Navy.* The US Navy has been researching the SDCHM since the 1960's. The homopolar machine concept has been investigated because of its ability to produce high and constant torque over a wide speed range. Homopolar motors are attractive for potential use in direct electric drives for ships because of their compactness and high power density. There are two types of SDCHM i.e disk armature machine and drum armature machine. Due to homopolar magnetic behavior, the field windings do not experience a mechanical torque in reaction to the armature torque. The reaction torque is developed in the current-carrying conductors of the stator of the motor and not the field winding. The constant current and field of the homopolar motor eliminates mechanical torque pulsations on the shaft. Eliminating the torque pulsations provides an acoustically quiet machine. DC motors are not being widely considered because of a lack of available brush and slip-ring technology. Additionally, DC motors require a significant amount of maintenance on their brushes, which further deters their use in shipboard propulsion applications.

(b) **AC Motors.** There are two types of AC motors which are being considered for warship propulsion. They are Permanent Magnet Synchronous Machines (PMSM) and Advance Induction Motor (AIM).

(i) **Permanent Magnet Synchronous Machines (PMSM)**. Synchronous motors are widely used in commercial shipping, large auxiliary ships, and cruise liners. The PMSM has received favourable consideration as a ship propulsion motor because of its power density and quiet operation. Synchronous motors operate on the same basic phenomenon as induction motors. The major difference is that the rotor magnetic field is not induced, but rather is provided by an external excitation circuit in a field wound motor or a magnet in a permanent magnet motor. PMSM can be placed in three different classes depending on direction of the magnetic flux. They are axial flux, radial flux and transverse flux. PMSM motors are presently under development stage, these cannot be considered for future *IN* ships till the time technology matures itself and prove to be successful for the propulsion of warships.

(ii) **<u>Advanced Induction Motor (AIM)</u>.** AC induction motors are the most employed electric machines in the world today. The simple and rugged construction of the induction motor contributes to its reliability and makes it attractive for shipboard propulsion applications. Advanced Induction Motor (AIM) has been evolving over the past many years. It was primarily developed for applications where low speed and high torque are required, such as in ship drives. AIM has various advantages over DC and Synchronous motors, some of them are as follows:-

(aa) **<u>High Power Density and Optimum Cooling</u>**. AIM has very high power density without any penalties in performance. Power density has been increased in the AIM through optimizing the electromagnetic design of the rotor. AIM is fundamentally an air-cooled machine, but can use an air/water heat exchanger when required. The AIM uses stator and rotor core construction incorporating radial ventilation ducts that are provided using a method known as “pin-vent”. The pin vent method provides an efficient way of removing heat from the windings.

(ab) **<u>Signature Reduction</u>.** Electromagnetic forces in the AIM are reduced by selecting the appropriate number of stator and rotor slots, poles, and phases. This minimizes the number and amplitude of forcing frequencies. The structural dynamics of the AIM and its mounting structure are designed to provide minimal noise transmission. The optimal strategy to control flux is employed at reduced speed to minimize electromagnetic noise. Further noise can be reduced by careful selection of converter for the drive. The rotor in the AIM is of simple construction, with solid copper conductors. The conductors are contained in slots in an iron core without use of insulation. AIM designs have been qualified to be used onboard warships.

(ac) **Cost, Size and Weight.** Since AIM has a very simple design and is inherently robust, it is less expensive than a similarly rated PMSM. The AIM is approximately 25% less expensive than the PMSM. The AIM is roughly the same size as an equally rated PMSM, but it is much lighter.

8. **Power Converters for Controlling Propulsion Motors.** The electric motors discussed as above will require power conversion and control equipment to provide effective speed control for the motor. The operation of motors will not be very beneficial without an appropriate controller or converter. The controllers must be designed to accurately control the motor's speed while introducing a minimal amount of harmonics. The design of propulsion converter depends upon number of motor phases, the phase connections, and the rated machine frequency.

9. **An Ideal Converter**. Converters for naval propulsion applications need to be engineered to withstand a single component failure and still function at reduced capacity. Converters need to be simple, reliable, and rugged however they need to include circuitry to provide the best waveform fidelity for acoustic performance. They must have convenient monitoring for diagnostics and troubleshooting, minimize source and load harmonics, be immune to problems with Electromagnetic Interference (EMI), and cooling, be modular to expedite maintenance and repair, and minimize cost. Technological advances in power electronics devices are a major factor in power converter technology. The requirements for high-power semiconductor devices include high blocking voltages, low leakage currents, and high switching frequencies with low conduction drops and losses.

10. **Types of Converters**. Various propulsion converters available for IEP are as follows:-

(a) **Cyclo-converter.** Direct frequency changers are known as cyclo-converters. They convert an AC supply of utility frequency to a variable frequency. They have small range of frequency variation, which is suitable for low-speed, high power applications such as ship propulsion motor. Due to their large size as compared to other converters, cyclo-converters are not appropriate for use in a small warship where space is at a premium. Other limitations include its limited output frequency range, its low power factor, the complex spectra of input and output harmonics that require passive filtering, and the large number of power devices to control.

(b) **Synchroconverter**. Synchroconverters are indirect frequency converters that consist of a rectification (AC-DC) and an inversion (DC-AC) stage. A large link inductor separates the rectifier and inverter stage. The inverter section is made up of thyristor devices, the large link inductor creates a DC current that is routed through the respective thyristors and machine phases, creating quasi-rectangular phase currents. There are substantial harmonics in the phase currents that lead to drive de-rating, torque harmonics, poor input current quality. The advantages of this type of converter are that it has the fewest number of components and it can be connected in series with other cycloconverters to provide redundancy. The main disadvantage is the substantial harmonics on the output waveform. These harmonics make this type of converter unacceptable for a surface combatant.

(c) **Pulse-Frequency Modulation (PFM)**. PFM is a direct AC-AC frequency conversion strategy. It operates by taking discrete energy packets from the input, storing the energy in a capacitor, and then controlling the release of the energy to give the proper frequency at the output. Since thyristors have a very large power rating, the need for paralleling or multi-level topologies can be eliminated. The advantage of this type of converter includes a low voltage spikes and a very high efficiency due to the natural soft-switching operation. These units also have a very high power density.

(d) **Pulse Width Modulation (PWM).** The PWM converter is also an indirect frequency converter. These converters also consist of a rectifier and inverter stage. Instead of having a link inductor like the previous converter, the PWM has a DC link capacitor to provide constant control voltage. At high power, PWM-based converters are typically built using GTOs, GCTs, IGBTs, or HVIGBTs. PWM converters usually provide stair-stepped phase voltages with high frequency notches and fairly sinusoidal phase currents with smooth motor torque.

11. **Integrated Power System (IPS)***.* IEP onboard warships can be implemented through IPS, which will provide electric power for propulsion, weapons, and ship services. IPS provides electrical power to ship service loads and electric propulsion for a wide range of ship applications including surface combatants, aircraft carriers, amphibious ships, auxiliary ships. IPS consists of a family of modules from which affordable and high performance configurations can be developed for the full range of ship applications. An IPS can reduce the number of installed prime movers by using a network of distribution busses and switching, an IPS can ensure that vital systems receive electric power in casualty situations. The IPS will provide the ability to rapidly reconfigure the electrical distribution system in the event of a combat equipment casualty. The IPS architecture integrates the generation, distribution, storage, and conversion of electrical power for both ship service and electric propulsion loads. Modularity of this system also promises to reduce cost by enabling the assembly and testing of modules using flexible manufacturing techniques. However, a cost effective module requires careful design and a thorough understanding of the ship design, construction, and maintenance processes. The integration process uses a methodical system for developing tailored configurations for the range of ship applications.

12. **Challenges.** Electrical propulsion faces following challenges:-

(a) **Conversion Losses**. Electric Propulsion incurs more losses, due to the additional conversion stages in power converters and electric motors. These losses lead to an increase in fuel consumption, particularly close to top speed of the ship.

(b) **Running of Redundant Engines**. To achieve high propulsion availability, redundant engines are also run, which are required for various sensitive operations, these engines run at low part load, which leads to poor fuel consumption and more emissions.

(c) **Increased Cavitation**. Since, electric motors with variable speed drives can provide maximum torque at every speed and run in reverse also, most of the ships with electric propulsion use FPP, which increases radiated noise due to cavitation.

(d) **Fluctuations of Voltage and Frequency**. The electrical network performs on voltage and frequency, this voltage and frequency can swing under fault condition leading to disruption in electrical systems. Thus reducing reliability and availability.

13. **Way Ahead**. To achieve IEP system onboard *IN* ships following systems, equipment and module are to be carefully designed and selected depending upon the power and propulsion requirement of the ship:-

(a) **Power Generation and Propulsion**. A suitably designed power generation system is required (Diesel Engines/Gas Turbines, Generators and Rectifiers) to meet power requirements of propulsion and auxiliary ships load (weapons, sensors, lighting, ventilation etc.). Implementation of IEP will ensure significant reduction in power generating equipment and continues availability of power supply to all systems using power distribution module.

(b) **Propulsion Motor**. Advance Induction Motor is most suitable for electrical propulsion onboard warships. It allows for fine speed control, which simulates a synchronous motor's flexibility. They also provided the best noise performance and minimal stator design impact. However, position of the motor will ensure smaller shaft length.

(c) **Propulsion Converter.** A PWM converter is most suitable convertor for controlling the speed. By controlling the switching signals of the PWM converter, will control the propulsion motor torque and flux and will achieve required shaft speed. The PWM converters has higher, more constant power factor for better efficiency. Also, constant harmonic frequencies to ease any supply filtering required and smaller size and weight.

(d) **Power Conversion Equipment**. The Power Generation System will provide electrical power with fixed frequency and fixed voltage. It is required to convert frequency and voltage of input supply to other form depending upon requirement of various equipment, weapons, sensor etc. The conversion loss from one frequency/ voltage to another can be controlled with available technology by designing efficient transformers, convertors and other conversion equipment.

(e) **Integrated Power System**. A suitable designed software based IPS will help to maintain voltage and frequency of electrical network stable by giving commands to control droop speed control in governors for frequency stability and using Automatic Voltage Regulators for voltage control. This system will also help to control the speed and voltage set points as to maintain voltage and frequency within the operating limits of the system during system dynamics. It will also give commands for automatic starting and stopping of generator sets during load changes and ensures online engines are not overloaded by limiting propulsion drives and other loads as necessary. It will also perform protection functions such as preventing blackout, switching off faulty system parts and reconfiguring the electrical network after blackout.

14. **Conclusion**. With growing energy requirement worldwide, fossil fuels will be extinct soon. In order to achieve a clean and energy efficient Navy, an IEP system is the future for *Indian Navy.* Also, the advantage an IEP has over conventional propulsion system is immense. Therefore, as a pilot project *Indian Navy* should embark in designing a surface combatant using IEP system.

PROPULSION SYSTEM INTEGRATION - A CRITICAL GAP IN INDIGENOUS WARSHIP BUILDING CAPABILITY

Cdr Kumaran

Introduction

1. India's foray into shipbuilding dates back to ancient times. More recently, during the colonial rule also, there was a great demand for ships made in India, specially the Bombay Dock, as they were made of fine wood and were sturdy to withstand any onslaught of war or weather. But that was in the era of wood. In the latter half of the 19th century, the European prowess in shipbuilding showed tremendous pace post Industrial revolution and Indian indigenous shipbuilding expertise was lost in some manner. Till independence, the country was in a state of transition and there was hardly any shipbuilding activity of importance, taking place in the country. During this era, most home grown industry had been either shut down or had been merged with much larger British firms. The Royal Indian Navy too, was operating ships constructed in Britain, which became the main source of warships for India even post independence.

2. Post independence, the Indian Navy, in its infancy, was born with just a few ships handed over by the then colonial masters. However, gradual expansions through the 50s & 60s saw a steady induction of warships and submarines bought from other countries. In about half century post independence, the Indian Navy has had a laudable transition from being a minor littoral force to the fifth largest Naval power in the world today. Today, it has transformed itself into a "Builders Navy", thanks to a steadfast indigenization program started in the late 70s, and is now considered a modern & professional Blue Water Force to reckon with.

3. Despite a slow start, the Indian Shipbuilding industry has indeed come of age and has produced world class ships for the Indian Navy. A big percentage of our frontline warships today are of Indian origin and this trend is here to stay. As per the Indian Navy's Maritime Capability Perspective Plan (2005-27), it is envisaged that about 45-50 major warships of various kinds

will be inducted in the next 15 years. When added with about 150 ships for Coast Guard contracted so far and likely to be increased substantially in the next financial year, the total figure comes to around 300-350 ships required in the next 12-15 years. As a result, despite a gloomy scenario in the world of shipbuilding today, there lies a healthy opportunity for warship building within India.

4. However, although great strides have been made by the indigenous warship building industry, discernable inadequacies still persist in certain critical technological frontiers. These deficiencies are resulting in continued dependence on foreign sources for required technology as well as expertise. Although, the Indian Navy in collaboration with the research laboratories is undertaking R&D activities in some of these critical areas, these efforts need to be better supported by the industry and synergized with other stakeholders.

Indigenous Warship Construction

5. Warships are significantly more complex than even the largest, most modern commercial ships due to the complicated design & construction process. The critical requirements of Speed, Weapons & Sensors, Signature Management, Survivability and Multi role operations put any warship on a different pedestal when compared to any commercial liner. These critical requirements lead to significant changes in the design and construction process which are iterative in nature and may take more than a decade from drawing board to delivery.

6. Design of a warship is a complex task which starts with an assessment of requirement in accordance with the envisaged role and threat perception. The roles envisaged for a warship can cover an entire gamut of operations, right from peaceful search & rescue to full combat missions in blue waters. Further, a warship has to cater for robustness of design and obsolescence of critical equipment to ensure optimal performance in the intended role through the designed life which may extend to more than 40 years. The construction process also is unique in terms of basic parameters and configuration. While the external features of a warship are determined by its hull profile, weapons package and deck

machinery, the internal features are determined by its operational space, machinery and propulsion systems. In short, to carry out its function, a warship has to be well designed and equipped with all capabilities

7. It is to the credit of the Indian Navy that as part of the indigenous warship construction, more than 80 ships comprising of 17 different classes of warships have been designed in-house. The path of indigenization in terms of design and construction of warships, that the Indian Navy has traversed, has yielded excellent results in terms of development of required expertise, creation of specific skill sets, and mastering of modern shipbuilding technology. However, though an in-house capability exists for most of shipbuilding processes, capability related to production and integration of critical equipment such as Weapons, Sensors and Propulsion System is yet be fully realized more so because of lack of indigenous expertise and Industry support. While the Weapons & Sensors belong to a fully defence related industry and therefore has limited appeal in the outside world, the propulsion equipment and its integration with other systems is of equal use to defence as to the other sectors such as Shipping, Aviation and Power Generation etc..

Propulsion System Integration – Capability Gap

8. **Propulsion System Integration**. Propulsion System Design and integration is a process that combines prime movers, transmission elements and propulsors in an optimum manner to achieve required propulsive performance of the ship in all regimes of operation. The Propulsion System is the backbone of a warship and its design, selection and integration forms an integral part of the ship design and construction process. Unlike other system and equipment, which may undergo a change with better equipment during ships' life, the propulsion system is designed for the life of the ship and is seldom changed and even so, minimally. It is necessary to incorporate the configurations of the propulsion system at the initial stages of ship design itself. The importance of Propulsion System Integration (PSI) can be gauged from the fact that the overall propulsive efficiency of the ship in terms of optimum performance at all regimes of engine operation critically depends upon accuracy and depth

of PSI studies undertaken at the design stage. Being a significant facet of the ship building process, the PSI expertise in terms of critical knowhow, technology tools such as specialized software, reference data and experience available within the country is extremely limited. It is appropriate to say that the paucity of necessary infrastructure, depth of technical knowledge and skill levels available within the country, are imperatively required to be enhanced significantly and remain a closely targeted area for the IN to initiate appropriate steps to bridge this critical capability gap.

9. The process of selection of individual components of a propulsion system and their integration for achieving overall efficiency can be done in a variety of ways to obtain a number of possible solutions for a given ship. None of the solutions can be termed as most perfect as there can be more than one solution to each scenario. Factors such as Size & Weight, Cost, Availability, Reliability, Maintainability (ARM), Speed and Power requirement and complexity etc have a large bearing on the solution chosen for a particular warship. As the overall system characteristics are a consequence of the individual components, it is important to evaluate the advantages, disadvantages and operating peculiarities of these components.

10. Propulsion System Integration has a wide scope of activities right from design board to delivery of the warship. It is a process which has interfaces with all other system installed onboard and is therefore critical for achieving the intended role of the ship. The complete scope of Propulsion system integration includes the following:-

(a) Resistance Calculations & Powering Estimation
(b) Design & Selection of Propulsion equipment
(c) Design of propulsion train including:-

(i) Propeller design
(ii) Engine propeller matching
(iii) Shaft design and analysis
(iv) Gear Box design

(d) System design based on:-

(i) Torsional and bending moments
(ii) System Dynamics
(iii) Signature Management

(e) Selection of propulsion plant control system
(f) Intake / Exhaust design
(g) Endurance and fuel consumption calculations
(h) Stability Analysis as a result of Propulsion Equipment installation
(j) Integration of Propulsion and Auxiliary systems
(k) Interfacing of systems and components
(l) Performance curves and design of IPMS

11. The above is an indicative list of activities only. Nevertheless, it can be seen that the PSI covers a wide canvas of critical activities in the design of a ship right from Concept design to Functional Design and then on to Detailed Design encompassing complete design and construction phases of the ship till induction. It is not difficult to gauge that all these activities require extensive scientific calculations and data analysis backed up by specialized software. Accurate in-depth studies are required for selection and integration of the prime mover, Gearbox and shafting arrangement for evolving an effective propulsion system to match the ship's hull and tonnage.

12. The Propulsion System Integration can be applied equally to all ships, however, due to large number of commercial ships built to the same design, its importance is never felt in the merchant marine shipping world. On the other hand, a warship, not only more complex due to varied requirements, is also constructed in lesser numbers before the design gets changed necessitated due to role change. For example, the IN typically, orders construction of three warships in a given class before the design gets changed. Therefore PSI assumes significant importance in case of warships.

13. Due to a lack of necessary expertise and infrastructure in the country, the propulsion system design and integration studies are presently being sub contracted to foreign ship designers and vendors at exorbitant costs. What is of more concern is the fact that by contracting the system integration study to external agencies, what is only achieved is an end

product in the form of a report which is applicable only for that specific project without any transfer of technology takes place. Moreover, as there is no single optimum solution for a PSI Design, the consultant or the integrator generally offers a design ensuring procurement of PSI equipment in a way so as to gain commercially by limiting the choices for the Navy. Due to a lack of in house expertise and experience, the offered solution is generally concurred with and is seldom questioned. With a large number of indigenous ship building programs envisaged in the future, there is a dire need to acquire adequate expertise and in house competence in this field to bridge this critical capability gap.

14. This critical gap exists due to varying reasons starting from limitation of adequate infrastructure to lack of emphasis on this subject. The technology, tools, skillset, expertise and experience required to undertake PSI tasks is presently not available inhouse or indigenously. Few limitations are brought out in the succeeding paragraphs:-

(a) **Lack of Expertise**. The propulsion system integration is a highly complicated and specialized technology having extremely focused end use. Due to this reason, the development of technology has been highly concentrated in few countries or companies only. Consequently, a very limited number of specialists agencies exist who can undertake the PSI design and none of them are of Indian origin. It may be of interest to note that while more than 80% of world's shipbuilding happens in East Asian countries like S Korea and China, almost entire expertise and tools for PSI are of European Origin. One of the reasons of lack of availability of expertise is the fact that undertaking a PSI design requires skills in multiple engineering fields such as Mechanical, Marine, Structural, Naval Architecture, Fluid Dynamics, Hydrodynamics etc. It also requires skills for in depth analysis of propulsion equipment and components using advanced tools such as scientific software. Due to relatively low requirement of PSI in fields other than shipping or aviation, the expertise required is extremely rare worldwide and more so in India. Although, it is being undertaken with help of foreign consultants so far by focusing on the immediate requirement but in the long run, there is a need to establish dedicated Centres of Excellence to provide a range of services from establishing benchmark Standards, promulgating guidelines and undertaking Independent Validation & Verification (IVV).

(b) **Lack of Benchmarks & Guidelines**. Together with the expertise, there is lack of available standards and guidelines to undertake the propulsion system design indigenously. Though, there are standards or guidelines available from Admiralty, NATO standards and Classification Societies. However, they all have subtle differences owing to the specific conditions such as ambient temperature, seawater temperature, salinity, humidity etc. Moreover, as has been said earlier, a PSI design brings out multiple solutions which are workable and have to be evaluated with respect to other factors. Presently, there are no home grown benchmarks or guidelines and the study has to depend on the guidelines borrowed from other agencies.

(c) **Lack of Available Tools & Technology**. As discussed earlier, during the course of a PSI design development, a multitude of different tools and technologies are required. Some of them are:-

(i) Tools for specialized design for shafting, propellers and Gearbox etc
(ii) Tools for intake/ exhaust design
(iii) Tools for signature management including technology for raft mounted equipment.
(iv) Technology for alternative forms of propulsion such as Water Jets and Pump Jets.
(v) Lack of sufficient data for integrating different hull forms with alternative propulsion for specialized operations.
(vi) Lack of technology for manufacturing such as Propellers

(d) **Lack of Indigenous Equipment**. A major hurdle in achieving self-sufficiency in PSI is an almost complete lack of Indigenous equipment for propulsion. Significant development has been made in the production of Boilers & steam turbine and small diesel engines. Diesel engines installed onboard IN ships for main propulsion are in the range of 1-7 MW and majority of them do not comply IMO emission norms. This is mainly because our OEM's are yet to bring in the necessary technology & infrastructure. Specialized equipment such as high powered Main Engines (Diesels & Gas Turbines) to Gear boxes, Transmission equipment such as shafting, Thrust Block and Fixed and Controllable Pitch Propellers etc are almost invariably sourced from foreign companies. Even minor equipment like high capacity S&V mounts and TMDs utilized in critical equipment for limiting the Radiated Noise Levels are sourced from abroad. Sourcing this equipment from abroad has a long term bearing in terms of spares & support of this equipment but also entails sourcing of other auxiliary equipment for reasons of better integration and single point responsibility. Leading OEMs have a virtual monopoly in this regards. Selecting their equipment invariably leads to practically limiting the procurement of related auxiliary equipment also from the vendors designated by them. Often, even the control system or the IPMS is also required to be procured from the vendor designated by such OEMs. Further, most of the time, equipment subscribing to the latest stipulations such as Tier 2 norms of IMO Annexure VI for reduction of NOx emissions are not available within the country. It is understood that all the equipment cannot be indigenized and neither there is any requirement to do so provided the larger system can be integrated within the country by sourcing the auxiliary equipment from indigenous resources. On the question of maintenance and spares support also, the system at large should be supportable indigenously. It is often observed that minor equipment like PCBs which form a critical component of any control system, cannot be repaired within India and have to be shipped abroad for maintenance causing avoidable delays and costing substantially more than costs of such repairs in India.

(e) **Lack of Higher Learning and Skill Set Build Up**. As the PSI is purely a shipping requirement, particularly required by Navy, and encompasses multiple engineering streams and skills, there is a visible lack of higher learning available in India. Understanding these fundamentals is essential for our designers, marine engineers and naval architects involved in design & construction of ships within the country. It is unfortunate that these fundamentals are not covered in any engineering stream covered anywhere within the country. There is, thus, a dire need to carve out a suitable syllabus for PSI and offer the same along with practical skills at Graduate and Post- Graduate levels. Similarly, there is a requirement to upgrade the skill set of general marine engineers and Architect by undertaking Resistance Calculations, Powering estimation, Propeller Design, Marine Shafting Design using specialised software. At present no short or long courses of this nature are offered anywhere in the country. Our institutes of higher learning can collaborate or tie up with universities / institutes abroad which offer these courses and make these courses available in India as a yeoman service for the shipbuilding industry. Gradually, as the expertise grows, the dependence on foreign universities will become redundant.

Propulsion System Integration Centre at NSTL – A Navy & DRDO Initiative

15. To bridge the capability gap brought out above, Indian Navy & DRDO have collectively embark upon an initiative to establish the PSI Centre at Naval Science & technological Laboratory at Visakhapatnam. This centre has been established with a broad charter of duties with the aim of becoming the Centre of Excellence for all PSI related activities of IN and to carry out research into New propulsion technologies, their integration, and create & maintain data bank of reference documents. In addition to being a CoE on PSI, the charter of duties of the Centre comprises the following:-

(a) Selection and Design of Propulsion system based on technical staff requirements specified by IHQ

MoD (Navy).

(b) Model testing of proposed hull form, generation of propeller curves for establishing power requirements and design of high efficient propellers.

(c) Undertake design and interfacing of propulsion system components.

(d) Undertake Dynamic simulation and Platform management of complete propulsion system.

(e) Design & Evaluate layout, installation and trials of propulsion / power generation systems.

(f) Participation during various inspection and trails of propulsion system.

(g) Formulation of Guideline Documents, Benchmarks and Specifications.

(h) Generation and maintenance of reference data bank and coordinate with IN authorities for seeking inputs for development in specialized areas of technology advancement.

(j) Undertake research in new propulsion technologies and re-engineering studies of existing naval platforms.

16. The PSI Centre has been located inside NSTL at Visakhapatnam as a large no. of critical activities pertaining to the PSI are also being undertaken at the laboratory, albeit, under different projects. NSTL, over the years, have developed capabilities in specialized area for warship design and analysis such as assessment of Hydrodynamic performance of propeller and hull, shock & vibration testing of equipment, equipment mounting systems and stealth technology. These aspects which have been traditionally being dealt as part of different projects by different technology centres would now be harnessed for undertaking PSI related research also. Few test facilities that exists in NSTL which are considered essential for carrying to PSI studies are:-

(a) **High Speed towing tank (HSTT)**. It is a hydrodynamic test facility recognized by International Towing Tank Conference. It is equipped with a model makings workshop to make scale down models of ships and submarines to carry out model tests for determining characteristics and evaluation of power plant requirements. The tests performed at HSTT are:-

(i) Resistance and self-propulsion tests to assess speed power characteristics.
(ii) Flow visualization to identify flow separation, if any.
(iii) Open water tests to obtain propeller characteristics.
(iv) Wake survey to determine flow velocities.
(v) Sea-keeping tests for head sea only.
(vi) Dynamic tests for high speed vessel, such as planning, multi- hulls, hydrofoil, SES etc.

(b) **Cavitation Tunnel**. It is one of the most modern and the state-of-art facilities in the world. It is used for study of cavitation inception of body profile and propellers. It is also used for the study of Acoustic measurements due to cavitation of propellers. The other tests performed in cavitation tunnel are:-

(i) Propeller tests in open water to measure performance characteristics in cavitating and non-cavitating conditions.
(ii) Tests with hull propeller model to measure self-propulsion characteristics, propeller working in the wake of the model in cavitating and non-cavitating conditions; hull propeller interaction.
(iii) Measurement of forces and moments on surface ships and submerged bodies including their control surfaces.
(iv) Determination of towing resistance of surface ships and submerged bodies.
(v) Cavitation tests - Inception and decay
(vi) Flow visualisation &Wake survey.
(vii) Measurement of hull pressure fluctuations

induced by propeller and cavitation.

(viii) Measurement of acoustic radiation caused by cavitating and non-cavitating propeller and hull.

(c) **Signature Management**. Measurement, study, analysis and mitigation of signatures of ships and submarines are essential for a stealthy fleet. Towards this several facilities exists at NSTL and a few which are part of PSI studies include Shock, Noise & vibration and IR signatures. NSTL is the shock qualifying agency for equipment to be fitted on board Naval ships. For shock, Noise & Vibration measurement the lab is facilitated with a floating shock platform, shock testing tank, Shock testing machine, Vibration shaker and Acoustic test Centre. At RTC-UWR Goa the RNL is measured by Noise range test facility. NSTL has developed test facilities for measuring ships IR signatures. The IR signature suppression device can test exhaust gas up to 6 Kg/s at 500 º C.

Conclusion

17. Having identified Propulsion System Integration and its wide array of critical activities, it is essential to identify core areas where the skill set and expertise can be created indigenously. It is extremely important to create a healthy ecosystem of various stakeholders for creating opportunity for development of technologies for production and integration of reliable equipment within the country. This healthy ecosystem will not only lead to advancement in technology and necessary infrastructure for manufacturing, creation of think-tanks, promulgation of Indian Standards & benchmarks and development of skill sets essential to pursue this key component of shipbuilding thus preventing undue dependence on foreign sources. This ecosystem has to attain sustainability at each level and gradually move beyond focus on Indian shipbuilding industry. This indeed will be a true testimony of harnessing Local talent for global service.

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MARINE ELECTRIC PROPULSION – AN ENGINEER PERCEPTION

Lt Cdr VP Tolambia

Introduction

1. Marine Propulsion is a system used to generate thrust to move a ship across water. The history can be identified with paddles and ores, used primarily to propel small boats and crafts. Later, these were replaced by sails, which remained the source of propulsion for a long time till end of 19th century, when coal-fired steam engines created a revolution in the field of propulsion systems, followed closely by induction of reciprocating diesel engines. The last century has seen a quantum leap in the propulsion technology with gas turbines, nuclear propulsion, electric propulsion and high speed water jet propulsions being inducted globally.

2. Indian Navy since inception has upgraded itself at par with global navies and today operates as the fifth largest Navy in the world. There has been a rapid growth in induction of advanced technologies along with adaptation to proven, efficient and effective methodologies. The paradigm shift from steam propelled warships to water jet FAC's and the parallel induction of gas turbines to propel its fleet or the introduction of combined propulsion systems like CODOG, COGAG,CODAD have been a testimony to the rapid speed at which the navy is embracing efficient technologies. The traditional propulsion system utilises power through different sources for main propulsion and power generation.

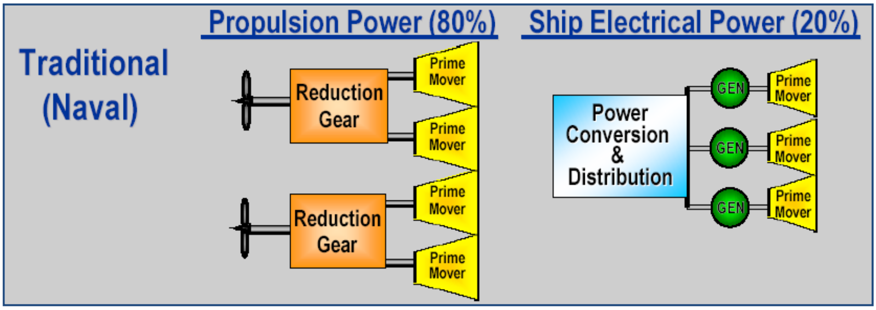


Fig.1 Typical traditional power management onboard

3. Also, it is imperative to understand that today's wars at sea will be determined by navies which can use stealth effectively, endure longer and be more resilient. The navy's pressing demands for dynamic response in speed, torque with reduced acoustic and structure borne vibrations have resulted in considering electric propulsion as the future at sea. The Navies of US, France, Germany, Italy and Royal British Navy have already adapted to this technology with a number of combatant ships. Whilst we have gained substantial confidence and self reliance in operating dieso-electric submarines, which are sailing across the globe, an endeavor for the induction of Electrical Propulsion Technology on our future platforms should be considered. Also, it is the right time to graduate into increased self-reliance by manufacturing technologically advanced equipment of Electrical Propulsion within India, in pursuance with the Government of India's vision of 'Make in India'.

4. The article on the Electrical Propulsion Technology will provide Engineer perspective towards induction in Indian Navy, its advantages over conventional propulsions and way ahead. The inception of new technology will be more fruitful while we simultaneously build self reliance and annul dependence on foreign manufactures.

Selection of Marine Power Plant Systems

5. Following are the pre-requisites for selecting a Power Plant System: -

(a) Reliability
(b) Machinery Space and Arrangement
(c) Machinery Weight and Volume Requirements
(d) Type of fuel and fuel consumption
(e) Machinery Costs
(f) Interrelations with auxiliaries
(g) Maintainability
(h) Vibration and Noise
(j) Reversing Capability
(k) Trained Manpower

Electrical Propulsion Technology

6. Electric power generation and propulsion is a solution conforming to an environmentally responsible/sensitive era with substantial fuel economy, higher flexibility (both for installation and operation), better comfort onboard, increased availability and an inherent capacity to be configured for fault tolerance.

7. The introduction of diesel electric ships had begun in the year 1903 in Russian tanker Vandal and the first warship, an aircraft carrier nonetheless was commissioned in 1922 by the US Navy as USS Langley. With a setback in the field of electric propulsion due to high costs in the 1960's electric propulsion has undergone wide research and the development of advanced and precise control along with proven methodologies and practices to reduce EMI/EMC have led to a spurt in the investment of time and money by all major navies. This enthusiasm is also met by proven technology being provided by leading global players like Rolls Royce, MAN, General Electric, Hitachi and ABB. Some of the most advanced warships like the Zumwalt class destroyers (US Navy), Type 45 destroyers (Royal Navy), Queen Elizabeth Aircraft Carrier (Royal Navy) and warships of the Australian, Spanish and Japanese navies have incorporated electric propulsion in the recent years. Numerous merchant vessels including patrol boats, LNG tankers, ice breakers, research vessels, cruise liners, ferries and cable and pipe laying ships use electric propulsion due to the flexibility and high maneuverability which the system provides.

(a) <u>Albion Class LPD (19560 Ton), UK</u>
02 x 12.5 MW; 02 x 3.1 MW DG
AIMs; HV System

(b) <u>Type 45 Destroyer (7500 Ton), UK</u>
02 x 25 MW GTG; 02x 2 MW DGs
02 x 20 MW AIM ; HV System

(c) <u>Queen Elizabeth A/Carrier (65500 Ton)</u>
02 x 36 MW GTG; 04 DGs 9-11 MW
04 - 20MW AIM

(d) <u>Zumwalt Class Destroyer (15600 ton), US</u>
02 x 36 MW; 02 x 3.9 MW RR GTG
02 x 34.6 MW AIMs

(e) <u>T-AKE Class Cargo Ships, US</u>
04 MAN B & W DGs; Total 35.7 MW
02 x 20 MW AIM ; HV System

(f) <u>Mistral Class LPDs (22000 Ton), France</u>
02 x 12.5 MW; 02 x 3.1 MW DG
02 x 7MW - Azimuth Thrusters

Fig. 2 Electric Propulsion in Foreign Navies

8. **<u>Principle of Operation</u>**. The principle of operation includes conversion of kinetic energy (prime mover) to electrical energy (generator) and back to kinetic energy (motors) to propel the ship.

9. **Functioning**. Electric propulsion is the transmission of power from the prime mover to the propeller through rotating electrical machinery. In this system, electric generators driven by the prime movers supply power to the propulsion motors. These motors can either be connected directly or through reduction gear units to the propeller shafting. The generator can be either DC or AC with diesel engine or gas turbine as the prime mover, depending upon the requirement and role of the ship. The speed and direction of the rotation of propeller is governed by quality and quantity of electrical supply provided to the motor.

10. **Architecture**. Dieso-electric propulsion plants are systems, where the Diesel engine can operate on a constant speed thereby reducing fuel consumption. Here, the high efficiencies of conventional prime movers at high speeds can be easily exploited at all load ranges as prime movers are used only to drive generators. Speed of the propulsion motor coupled to the generator can be varied by controllers as required by the user. In this system, the generator is providing power to main propulsion motors along with the ship's load. This system eliminates the mechanical connection between prime mover and propeller thereby enhancing optimization of space usage. The power distribution in the ship can be through Common DC distribution, Frequency Controlled Drives or conventional AC Sub-Distributions. The system also allows the integration of energy storage sources like batteries which reduces the transient loads on the Diesel engines and gives better dynamic response times of the propulsion system.

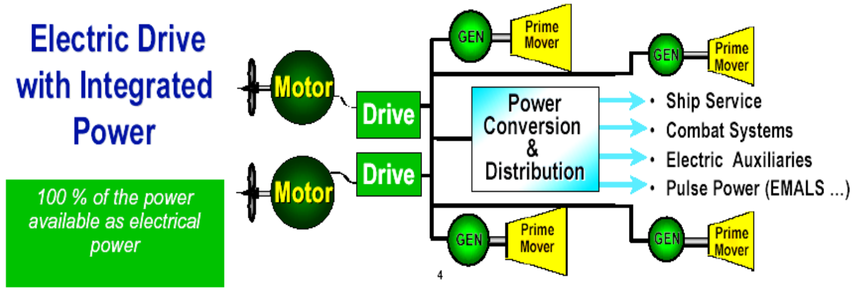


Fig.3 Diesel- Electric Propulsion Plant

11. **Categories of Electrical Propulsion Systems**. The electric propulsion system falls under three broad categories, namely Hybrid, Integrated (IEP) and Integrated Full (IFEP). The same are defined as below:-

(a) **Hybrid**. Where Mechanical and Electric drive are combined.

(b) **IEP**. Where a common power source is utilised for both ship services and propulsion system like Dieso-Electric.

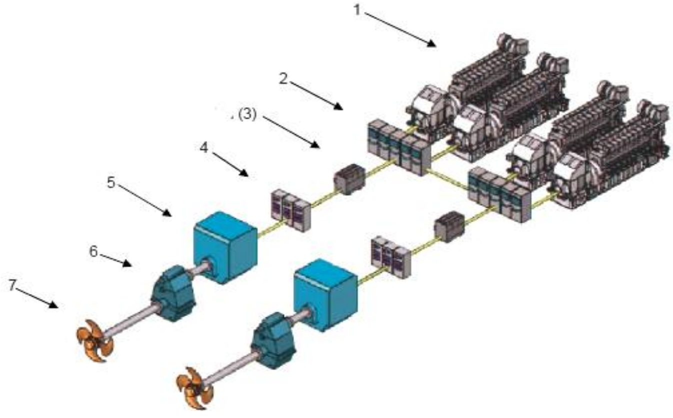
(c) **IFEP**. In this IEP is supplemented with advanced power electronics and energy storage into the architecture.

12. **Components**. The electric propulsion system components can be divided into three broad categories: -

(a) **Electric Power Generation**. This category consists of Prime Movers, Generators and Energy Storage Systems.

(b) **Electric Power Distribution**.This category consists of Energy transmission switchboards, transformers, filters and power converters.

(c) **Electric Power Consumption**. This category consists of propulsion motors and control units.



Legends

1. *Gensets: Engine + Alternators*
2. *Main switchboards*
3. *Transformers*
4. *Convertors*
5. *Propulsion motors*
6. *Gearbox (optional), dependent on the speed of the motor*
7. *Propeller/propulsors*

Fig. 4 Architecture of Electric Propulsion

13. The main components required in an electric propulsion system are as follows:-

(a) **Prime Mover**. The function of the prime mover is to deliver mechanical energy which will be converted into electrical energy. Various prime movers being used are Steam, Diesel, GT and combined. The requirement of high efficiency excludes steam turbines as an option leaving gas turbines and diesel engines as the alternatives. Diesel engines are used in applications which require good fuel economy over a wide speed range. The speed range of diesel engines provides direct coupling to DC and AC generators. Gas turbines require gearbox as a speed reduction mechanism before coupling it with alternator, due to inherently high RPMs produced by gas turbines. Turbo-charged diesel engines are at their peak efficiency over a very narrow operating load and RPM range. Long periods of low speed, low load, low RPM and high torque requirements are highly inefficient and are harmful to the health of the engine. Modern generator systems with load sharing, auto-start, and load shedding features make it possible to efficiently utilize the installed horsepower of a diesel electrical system. A large variation in propulsion power requirements, such as long periods of low speed operation or the necessity to shift power from main propulsion to thrusters for dynamic positioning purposes, can also justify diesel electric systems.

Feature	Diesel Engine	Gas Turbines	Boilers
Weight	Moderate weight for same power	Lesser weight	Higher weight
Speed	Moderate speed	Higher speed	Higher speed
Fuel Consumption	High fuel consumption at partial loads, Lower at higher loads	Higher	Higher
Gear Box	Not required	Required	Required
Efficiency	High at constant higher loads	High at higher loads	Low
Cost	Lower for same power	Higher for same power	Higher for same power
Requirement of Area	Lesser	Moderate	Higher

Table 1 Comparison between Prime Movers

(b) **Generators**. The generator converts the mechanical energy obtained by the prime mover into electrical energy which is used for both, propulsion motors and ship supply. DC generators are steadily being replaced by AC generators due to commutator maintenance issues. High Kilowatt ratings and absence of a commutator resulted in wide use of AC generators onboard ships. The energy produced by the generators can be stored in batteries or super capacitors post conversion.

(c) **Electric Power Distribution**.The electricity produced by the generators is fed to the switchboards consisting of power electronic components. The high voltage is step down using transformers and noise is eliminated using various filters. The quality of the supply is changed using various converters. Solid state converters are used in electrical propulsion installations for converting AC to DC and to change the frequency of alternating current. The conversion from AC to DC is also achieved using rectifiers. For conversion of frequency cyclo-converters are used.

(d) **Motors**. The propulsion motor is used to drive the propeller which is being fed by ship generators by converting electrical energy into kinetic energy. These motors can be placed just above the propeller or transmit the power to the propeller by the use of a regular horizontal shafting assembly. With development of ‘Azipod’ (Azimuthing Electric Podded Drive) which combines the functions of a propulsion motor, main propeller, rudder and stern thrusters in a single unit, the system can be integrated with an electric motor which drives the shaft, saving space on board and eliminates the need for a gearbox. The elimination of a speed reduction gear in DC motors due to its slow speed makes DC motors a preferred option in most electric drive installations. In such motors the power and torque can easily be controlled by varying the field current. The direction of rotation of the propeller shaft can also be changed by varying the direction of armature current supplied to the DC motor. However, with the advent of technology, AC motors are also finding place in electric propulsion applications. AC motors are of two types viz. synchronous, conventional induction motors and now more advanced Permanent Magnet Induction Motors. The speed of synchronous motors can be controlled by the use of power electronics where induction motors can be controlled by Variable Frequency Drives.

Feature	**DC Motor**	**AC Motor**		
	Brushless DC Motor	**Brushed DC Motor**	**Synchronous Motor**	**Induction Motor**
Commutation	Electronic Commutation based on Hall Position Sensors	Brushed Commutation	No Commutator	No Commutator
Maintenance	Less required due to absence of brushes	Periodic maintenance required	Less	Very less
Life	Longer	Shorter	Shorter	Shorter
Speed / Torque Characteristics	Enables operation at all speeds with rated load	At higher speeds, brush friction increases, thus reducing useful torque	Lower than the DC motor of the same power	Lower, speed / torque can be varied
Efficiency	High – No voltage drop across brushes	Moderate	Lower than DC motors	Lower than DC motors
Output power /	High- Reduced	Moderate /Low- the	Lesser frame	Lesser frame

frame size	size due to superior thermal characteristics. As the stator windings are connected to the stator, the heat dissipation is better.	heat produced by the armature is dissipated in the gap, thus increasing the temperature in the air gap and limiting specs on the output power/frame size.	size than a DC rotor of the same power	size than a DC rotor of the same power
Rotor Inertia	Low, because it has permanent magnets on the rotor. This improves the dynamic response	Higher rotor inertia which limits the dynamic characteristics	AC motors require external sources to overcome the inertia	Less inertia
Speed Range	Higher- No mechanical limitations	Lower - mechanical	Operates in medium	Operates in medium

	imposed by the brushes	limitations imposed by the brushes	speeds	speeds
Electric Noise Generation	Low	Arcs in brushes will generate noise causing EMI in the equipment nearby	Higher	Higher (based on speed)
Cost	Higher- Since it has permanent magnets, building costs are higher	Low	Moderate cost	Moderate cost (higher than synchronous)
Control	Complex and expensive	Simple and inexpensive	Complex & expensive	Complex & expensive
Control Requirements	A controller is always required to keep the motor running. The same	No controller is required for fixed speed, controller	Controller is required for variable speed. Exact	Controller is required for variable speed. The rotor

	controller can be used for variable speed control.	is required for variable speed drive	synchronism with the line frequency is achieved	rotates slightly slower than the AC current alternations to induce current in the rotor winding

Table 2 Types of Motors used in Electrical Propulsion

(e) **Power Converters**. Several different types of converters are being used to cater to the requirements of the propulsion motors. Power converters are limited by the voltage and switching characteristics of the semiconductor devices and the devices that have helped realize IEP are as listed below:-

(i) Cyclo-converters
(ii) Synchro-converters
(iii) Pulse Width Modulated (PWM) converters
(iv) Pulse Frequency Modulated (PFM) converters

Electrical Propulsion Technology – Advantages

14. The present warships have elaborate equipment fit for various applications viz. Radars, Sensors, Weapons, Communication and Engineering equipment, all utilising electric components which leads to a load requirement that varies with applications. In conventional systems different sets of prime movers are required for power generation and main propulsion along with auxiliaries and the shafting arrangement. The electric propulsion technology offers significant benefits for warships in terms of increasing ship's stealth features, payload and power availability for non propulsion uses. The technology is undergoing constant growth with advancements in power

electronics and major advantages offered by the technology are as follows:-

(a) **Power Efficiency**. A diesel engine has its highest efficiency of 40% at full load which drops to a staggering 24% when run at low load (25%) conditions. A dieso-electric system of the same power rating provides efficiency in the range of 31% to 37% in the same load range. The efficiency of diesel engines at part loads can be increased by employing smaller engines. All the engines can be made operational for full load conditions and one or more smaller units can be shut down at part load conditions to maintain higher power efficiency (upto 38%).

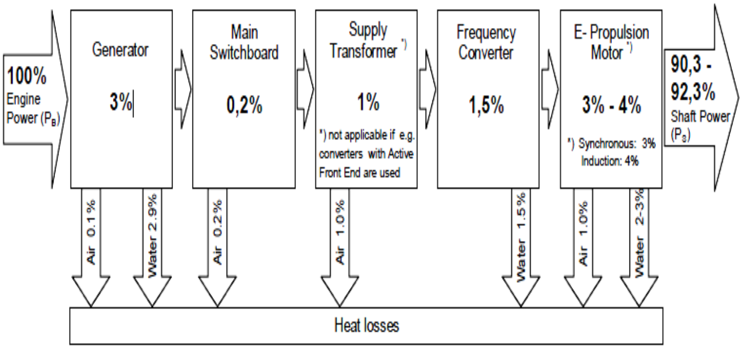


Fig. 5 Losses in Dieso-Electric Propulsion System

(b) **Load Diversity**. There are advantages in having a single central power generation facility which can service the propulsion and all other ship loads as required.

(c) **Fuel Economy**. With dwindling natural resources becoming a major source of concern for Navies across the globe, the stress on fuel economy is understandable. The most commonly used propulsion systems such as Diesel engines and Gas turbines have their associated limitations when it comes to fuel economy. At low loads, Diesel engines face the problem of low load running, which affects the health of the engine where the operation of Gas turbines at low loads is not economical as their rate of fuel consumption is very high. At reduced propeller speeds, electric propulsion is more efficient as the power demand can be catered by matching the number of supply generators. Some of the generating units can be shut down completely and the others can be exploited near full load and at high efficiency. In a study conducted by GE Corporation on the U.S. Navy's amphibious assault ship, USS Makin Island which was installed with a hybrid propulsion system, comprising of two GE LM2500++ gas turbines and auxiliary electric propulsion system registered fuel savings amounting to in excess of $15 million over a seven month period. According to the U.S. Navy, lifetime fuel savings are anticipated to be in the order of $250 million.

(d) **Flexibility of Installation**. As the propeller shaft need not be connected directly to the prime mover, we have complete flexibility in positioning the Diesel engine or the Gas Turbine within the ship as it is just subjected to the distribution of electric power through cables. It is estimated that a reduction of about 30% volume is possible compared to a conventional mechanical drive system.

(e) **Stealth Features and Lower Acoustics**. The engine can be separated acoustically from the hull thereby reducing the acoustic signature of the ship. The engine can also be located well above the waterline, thereby having the advantage of significantly reduced radiated noise. The reduction in the hull borne vibrations and subsequent reduction in noise produced by the ship is a vital stealth feature, desirable in every warship.

(f) **Reduced Emissions and Engine Health**. The prime mover can be operated at its highest efficiency and also can run in a constant speed as it is used only for power generation. The propeller can run at all speeds and torques within the design limits without any limitations on the engines. The engine is oblivious to the load fluctuations (torque) of the propulsion system which is supplied by the generators, thereby resulting in lower emissions of NOx/NO,CO and CO2. The engine health can also be maintained while significantly reducing the maintenance costs.

(g) **Standardisation**. While the generating sets onboard ships equipped with electrical propulsion can be used for both propulsion and for shipboard supply. The need for different prime movers for propulsion and electricity generation can be eliminated. Today ships employ combined propulsion (CODOG) designs for cruise and boost regimes which reduce the commonality and inter operability of machinery spares further increasing costs and spares required.

(h) **Reliability and Redundancy**. All combat platforms ensure redundancy in their vital systems. Multiple generators and motors can be used to ensure redundancy. The loss of one unit does not result in total power loss unlike conventional ships, where the emergency generators have to be started to restore power. Service and maintenance of individual units can also be easily undertaken when compared to single large capacity units.

Challenges with the Electrical Propulsion Technology

15. The major challenge for inducting Electrical Propulsion Technology are as follows:-

(a) **EMI/EMC Control**. The introduction of Electric propulsion will increase the EMI/EMC concerns onboard ships. All shipboard equipment installed have to comply with the stringent standards as per defence requirements. The electrical equipment has to be checked for electromagnetic compatibility with other co-located equipment. The amount of electric power which is supplied to the propulsion motors is much higher than that in conventional ships. This will marginally increase the electromagnetic interference due to the very high current (about 1500 Amperes) being passed through the cables which in turn increases the magnetic field created by them. The solid state devices within frequency changers will also be a source of electromagnetic interference. The varying frequency due to cyclo-converters will radiate and cause interference with other devices. Spacing between electrical equipments and placement of susceptible equipment outside the susceptible field regions will also be a challenge considering the space constraints onboard typical warships. Solution will be to provide EMI control through means like shielding, grounding, bonding, cabling and filtering. EMI control techniques such as bonding and cabling must be strictly adhered to. Equipment door seals, ventilation screens, filters and cable shielding must be maintained and checked on a regular basis. Effective attenuation of electromagnetic emissions must be constantly ensured.

(b) **Safety & Protection**. The use of electrical equipments has conjoined challenges in the form of safety & protection. The cables have to be protected from possible damage due to fires, corrosion of wire encompassing conduits (in pipes passing through bilges), Ingress protection for various electrical equipments, material degradation in the highly corrosive marine environment etc and the operators will be required to adhere with the safety guidelines.

(c) **Trained Manpower**. The training of ship staff and repair agencies in operating and maintaining electric propulsion systems will be required. As *IN* has already been operating Dieso Electric Submarines for the past five decades, the training of personnel will not be as big a challenge from starting from scratch.

(d) **High Initial Capital Costs**. The associated costs of machinery, installation, training and spares will be higher than conventional systems. But considering the advantages associated with the system, these can be absorbed as a onetime investment and the lifetime cost saving from reduced fuel consumption may exceed the higher initial procurement cost of electrical propulsion.

(e) **Additional Components** *IN* operates a plethora of equipments ranging from Auxiliary motors to Weapons systems, which have a wide range for power requirements. In a conventional ship, the switchboard has to cater for the ship's supply, weapons, radar with some electrical auxiliaries. Thus the usual scheme of power flow is from the generators to the switchboards; from the switchboard, the current was supplied to various consumers through various EDC's (Energy Distribution Centre's). The induction of electric propulsion will result in a very high power requirement from the generators to suffice for both propulsion and power generation onboard. This will lead to the induction of multiple transformers as the ratings of the envisaged generators will be very high.

Modalities of Induction of Technology in the *IN*

16. Electric Propulsion is not a new concept to the Indian Navy. The *IN* has previously operated *Ex INS-Amba* which was equipped with an Electric propulsion package. Even the conventional Dieso-Electric propelled submarines operate on the same lines. There is no denying of the fact that Electrical Propulsion technology is gaining popularity round the globe. The Indian Navy's initiative to procure electrically powered LPDs is a step in the right direction and these ships are set to join the *IN* arsenal within the next 8-10 years. Induction of this technology at such a large scale has to be well planned and executed so that the equipment can be maintained and exploited in the most efficient and effective manner. Formulation of a comprehensive policy on maintenance of propulsion system and its related power system components is an inescapable requirement. Electric Propulsion, being inherently a hybrid system, has to be treated differently when compared with the three established propulsion mechanisms, namely, IC, Steam and GT. Accordingly several aspects that have to be customized and re-aligned in order to manage this technology effectively are listed below:-

(a) **Onboard Organisation**. Traditionally propulsion systems onboard ships have been the domain of mechanical engineers and accordingly, the system along with its auxiliaries have always been operated and maintained by the Engineering Department. The employment of electrical propulsion onboard a ship involves a great degree of use of electrical units/ PGD units which are traditionally maintained by the Electrical

Department. Management of electric propulsion as a whole needs to be factored during the induction phase for smooth transitioning. The operation and maintenance of electric propulsion plants would continue with the Engineering branch.. Creating an additional stream of ERA (EP) and ME (EP) in addition to the existing streams of Steam, ICE, GT and Controls would be required during the ab-initio training at INS Shivaji. These engineering sailors would subsequently be positioned onboard the Engine Room department of electrical propulsion ships. An extended PCT would be required for officers being positioned as EO/SEO/AEO of electrical propulsion ships.

(b) **Support Organizations**. With the induction of Electric Propulsion, additional infrastructure onboard ships and in repair yards will be required. The set up will require a separate centre to deal with maintenance of high power/ high voltage rating electrical motors and associated fittings. Material Organisation will be required to cater for appropriate stores for electrical propulsion. The optimization of infrastructure could be achieved with standardization starting from the conceptual phase. Trial agencies like MTU, DTTT/ GTTT and ETMU continue to undertake trials of their respective system with existing regulations already stipulated.

(c) **Training**. Subsequent to ab-initio training at INS Shivaji, the tpe training to the ship‘s crew and yard personnel must be provided by the OEM on the equipment installed onboard whereas the subsequent transfer of knowledge, experience and expertise can be facilitated by posting these officers and sailors at INS Shivaji. Operation and maintenance philosophy of electrical propulsion system, specific training for handling of high rated electrical components, fire fighting training with regard to MT/ HT voltages in the order of >3kV would need to be addressed in the training curriculum.

(d) **Safety**. Standard Operating Procedures customised for high voltages will be required to be ensured for a safe working environment. Safety training on aspects like maintenance & testing requirements for high voltage rated electrical devices, power transformers, circuit breakers, switchboard, grid systems and batteries along with their chargers should be incorporated in the curriculum. Also, the focus should be on correct exploitation of the system, fault diagnostics / repairs and breakdown drills.

(e) **Industrial Support**. The manufacturing sector in India has seen a significant growth in the last few years. The ingenuity in Indian made designs have been well accepted into the armed forces and in particular the Navy. The potent organizations who can manufacture these systems as per Indian Navy's SQRs for development of LPDs are M/s Larsen and Toubro Ltd, M/s Pipavav Defence & Offshore Engineering Company Ltd and M/s ABG Shipyard Ltd. Once a start is made, the industrial support is likely to further grow and flourish.

Conclusion and Way ahead

17. Electrical Propulsion Technology has emerged as a future propulsion technology with various advantages surpassing the challenges. The technology is under a developmental phase with constant improvements in power electronics. While, *IN* has been operating Electric Propelled submarines with planned procurement of four LPDs with Electrical Propulsion Technology, the need has come to address the challenges with participative commitment from all stakeholders (policy makers, R&D organisations and Industry). The key to operational availability of combat platforms for any Navy is self reliance, so it is an appropriate time for us to plan the induction of new technology with prime focus on 'Made or Make in India' concept. Considering the vision of the IN. engineers are to create a road map for building self reliance in the Electrical Propulsion Technology right from its inception.

The author is presently serving as Senior Engineer Officer onboard INS Beas

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INTEGRATED ELECTRICAL PROPULSION SYSTEM CHALLENGES AND WAY AHEAD

Lt Cdr Anuj K Singh

Abstract

Electrical Propulsion (EP) is a novel concept in marine systems. The availability and ease of operation of power electronic converters has proved to be the Key Enabling Technology for electrification of large ships. This paper starts with a summary of EP drives, which led to the birth of All-Electric Ships (AES) followed by a brief description about Electric power generation and control systems, which made it possible to exploit the integrated electrical power system. The goal of this paper is to bring out the challenges and way ahead for our Navy, by demonstrating that challenge faced by Indian Navy lies in effective Research and Development (R&D) of EP technology by in-house resources based on our specific requirement, rather than buying / depending on the technology from foreign OEMs.

Introduction

1. The basic assignment of a ship is to maximize the share of payload and to minimize the acquisition and operating costs for the ship. In past around middle of the 20th century in the area of ship building / design owing to development in the field of mechanical engineering it was possible to reduce internal spaces dedicated to engines on one hand and improve efficiency & reliability on the other. Later in the 20th century (around 1990), an era of new generation electrical technology made it possible to install complete Electric Propulsion (EP) drives there by increasing vessel sea going efficiency. Further, with the advancement in the field of power electronics it is now possible to develop the electrical equipment / technology that are similar to that in industrial fields (like steel industry, rolling mills, railways, petroleum, chemical plants etc.) for the marine standards for electrical propulsion system. As a whole it can be seen that with the introduction of electrical propulsion it is possible to redesign the whole architecture of conventional shipboard power generation, distribution & utilization completely from scratch. It is important to mention that this IEPS technology has brought significant changes in the entire ship design,

allowing space saving, fuel efficiency and increased flexibility without impairing reliability. Also the scope is available for ships which are initially fitted with the conventional propulsion system to be retro-fitted with the new electrical propulsion system. In All Electric Ships (AESs) the thermal engines (Diesel or Gas Turbines) are used exclusively as prime movers of the synchronous generators. AESs are endowed with a power station that generates the electrical power that feeds all shipboard loads (propulsion and auxiliaries) through the integrated electrical power system. It is important to mention that this technology has a weak link which is power grid, in the sense that, there are single loads or single generators whose rated power is of the same order of magnitude as the total installed power. That means the scope for future expansion / installation of equipment is limited

Conventional Propulsion System

2. A brief description of existing Mechanical Propulsion system (Conventional Propulsion System) in Indian Navy with Pros & Cons are as follows: -

(a) Mechanical system has better full load efficiency.
(b) Does not account of mission and load profiles.
(c) Does not take account of low speed operation.
(d) Does not take account of ability to shut down any of the propulsion prime movers for maintenance.

3. **Electrical Propulsion System**. The integrated electrical propulsion or full electric propulsion is an arrangement of marine propulsion system such that the Gas Turbine or Diesel Generators or both, used to generate three phase electricity which is then used to power electric motor turning either propeller or water jet impellors. It is modification of the combined diesel – electric and gas propulsion system for ships. This means EP system are created by installing one or more electrical drives / motor for each propeller. EP motors that are fed through power electronic converters, functionally replaces the conventional diesel or Gas Turbine propulsion system. For example, in case of the Cruise Liner or Cargo ships, Electrical Propulsion motor per single propeller is of approximately 15–20 MW capacity. In general, all electrically propelled cruise liners or cargo ships are equipped with two propellers i.e electric

propulsion motors of capacity 30–40 MW. A conceptual diagram of EP is as follows: -

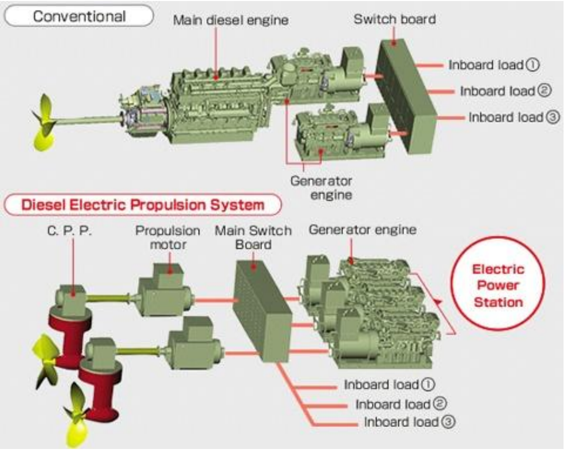

Fig. 1 General Layout of EP

4. The Electrical propulsion has a series of well-proven advantage with regards to the marine architect and to the ship designer which are as follows: -

(a) Diesel Generator and Gas turbine alternators in an Integrated Electric Propulsion are normally run at high loads/ high efficiencies.

(b) Big/small Gas turbine alternators and/ or Diesel generator set combinations can be used to match varying power requirements at sea or in harbour.

(c) Superior dynamics (start, arrest, speed variation) offered by electric motors over the conventional diesel engines (or gas turbines).

(d) Possibility of accommodating electrical motors with more flexibility, installing shorter shaft lines.

(e) Reduced fuel consumption is possible due to the variations / combination of thermal engines running at a time i.e. the number of generators on duty is adjusted in order to keep them working at their minimum specific fuel oil consumption.

(f) Higher comfort due to reduction in overall vibration i.e. thermal engines run at constant speed, therefore vibrations filtering / damping is much efficient. Therefore, having reduced acoustic signature of the ship which is of significant importance to military operations.

(g) High level of automation of the engine rooms thereby reducing manpower onboard ships and quality of qualified / skilled manpower increases onboard.

Salient Points of Power Systems Onboard AESs

5. The power system onboard AESs must satisfy requirements that are different from the conventional ones (here “conventional” refers to a ship where a dedicated power system and mechanically propulsion system is available). A first difference is regarding identifications of user, in conventional system various category of users are defined like navigational, communication, weapon, firefighting, galley and lighting, whereas for AESs power system there are only two categories i.e. the essential and nonessential users. Essential users are loads whose supply and correct service must be assured. Also in the case of a major system fault, these are defined by rules and regulations as their functionalities are essential for the ship’s safe operation. These traditionally include propulsion systems, rudder motors, thruster system, fire suppression systems, communication systems, emergency lights, and navigation systems. Non - Essential users are loads of air conditioning, ventilation, toilets, and sanitization systems etc. In fact, although they are not essential, they assure the onboard living standards. A second important aspect of Electric Propulsion System is the absence of power bus-bar onboard a ship i.e. like a dedicated power bus - bar present onboard conventionally propelled ship same is not available on AESs. Therefore, in AESs the insertion or disconnection of both large loads and generators can result in electro-mechanic alarms, and longer recovery times for voltage and frequency in comparison with the conventional power networks.

Features of IEPS Management System

6. In IEPS the Electrical Propulsion can absorb more than 50% of the total installed power, therefore becomes an important member of the IEPS management system, for both in steady state and transients condition. Accordingly, the IEPS design requires a strong complete approach, with a particular attention to the functional integration of the different subsystems. Therefore, existing knowledge of Conventional power system is not enough, because the IEPS of a large AESs includes almost all the possible electrical engineering subsystems. For example, it is like a large power station with generators working in High Voltages(HV) with two distribution system a main HV distribution system & a secondary distribution system working in low voltage (LV) which include almost each kind of electrical machinery used in industrial applications (both in HV and LV, either direct-on-line or supplied by a variable-speed drive). A modern IEPS also has an extended use of power electronics, real-time control systems (lower automation layers), and distributed automation systems (higher automation layers), each built and installed by different suppliers / OEM, which have to be fully integrated, representing the core of the power management system. For example, on land this network of power generation and distribution will be termed as MICRO GRID with large power sources and integrated power control and management system. Accordingly, the degree of Integrated Console Terminal (ICT) applications dedicated to power control make the AESs' IEPS is a natural-born multi-megawatt smart grid. Therefore, its design requires skill and the application of the best engineering practices available i.e. each ship is different and has different requirement from each class of ship, therefore each time a different & fully customized IEPS has to be designed. It has to be observed that in an AES, almost all the loads are powered by the IEPS, making it a system with high level of Quality of Services (QoS) requirements. Finally, it is important to mention that the core focus of IEPS designer should be that a total blackout situation must be avoided at any case, because it results in both the total loss of the ship's maneuverability and in the loss of the life support systems. In view of these critical issues discussed an electrical engineer designer has to think and design / act, not only as a traditional plant designer, but also as a real time system integrator, of both the IEPS's electro-mechanic and the

Integrated Console Terminal (ICT) including simulators and software's.

Voltage and Frequency Regulation / Control Issues in IEPS

7. The IEPS is required to have the capabilities of power generation, distribution, management and control in order to provide power supply to all the shipboard equipment. In order to comply with such huge requirements, an IEPS is equipped with a main onboard power station that having the main generators (i.e., all generators except emergency ones). These main generators are directly connected to the main switchboard HV for large power applications and LV for low power applications, which feeds to all the shipborne equipment. The equipment operating at high voltages are generally, mountings, air conditioning system compressors, capstan, heating equipment, ventilation equipment and thrusters (direct-on-line asynchronous motors) which are connected to electric propulsion while all the remaining users are like electronics, communications, entertainment, galleys, lighting, auxiliaries, etc. are usually supplied by LV switchboards. The power station is generally divided into two sections AFT and FWD. The main switchboard and the alternators are connected to the switchboards without the use of transformers. Frequency is regulated through prime movers Speed Governors (SGs), while the alternators Automatic Voltage Regulators (AVRs) are used for voltage control. On some ships, AVR is used as a Master tasking of eliminating the bus voltage error at steady state. Both SGs and AVRs are real-time control systems and fundamentally used for the regulation of voltage and frequency of the shipboard power grid. Their control action is most critical when transients takes place due to EP power fluctuations, switching ON / OFF large induction motors (compressors, thrusters), connection / disconnection of harmonic filters, disconnections of generators, network faults and reconfigurations.

Implementation of IEPS (Integration & Testing)

8. System integration is critical component of entire IEPS. The fault / feeble design integration system can bring power quality problems/ issues, degradation of the electric service, electric alarms and the generalized blackout. The integration of IEPS components is a challenging task for designer/ ship builder.

Further, the softness / critical issues of control system of IEPS is that all components/ subsystems of IEPS management system are of different OEM / suppliers designed, assembled, tested/accepted in factories, then installed and commissioned by different companies as ordered by the shipyard

9. AVRs are the important part of the control systems whose selection purely belongs to the electrical engineer's competence, as AVRs being the components that are involved in the fastest dynamics (excluding protections intervention). Also the general / basic assumption is to achieve voltage control by using a set of independent/standalone AVRs.

10. In some classes of ships (such as naval vessels and offshore units), tests using software simulators or even testbeds trials are requested by the ship owners and/or by approved standards. From the QoS point of view, in an IEPS the crucial point is to keep well-regulated both frequency and voltage at the main switchboard. Therefore, entire simulators and testing software's of IEPS are designed to keep the voltage and frequency in control. Since, if this control over voltage and frequency is accomplished, then all the remaining sections of the power system are expected to operate correctly. Therefore, the IEPS can be considered as a single complex system, exploiting a multiple-input-multiple-output (MIMO) architecture, which means various independent voltage control loops of the AVRs are interacting with each other and thus providing the required voltage regulation in order to achieve stable parallel operation in the steady-state condition.

IEPS and Ship Design Concept

11. The peculiarities of AES's design are mainly depended upon EP and IEPS design phases, while the rest of the ship design can be considered comparable to mechanical propelled ones. Keeping this design philosophy as discussed above, it is possible to define an overall sequence of ship design which is aimed at obtaining a complete ship from the initial design requirements. The IEPS design has overlaps at different phases, starting from concept design phase (where all the possible layouts of the IEPS onboard are conceived) up to the functional design. Throughout these phases, the IEPS design proceeds as a partially independent activity. However, such an activity

maintains interrelations with the other ship design activities and thus becomes critical / important part of the overall ship design. Indeed, due to the limitations such as the role of the ship (patrolling, destroyer, frigates etc), each subsystem of IEPS is different for different ships. Therefore, at present the competition amongst the OEMS are generally in terms of space & weight utilization of the system, which means provisioning of more space to other ship systems. So, a balance between costs, space requirement and achievable performance has to be reached, at the same time assuring the compliance with requirements.

Need for Innovation in Shipboard IEPS Technology & Present Scenario

12. Modern shipboard IEPSs are complex systems, whose design and management are difficult tasks. Such complexity comes from the need to comply with the strict standard requirements of modern vessels, on both the system performance level and QoS. Moreover, special applications, such as military / Naval or Dynamic Positioning (DP) vessels, have ever-higher requirements than common commercial ships, there by leading to an increase in overall system's complexity and technology level of installed subsystems. In general, the QoS considered the following parameter for a new design of vessel:-

(a) reduction of volumes/weights
(b) efficiency improvement
(c) maximization of payload
(d) cost reduction
(e) Environment protection

IEPS Technology and Future Technology

13. The catch for a good ship IEPS design is to reach ever-higher performance levels for the common design requirement (which are pushed forward by owners and to comply with the QoS requirement set by classification societies and regulations). The solution for this issue is extensive research activity on marine power systems as per the requirement and use of suitable power equipment (motors, transformer etc), power converters, and power electronic & softwares. Indeed, in both the

commercial and military sectors, a large amount of competitors is present to provide the best IEPS. In case of Naval requirement, the focus area remains on the latest technological supremacy. Due to this, it is evident that the competition in both the commercial and military sectors imposes to change the current IEPSs in order to keep the leading position. As seen from so far discussion, research in the shipboard power systems area is extensive, mostly regarding technological aspects. Research topics promoted by the shipyard across the globe and countries have a broad spectrum, covering almost each aspect of shipbuilding. These technological researches are mainly dedicated to efficiency and cost reduction. At present the technological research on power propulsion system course is leading toward a shift from the IEPSs to integrated electrical and electronic power systems (IEEPS) concepts.

Advantages/ Disadvantages of Integrated Electrical Propulsion System for Naval Vessel

14. In IEPS system the major advantage is that, a single prime mover circuit is used for producing electricity as well as for propulsion there by reducing the requirement of fuel, capital cost and maintenance cost. The other advantages of this propulsion system are increase in freedom / space flexibility for placement of the engines, acoustical decoupling of the engines from the hull which makes the ship less noisy, and a reduction of weight & volume. As far as Naval forces are concerned the key feature of reduced acoustic signature is particularly important as it helps in operating in Anti-Submarine warfare / operations by making warship Stealthier.

Way Ahead: Indian Navy & IEPS

15. The specific roles of the Indian Navy in future would continue to extend across the entire spectrum of security of the nation ranging from peace keeping through the low intensity segment to high-intensity conventional hostilities up to and including nuclear conflict. The Indian Navy will necessarily need to perform its varied tasks in the expanding presence of neutral and multinational/ extra regional forces in the Indian Ocean Region (IOR). In the last two decades, the capabilities available with our potential adversaries have grown considerably and are forecasted to only improve with time. The Indian Navy would,

therefore, require to acquire adequate deterrent war fighting capabilities.

Indian Naval Propulsion Systems & IEPS

16. India is still lagging behind in development of Indigenous Propulsion Systems especially engines. The growth in marine propulsion technology for warships and the opportunities for participation by private players in pursuance of Government of India's vision of "Make in India".

17. The main challenge for Indian Navy in implementing the IEPS technology is designing of different capacity of advanced propulsion motors, speed and power conditioning equipment (like transformer, rectifiers, PWMs & converters), simulators, training facilities & advanced safety devices like firefighting and Personnel Protective Equipment (PPE).

18. The thrust to move a ship across water and its performance greatly depends on the selection of the main engine. The choice of propulsion system is very critical to meet the desired performance and speed requirements for a given displacement and role of ship.

19. The ship has a significant share of the total shipbuilding cost as well as annual operating cost in fuel consumption. It is divided mainly in, Main engine, Gear box, Shafting and Propeller and the control provided by human-machine interface.

20. The Indian Navy has acquired adequate expertise in the hull design and construction of various types of warships. In the field of propulsion systems (barring marine Gas Turbines) and related auxiliaries, support services like air conditioning, refrigeration, etc., adequate expertise and production capabilities are available in the country, perhaps due to commonality of requirements of the civilian sector. We are also reasonably self-sufficient in power generation and distribution systems, communication systems, Combat Management Systems, Sonars and Electronic Warfare Systems.

21. The Propulsion systems used by the Indian Navy have been limited to mainly three conventional modes: Steam Plants, Diesel Engines and Gas Turbines. Indigenously manufactured

steam turbines of BHEL and main propulsion diesels of Kirloskar Oil Engines Ltd. Nuclear propulsion and Integrated Electric Propulsion are envisaged for future ships and submarine and are yet to make major headway. The number of projects are underway for indigenous development of marine propulsion systems including main propulsion controls through various agencies such as DRDO, Defence Public Sector Units like BEL, Private sectors firms like L & T, Mahindra Defence Systems and Tata power SED.

22. **Environmental Aspect**. As ships spend more time at lower or cruising speed, fewer engines are used to run out of pool of engines at full power which result in a greater energy efficiency and less fuel consumption. Therefore, IFEP has more advantage as far as emission of harmful gases like NO_x and CO_2 when compared to conventional propulsion technology.

23. **Maintenance Aspect for IN**. The electrical propulsion system is designed to be highly automated and self-monitoring hence requires less maintenance and manpower when compared with mechanical drive system. However, the challenge lies in providing high standard of efficient / qualified manpower for maintenance of IFEP system. It is estimated the IFEP technology will increase the life span of ship from 10 to 30 years, if maintained well.

24. **Financial Aspect for IN**. One-time installation cost of IFEP is higher than conventional propulsion system. Also the requirement of number of electrical equipment is higher in IFEP technology. However, the ships with IFEP may save an estimated 15 – 25 % in fuel compare to a similar ship with mechanical drive. The life time cost saving from reduced fuel consumption may exceed the higher initial procurement cost of electrical propulsion

25. **World of IFEP System & Indian Navy**. The UK and USA are leading in the absorption of IFEP technology for the surface ships and have integrated IFEP system in the ships like Queen Elizabeth-Class aircraft carrier and US Navies DOG 1000 Zumwalt-Class destroyers. Many navies across the world are adopting IFEPs technology for future construction of ships and submarines. Indian Navy has planned to adopt next generation propulsion system for all its future principle surface combatant

projects. Indian Navy's second indigenous aircraft carrier INS Vishal has been planned to be propelled by complete IFEP System.

Recommendations for IN

26. The way ahead for implementing IFEP technology in Indian Navy is as follows: -

(a) Extensive research and development by Indian PSUs on development of hardware and software components related IFEPs.

(b) Conversion of old ships, which are about to be decommissioned, as platform / pilot project for initial implementation of IFEP technology.

(c) Development of IFEPs prototype on small boats / ships like INS Tarangini & ISVs etc.

(d) Development of facilities & Safety equipment's for handling IEPSs.

(e) Encouragement to private shipyards like Reliance, L&T, GRSE etc for implementation of this technology in consultation with Government of India / Indian Navy.

(f) Implementation of test benches for simulation of IEPS technology at design level.

(g) High level Training infrastructure at training centers.

Conclusion

26. The goal of this paper has been to give the concept of Integrated Electrical Propulsion System and its dependency on the various factors like the design, implementation, maintenance, financial and environmental aspect. Further various challenges lay ahead for Indian Navy whilst migrating to this technology. The important lesson learnt from the navies across the world which have undertaken this technology leap and which will help our navy are to focus on the key issue of Research on Design

methods on the basis of the needs concerning the design, integration, and management. It is pertinent to mention that to start with, this technology can be demonstrated easily at laboratory with help of software simulator. In this paper some of these technologies are presented with the aim of motivating the need for new design method and tools. Finally, the proof of concept in ship building industry is not related to the demonstration of working technology, but it is mainly related to the advantages it can accrue to the vessel.

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MAINTENANCE AND MANAGEMENT OF GAS TURBINE CONTROL SYSTEM

Cdr AP Singh, Lt Cdr D Ameer Basha

1. Gas Turbine propulsion was introduced into the Indian Navy in the late 1960s with the induction of Petya class of ships. Since then, Gas turbines have brought in a major 'boost' to propulsive power of *IN* warships and have gradually become the mainstay of marine propulsion in the Navy. Since the induction of these engines, there has been a swift and steady transition of the GT control system from simple relay based controls on M2B GTs of Petyas to sophisticated VME based controls on Teg/ Kolkata class. This evolution has come along with its associated issues of maintenance and defect diagnostics/rectification. Although, state of art control system ensures better operation, control and monitoring, at the same time a defective control card can render the engine inoperative. Considering the critical requirements of GTs, sustained optimum availability of these engines cannot be over emphasized.

2. Barring the P 17 class ships (in the Eastern Fleet), *IN* operates Gas Turbines manufactured by M/s Zorya Mashproekt, Ukraine. Though the principle of operating the GTs has remained the same, the control system design has undergone a sea-change since receipt of the first Petya Class ships in late 1960's. The engines and control systems were originally manufactured, installed and supplied by the erstwhile Soviet Union, of which Ukraine was an integral part. However, after separation of Ukraine from Russia, issues of support have emerged view the control system OEM and the GT OEM being from two separate countries.

3. With the increase in number and types of Ukrainian origin GTs being presently operated by *IN*, the major challenge is maintenance and management of gas turbine control system, given the criticality of the same. Further, with change in the maintenance philosophy *wrt* gas turbine control system, where in complete responsibility is being handed over to engine room department progressively, the maintenance and management of gas turbine control system will prove to be the biggest challenge for marine engineers. This paper aims at bringing out these

challenges and proposes way ahead for better maintenance and management of Marine Gas Turbine control system.

4. **Problem Areas**. The present GT control systems available in the IN vary from relay and microprocessor based systems onboard SNF/Delhi class of ships to electrohydraulic controls onboard 1241 Res to the state-of-the-Art VME based control system of Talwar/ Teg / Kolkata class ships. These systems are marred with several issues. Some of these issues are highlighted below:-

(a) **Obsolescence**. Rapid advancements in technologies have been as much as a bane as a boon. The life cycle of any digital component/ device is about four to seven years. This results in rapid obsolescence of the systems resulting in supportability issues. Following are the immediate drawbacks of rapid advancements in technology:-

(i) Non availability of component/sub-component for repair/ replacement.

(ii) Requirement of carrying higher inventory for ensuring long term support, shelf life issues, high quantities of unused/ obsolete stocks and related cost over runs.

(iii) Inability of the OEM to provide long term support for obsolescent systems is a matter of concern view non-availability of expertise to undertaken maintenance of older systems.

(iv) Due to rapid advancements, version control of components and software is mandatory as newer versions are not backward compatible thereby requiring the user to upgrade the systems at frequent intervals leading to large cost over-runs.

(b) **Inability to Repair**. VME based systems fitted onboard new generation ships are highly modular and DI/DR is primarily based on plug and playrepair by replacement philosophy. However, the IN has not yet transcended into this new philosophy and reliance on 'repairs' by repair agency/OEM is primary mode of DR on these modules. This is difficult/ cumbersome as the repair agencies are also lagging behind in setting up of repair and testing infrastructure and training of personnel has not been undertaken in full scope/ not been undertaken at all.

(c) **Resident Expertise**. Further, for such systems, it is essential to identify the 'high turn-over' items and maintain requisite stock levels in OBS and B&D at all times. But, ranging and scaling can only be undertaken after exploiting these systems over a considerable period of time. However, with the present policy of regular and frequent turn-around of personnel due to transfers, the 'resident expertise' is lost leading to 're-inventing the wheel' and re-trending of defects and failures and forecasting of spares.

(d) **Documentation**. Comprehensive documentation for operation and maintenance of GT systems (Technical Description, Operating Instructions, Albums of drawings, Repair Technical Documents (RTD), process charts etc) is a must. The documentation for initially inducted systems of Russian origin was complete and comprehensive. However, for latest induction electronics equipment, the documentation is sparse and without sufficient detail. This is a direct result of insufficient data and experience of working on such systems and the tact of the OEMs to withhold data which can assist in repair and operationalization of systems. Also, Intellectual Property Rights for software cannot be violated leading to increased dependence on the OEM.

(e) **Tools/ Test Equipment**. In addition to the generic tools (Testers, calibrators etc), the specific tools and test equipment required for all levels of maintenance have not been provisioned both onboard ships (1^{st} / 2^{nd} levels) and at repair organizations (2nd /3^{rd} levels). In addition, repair and reference systems are not available at Naval Dockyards to facilitate quality testing/tuning and calibration of control system components of Teg and Kolkata class of ships.

(f) **Extended Lead Time for Procurement**. The procurement of spares from foreign OEM is not only restricted by the prohibited cost factors but is also stymied by the excessive lead time in their delivery.

Fig. 1 Challenges Being Faced in Maintenance and Management of GT Control System

Spare Management of Gas Turbine Control System

5. **Present Procurement Procedure**. Spare management is a critical area and requires focused attention to maintain the operational availability of the ships. The present system is cumbersome and has extended lead time and begins with annual review of demands at MOs. This is followed by raising of Indent by CMP. This indent is then cleared by MS and is forwarded to DLS. DLS thereafter takes the required clearances and obtains AON from COL/ COM in NLC II / NLC I. This is then forwarded to DPRO to commence the procurement procedure.

Tender enquiry is floated by DPRO and after receipt of offers, requisite procurement clearances / sanctions are obtained and consequently Order is placed. This is an extremely lengthy and time consuming process and seldom prioritises the spares as per criticality.

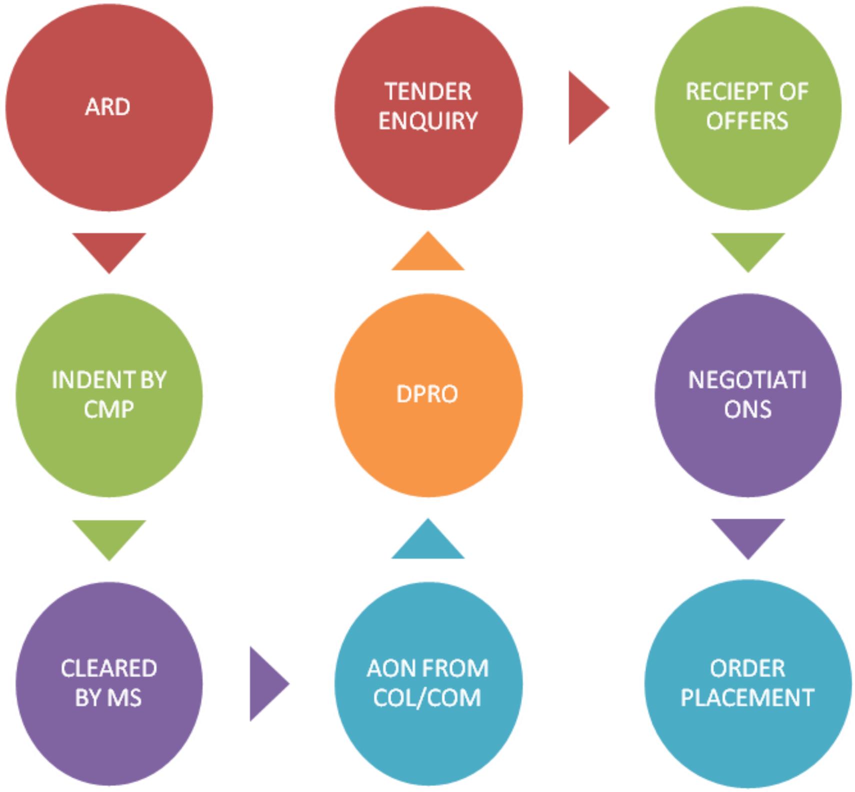

Fig. 2 Procurement Procedure

6. Further, the procurement is based on FCL for upcoming planned routines and consumption of certain spares during past DRs. This system is a traditional way of managing spares and generally results in lot of dead / nonmoving inventory as it is unlikely that all the anticipated spares are consumed during a planned routine and a similar defect will again be observed on some other engine. This is evident from the fact that at present, several GT control spares are lying in the MO as dead inventory. Further, as it can be seen, spares required for DR of a new

defect are not available and the requirements are being met by cannibalising or procurement from local sources.

Options Available

7. **Indigenisationof GT Control System Spares**. As brought out earlier, procurement of spares from the OEM has considerable lead time; therefore indigenisation of spares, as a long term measure to develop an efficient logistics chain to support the operational availability of GTs and also achieve self-reliance is the need of the hour. It is an established fact that utilising in-house and local resources for development of indigenized spares offers a quick and cost effective alternative for spares of foreign origin and therefore should be encouraged at all levels. Towards this certain steps have been taken at HQWNC. Notable ones are as follows:-

(a) **Automatic Data Acquisition System(ADAS)**. The Automatic Data Acquisition System was conceptualised by GTTT (Mbi) & designed and developed by M/s L&T for GTs of 1241 RE class of ships. These ships are fitted with primitive electro-hydraulic control system for GTs which provides very limited parameters for monitoring and accessing the health of these engines. Health and parameter monitoring including restricted operating zones is undertaken by the ship staff with limited parameters available. Further, due to the vintage of these platforms, maintenance of original fitted control system is a colossal task. ADAS was conceptualised to mitigate these issues by providing redundancy to original control System. Successful trial of this system on Stbd Boost GT was completed onboard Vipul in 2010 and presently fitment of ADAS for remaining other three GTs is in progress. Successful integration of ADAS with existing control system is a gigantic step towards self-reliance in the field of GT controls for Ukrainian origin GTs. The system is indigenously developed and has given a lot of confidence for developing indigenous system to mitigate obsolescence issues of other GT control systems through Indigenous vendors.The system has following functionalities:-

(i) Calculation of GT power based on HPC characteristics.

(ii) Online monitoring of RG loading based on GT power and propeller shaft speed.

(iii) Online monitoring of Slip of the GTs.

(iv) Running hours logging including hours at restricted exploitation regimes.

(v) Parameters like total hours of operation at various regimes, Operation at combination mode, Operation at independent mode is listed under this function.

(vi) Calculation of Running Down time.

(vii) Field Temperature Analysis.

(viii) Monitoring of Parameters like Pressure, Temperature, Running Modes of GT, and Speed-I/II selection etc.

(b) **CAKT-02 System of Delhi Class**. The CAKT system measures the oil temperatures of several bearings on the GTs and the shafting. It also provides an analog display of the same at the respective TCR. The CAKT system is an old & obsolete system and repairing/ replacing of the same was an economically unviable solution. It was therefore decided to replace the existing system with a new age digital system. The same has been developed by M/s Anadig Systems with support of GTTT (Mbi) and has been successfully installed onboard Mumbai. This has not only enhanced the operational availability and reliability of the system, but is a huge step towards self reliance.

Fig. 3 ADAS - Vipul

Fig. 4 Temperature Monitoring System for RG & Shafting - Mumbai

(c) **Various Sensors and Instrumentation**. Several sensors and other instrumentations for GTs and associated auxiliary systems have been developed through local firms for GT Ships based at Mumbai. Important ones are:-

(i) OSTK Temperature Sensor and Relay Box for 1241 RE GT Lub Oil System.

(ii) Scoop Valve Microswitch for 1241 RE GT sea water cooling system.

(iii) CGT Digital RPM Indicator for 1241 RE ships.

(iv) CGT Analog Indicator and the Additional Amplifier Unit for 1241 RE ships.

(v) Fuel Pressure Relay for GT Fuel system for 1241 RE ship.

(vi) MCT Pressure Switches for the GT / RG of 1241 RE / SNF / P-15 / Talwar, etc.

(vii) MCTB Pressure Switches for the GT / RG of 1241 RE / SNF / P-15 / Talwar, etc.

(viii) CDY Pressure Relays for GTG.

(ix) GTG Tachogenerator and Indicator for GTG.

(x) Level Relays of GT/RGLub Oil tanks.

(xi) Temperature relays for GT Lub Oil Temperature.

8. **Advanced GT Control System Management Techniques**. As seen from the above, logistics support of marine gas turbine is an extremely important aspect and with the inclusion of state of art equipment, this becomes even more challenging. For modern day equipment, traditional way of inventory management may not be the most optimum or effective way of management. We need to think 'out of the box' and make use of modern day Supply chain management techniques available in the commercial market. Some of the techniques being effectively utilised are:-

(a) **Performance Based Logistics (PBL)**. PBL is also known as Performance based life cycle product support system and considered to be cost effective with increased performance. It is based on delivery of defined performance outcome of platform / system instead of acquisition of goods and services. PBL based support system is based on long term performance agreement with the buyer. It optimises total system availability while minimising cost and logistics footprint. PBL mandates the OEM to deliver the required performance and does not go into the details of spares etc. As part of the PBL the vendor would be required to maintain a Min Stock Level

(MSL) of spares at bases and depots for given operational requirement and also cater for basic planned routines and overhauls. This is an established logistics method in US Navy where several aero engines and Weapon systems are being maintained using PBL.

(b) **Letter of Acceptance (LOA) Contract**. In order to reduce the lead time, recently, an agreement was signed between Navy and M/s Zorya that establishes long term pricing philosophy and justifies price escalation rates for procurement of equipment, spares and overhaul of equipment. This will help in reducing the present timelines as it obviates the requirement of any further CNC till the validity of the contract. The next step in this direction could be to sign a LOA contract of fixed value and time for purchase of spares. Presently, a similar LOA Contract for spares management of INS Jalashwa is being executed by IN and is based on 'Just in Time' concept. This contract includes depositing a mutually agreed amount with the supplier upfront, however, the spares would be demanded as per requirement throughout the validity of contract at the price decided in the beginning of the contract. This system precludes any excessive inventory for not so regularly used spares (spares whose requirement cannot be pre-empted) that are used for undertaking DR of specific defect. Such contracts take care of shelf life and non-moving inventory issues also.

Recommendations

9. **Gas Turbine Control System Depot (GTCSD)**. Setting up of organisation responsible for Gas Turbine Control system support system to ensure effective and efficient management chain, which not only acts as procurement and issuing agency, but also a technical hub for all GT ships and concerned organisations is the need of the hour. To achieve this, a separate organisation GTCSD (Gas Turbine Control System Depot), akin to WED, under administrative control of HQWNC/HQENC, (through respective GTTTs) may be made responsible for maintaining control system related inventory as well as undertake indigenisation of spares of GTAs/GTG along

with IU(W)/IU(E) as per requirements. Proposed organisational hierarchy of the GTCSD is placed at Fig 5.

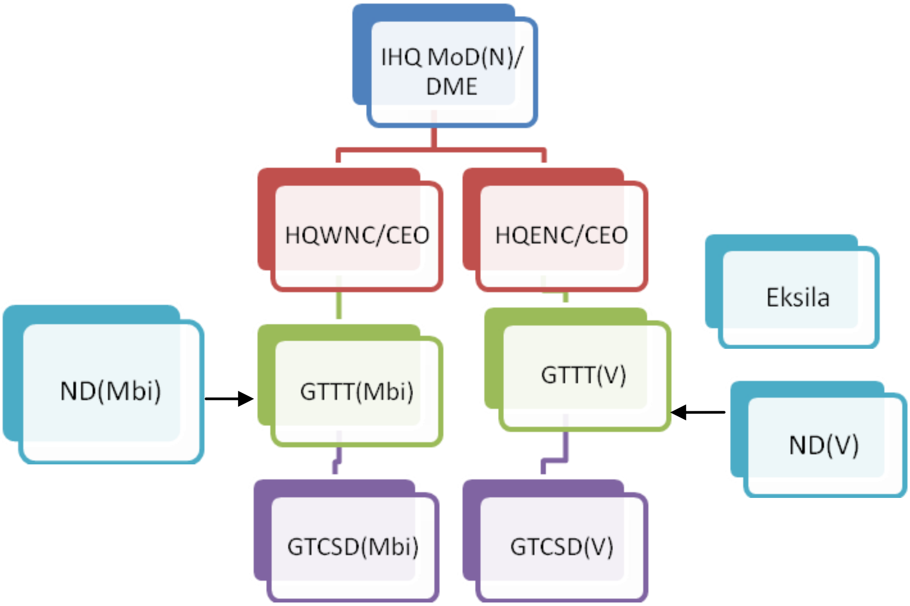

Fig. 5 Proposed Organisational Hierarchy of GTCSD

10. **Role of GTCSDs**. The proposed organisation should be responsible for procurement of control spares and equipment and act as backbone for life cycle support for GTAs. It will help in streamlining the entire procurement process and will have a considerable impact in reducing the timelines. It should also work in close association with Naval Dockyards and Eksila. It is envisaged that formation of GTCSDs will ensure effective and efficient spare management as by way of concentrated efforts for management of GTA/GTG spares. Mandate envisaged for GTCSDs are as follows:-

(a) Predicting requirements of spares engines and spare parts post collation of inputs from NDMbi)/ND(V) and Eksila.

(b) Initial provisioning.

(c) Re-provisioning as usage occurs.

(d) Identifying priorities in manufacture, repair & procurement and accelerating when necessary.

(e) Identifying delays in manufacture, repair and procurement and rectifying when necessary.

(f) Allocation and issue.

(g) Categorisation of spares as VED (Vital, Essential and Desirable) and as Critical/Not Critical.

(h) Self reliance through Indigenisation and overcome obsolescence.

(j) Documentation.

(k) Development of Test/Reference Equipment.

(l) Study pattern of failures to recommend modifications.

(m) Study inter-changeability of spares amongst different engines/ components

11. **Advantages Envisaged by forming GTCSD**. Advantages envisaged by having a separate inventory management system through formation of GTCSD are as follows:-

(a) Reduced Procurement Timelines though concentrated efforts and streamlined monitoring of spare utilisation.

(b) Hybrid approach of Inventory Management can be employed.

(c) Close liaison with Naval Dockyards and GTTTs will ensure that spares are demanded in time for routines and spares required for undertaking DR are demanded as per requirement.

(d) Priority for indigenisation can be decided as per requirement and criticality and cost of spare. This will aid in overcoming obsolescence of spares.

(e) Priority for procurement can be decided in case of funds crunch.

(f) Decision for repairing the defective module or replacing the same can be worked out with Dockyards and order can be placed accordingly.

(g) Close monitoring of dead inventory.

(h) Easy categorisation of spares as VED (Vital, Essential and Desirable) and as Critical/Not Critical.

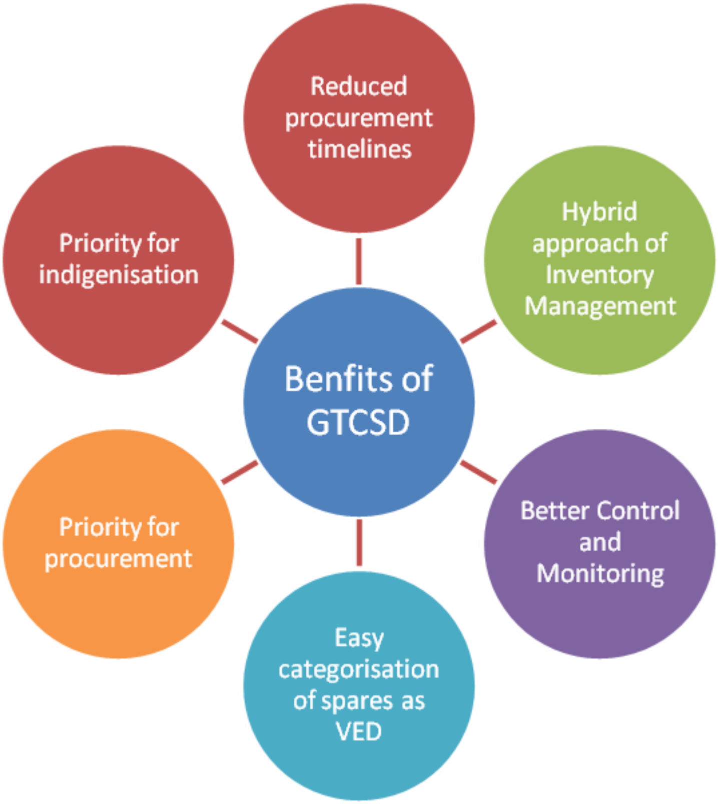

Fig. 6 Benefits by Formation of GTCSD

Conclusion

12. Gas Turbines are being exploited by IN for more than fifty years. Over the years, with the Indian Navy gaining experience in operation and maintenance, the frequency of failures has reduced. The GT however remains as demanding, unrelenting and uncompromising as ever. It is the correct time to take a quantum jump to the next level of optimum exploitation through better maintenance and streamlined logistics management of these power houses. Better maintenance and management of gas turbine control system will definitely be a added advantage for marine engineers to efficiently handle the change of responsibility *wrt* maintenance of gas turbine control system. With the development of technology in the local market and favorable government policies, impetus should be to encourage indigenisation to increase self-reliance in marine propulsion and enhance sustained reliable operational availability of Marine Gas Turbines of Indian Navy.

EMISSION NORMS, ALTERNATE FUELS AND *IN* ROADMAP

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Introduction

1. Over the past few decades, fuel consumption and emissions of harmful pollutants from international shipping has increased substantially. Ship emissions have been recognised as a growing problem for both scientists and environmental policy makers. Seagoing ships emit exhaust gases and particles into the marine boundary layer and significantly contribute to the total budget of anthropogenic emissions. The principal constituent of exhaust gases emitted from ships consists of CO_2, NO_X, SO_X, CO, volatile organic compound (VOC), hydrocarbons and particulate matter. The harmful emissions from ships have interrelated environmental impacts both on land as well as on the marine environment. The emission of these pollutants affects the radioactive balance of the atmosphere. Sulphur and nitrogen compounds emitted from ship oxidize in the atmosphere to form sulphate and nitrate, and thus contribute to acidification. Emissions of nitrogen oxides, carbon monoxide and VOC lead to enhanced surface ozone formation and methane oxidation, and thus affect the greenhouse warming.

2. The Indian Navy is presently in use of all three form of propulsion system namely Diesel engines, Steam and Gas Turbines. With majority of ships being propelled on Diesel engine and Gas turbines and Steam propulsion on downward trend of induction this paper concentrates on emissions and alternate fuels iro Gas Turbine and Diesel Engines. In the present scenario the Indian Navy does not monitor the emissions generated by the main engines of the ship. However, the International Maritime Organisation (IMO) vide Annexure VI of MARPOL regulation enumerates the limit/emission norms which need to be adhered by all sea going vessels. The International Maritime Organisation (IMO) began examining ship’s air pollution via its sub-organisation, the Maritime Environment Protection Committee (MEPC) in 1988. Consequently, a new air pollution addendum to MARPOL 73/78 was adopted in 1997– MARPOL 73/78/97

(International Maritime Organisation, 1997) to prevent ships' air pollution. It includes:-

(a) Emission standards for NO_X according to the power output of marine diesel engines and the required installation of exhaust gas cleaning systems.

(b) Use of alternate fuel.

(c) The syndicate has carried out literature survey of various research papers and books to determine an ideal solution to the ensuing problem.

Control of Combustion

3. Majority of IN warships are gas turbine/ diesel engine propelled. The combustion products from both the engines are very different from each other in composition primarily due to a huge difference in air to fuel ratio. In gas turbine there are mainly two different types of flames, which are as follows:-

(a) **Diffusion Flame**. In a diffusion flame, the fuel and oxidizer are separated at first. They mix through diffusion and the combustion occurs in that mixing zone at stoichiometric conditions [1][4].

(b) **Premixed Flame**. In a premixed flame the fuel and oxidizer are mixed prior to combustion which means that the combustion can occur at the mixing ratios present which could be either rich, lean or at stoichiometry [1][4].

4. Liquid fuels burn in gas form which means that the liquid first has to evaporate before the chemical reactions of combustion can occur. The smaller the droplet diameter, faster is the evaporation of the same. This in turn increases the probability to achieve complete combustion inside the combustion chamber. Due to heat losses at various places in the combustion chamber and improper atomization, incomplete combustion can occur. This will lead to emissions of CO, UHC and NO_X. The various measures which can be adapted to lower emission from a gas turbine are enumerated below:-

(a) Use of combined Fuel staging, air staging and selective non catalytic reduction reduces emissions by

50-70%. However, this entails major modifications in the combustor including burners with complex fuel control system and provides limited range of low emission operation [2].

(b) Use of water/steam injection in the flow path of the fluid prior entering into combustion chamber also reduces the NO_X generation by 40%, however this requires major modifications in the engine systems to facilitate usage of large amount of distilled water/steam. COSAG propulsion appears as a solution however it does not provide solution to the space constraints of a warship.

(c) Use of dry low Emission Combustion System. This system consists of a new fuel staged annular combustor, first-stage turbine nozzle, electronic staging controller, and fuel delivery system. The premixed combustor has a larger volume to achieve increased combustor residence time for complete reaction of CO and UHCs. The premixed combustion system uses parallel fuel staging, inlet guide vane modulation, and compressor bleed to maintain a nearly constant flame temperature over the engine operating range which ensures a lower NO_X emission. However this requires major modification in compressor rear frame and fuel control system [1].

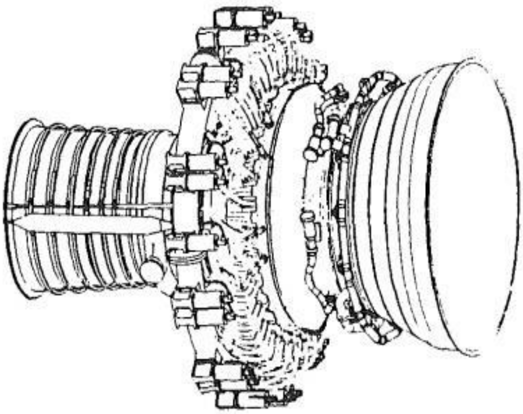

Fig. 1 Gas Turbine with dry low NO_X combustor [1]

5. On the other hand, the emissions from the diesel engines which are predominantly fitted onboard commercial vessels and many warships are higher when compared to a gas turbine. The various methods which can be adopted to reduce emission from these engines are as follows:-

(a) Common rail is a method to eliminate visible smoke from the exhaust, especially at low engine loads. Visible smoke generation is partly due to low injection pressure and striking of large fuel droplets on the hot surfaces during the combustion process. In this method, the fuel injection rate and injection pressure is controlled independently from the engine speed and load. Maintaining high pressure at lower loads prevents the formation of large fuel droplets during combustion and thus reduces visible smoke. This set-up and design allows individual control of injection timing and duration for optimized injection at different engine loading conditions.

(b) A major benefit of water injection is reduced NO_X emission. Injecting water increases cylinder pressure, due to added partial pressure of steam in the pre-combustion mixing process, and lowers flame temperature during the combustion phase. The flame temperature becomes lower and cooling losses are reduced with increased after ignition heat release. The three major methods of water injection are direct water injection, emulsified fuel, and fumigation. Water injection methods are well established technologies and are widely used [5]. However, this also requires major modification in the engine systems.

(c) Ceramic coating on the piston crown. Tests were carried out over three pistons; a standard metal piston and two pistons insulated with 0.5 and 1.0 mm thick ceramic coatings. The results indicated that the insulated engines showed improved performance in terms of the thermal efficiency and lower emissions. The thermal efficiency gain over the standard engine was 10 and 6% for thinner and thicker coatings, respectively. CO emissions were 30 and 60% lower for the insulated pistons. Also, a reduction by 35 and 40% for the HC emissions was achieved [7].

(d) Change in Diesel fuel composition has a direct implication on the combustion products, for example lowering the sulphur content lowers the SO_X emission however the cost of the fuel increases proportionally [6].

Exhaust Gas After Treatment

6. The various methodologies used for after treatment of gases are as follows:-

(a) **Exhaust Gas Recirculation (EGR)** Exhaust Gas Recirculation is an effective method for NO_X control. Re-circulated exhaust gas displaces fresh air entering the combustion chamber with carbon dioxide and water vapor present in engine exhaust and thereby lowers the effective air fuel ratio. The effective reduction in air fuel ratio affects exhaust emissions substantially. In addition, mixing of exhaust gases with intake air increases specific heat of intake mixture as a result reduction of flame temperature takes place. Thus combination of lower oxygen quantity in the intake air and reduced flame temperature reduces rate of NO_X formation reactions. Lower peak combustion temperature results in lower NOx production [6].

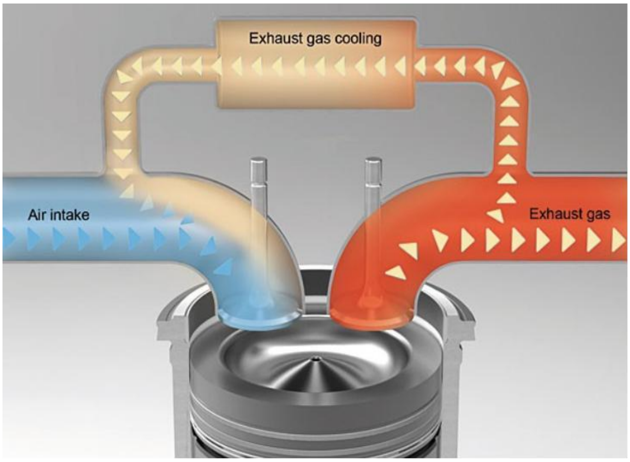

Fig 2 Exhaust Gas Recirculation [6]

(b) **Selective Catalytic Reduction (SCR)**. In this technology either ammonia or urea is continuously injected upstream of the catalyst. The catalysts convert the urea into ammonia and CO_2, the ammonia reacts with SCR catalysts and reduces NOx into N2 and CO2. The SCR catalyst is typically vanadium and titanium oxide mixture (V_2O_5 + TiO_2 + WO_3) coated on a ceramic honeycomb substrate of 200-400 cpsi. SCR system requires large space and additional tank to carry aquatic urea or ammonia.

(c) **Diesel Particulate Filters (DPF)**. A diesel particulate filter removes soot particles from the exhaust gas. This is done by directing the exhaust gas through the filter substrate, a fine pore ceramic structure with porous walls inside the filter. Soot particles are deposited on the walls of the channels as the exhaust gas passes through the structure.

(d) **Diesel Oxidation Catalyst (DOC).** It consists of a monolith honeycomb substrate coated with platinum group metal catalyst, packaged in a stainless steel container. As the hot gases come in contact, several exhaust pollutants are converted into harmless substances. The diesel oxidation catalyst is designed to oxidize carbon monoxide, gas phase hydrocarbons, and the SOF fraction of diesel particulate matter to CO_2 and H_2O.

Alternate Fuels

7. The increasing difficulty in sustaining the supply of petroleum products and the associated problems of pollution lead to a major impetus for research in alternative fuels. Out of the three specific alternatives viz a viz solids, liquids and gaseous fuels, considerable work has been done on gaseous and liquid fuels. Liquid fuels such as varieties of vegetable oils, bio-diesel, dimethyl ether, Synthesis gas, alcohols and gaseous fuels such as compressed natural gas (CNG), Liquefied petroleum gas (LPG), methane, biogas and hydrogen were found to be promising for use in CI engines.

Straight Vegetable Oil (SVO)

8. Pure vegetable oil should not be used directly in diesel engines. The published engineering literature strongly indicates that the use of SVO will lead to reduced engine life. This reduced engine life is caused by the build-up of carbon deposits inside the engine, as well as negative impacts of SVO on the engine lubricant. Both carbon deposits and excessive build-up of SVO in the lubricant are caused by the very high boiling point and viscosity of SVO relative to the required boiling range for diesel fuel. So, they have to be modified to bring their combustion related properties closer to those of diesel. Such a fuel modification is mainly aimed to reduce the viscosity to eliminate flow/atomization related problems. Four techniques can be used to reduce the viscosity of vegetable oils; namely heating, dilution/blending, micro-emulsion, and trans-esterification [9][12].

9. The problems attributed to high viscosity and poor volatility of straight vegetable oils is due to large molecular weight and bulky molecular structure. High viscosity of vegetable oils (30–200 cSt at a temperature of $40^{o}C$) as compared to mineral diesel (2 cSt at the same temperature) lead to unsuitable pumping and fuel spray characteristics. Larger size fuel droplets are injected from injector nozzle instead of a spray of fine droplets leads to inadequate air fuel mixing, poor atomization, lower volatility, and inefficient mixing of fuel with air contribute to incomplete combustion. This results an increment in higher particulate emissions, combustion chamber deposits and gum formations [9][12].

10. The viscosity of vegetable oils can be reduced by increasing its temperature (using waste heat of the exhaust gases) and thereby eliminating its effect on combustion and emission characteristics. Vegetable oils have energy density, cetane number, and heat of vaporization comparable with mineral diesel. In addition, they are biodegradable, non-toxic, and have a potential to significantly reduce pollution. Vegetable oils and their derivatives lead to substantial reductions in emissions of sulphur oxides, carbon monoxide (CO), poly aromatic hydrocarbons (PAH), smoke and particulate matter (PM). Moreover the effect of this emission is insignificant,

since carbon dioxide (CO_2) emitted during combustion is recycled in the photosynthesis process in the plants. Trans-esterification is well accepted and best suited method without significant long-term operational and durability issues. However, this increases the cost of processing because of the trans-esterification reaction involving chemical and process heat inputs [9][12].

Vegetable oil	KV @ 38°C (mm^2/s)	Density @ 15°C (kg/l)	Cetane number	Heating Value (MJ/kg)	Cloud Point (°C)	Flash Point (°C)
Corn	34.9	0.9095	37.6	39.5	-1.1	277
Cottonseed	33.5	0.9148	41.8	39.5	1.7	234
Crambe	53.6	0.9044	44.6	40.5	10	274
Linseed	27.2	0.9236	34.6	39.3	1.7	241
Peanut	39.6	0.9026	41.8	39.8	12.8	271
Rapeseed	37.0	0.9115	37.6	39.7	-3.9	246
Soybean	32.6	0.9138	37.9	39.6	-3.9	254
Sunflower	33.9	0.9161	37.1	39.6	7.2	274
Palm	39.6	0.9180	42.0	-	31.0	267

Table 1 Properties of Vegetable Oil

Bio-Diesel

11. Bio-diesel is an environmental friendly fuel that can be used in any engine running on diesel without modification. Bio-diesel is better than diesel fuel in terms of sulphur content, flash point, aromatic content and biodegradability. There has been renewed interest in the use of vegetable oils for making bio-diesel due to its less polluting and renewable nature as against the conventional petroleum diesel fuel. Due to its environmental benefits, the share of bio-diesel in the automotive fuel market is growing fast. Bio-diesel is fatty acid ethyl or methyl ester made from virgin or used vegetable oils (both edible and non-edible). The main commodity sources for bio-diesel in India can be non-edible oils obtained from plant species which bear seeds rich in oil such as Jatropha Curcas (Ratanjyot), Pongamia Pinnata (Karanj), etc [9][12][21].

12. The characteristics of bio-diesel are close to diesel fuels, and therefore bio- diesel becomes a strong alternative to replace the diesel fuels. The conversion of triglycerides into methyl or ethyl esters through the trans-esterification process reduces the molecular weight to one-third that of the triglyceride reduces

the viscosity by a factor of about eight and increases the volatility marginally. Bio-diesel has viscosity close to diesel fuels. These esters contain 10–11% oxygen by weight, which may encourage more combustion than hydrocarbon-based diesel fuels. Bio- diesel has lower volumetric heating values (about 12%) than diesel fuels but has a high cetane number and flash point. The high flash point attributes to its lower volatility characteristics.

13. Such diesel substitute requires very little or no gas turbine modifications up to 20% blend and minor modification for higher percentage blends. It can be blended at any level with petroleum diesel to create a bio-diesel blend or can be used in its pure form. It can be stored just like the diesel and hence does not require separate infrastructure. The use of bio-diesel in gas turbine results in substantial reduction of un-burnt hydrocarbons (UHC), carbon monoxide and particulate matters without reducing the output power significantly.

Synthesis Gas (Syngas) Derived from Biomass

14. Biomass gasification has attracted the highest interest among the thermo- chemical technologies as these offer higher efficiencies in relation to combustion, Biomass gasification can take place at higher temperatures and produces a mixture of gases with H_2. The synthesis gas includes mainly H_2 and carbon monoxide (CO), which is also called syngas. Biomass can be converted to bio-syngas by non- catalytic, catalytic and steam gasification processes [9][8].

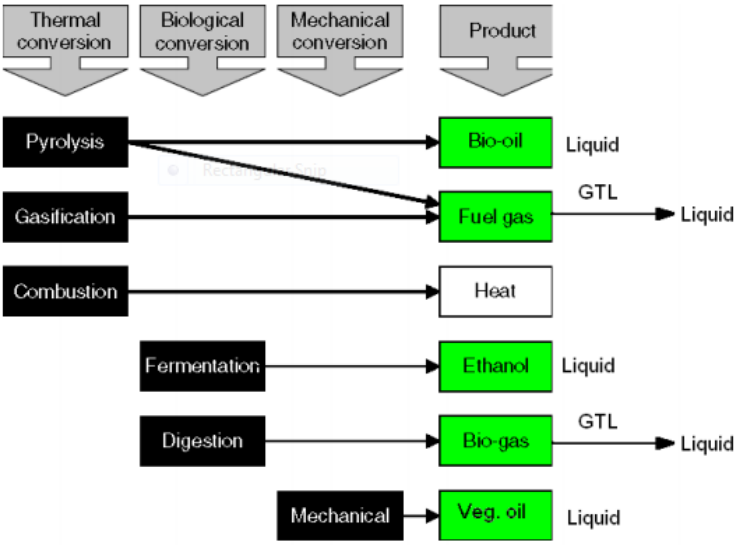

Fig. 3 Conversion processes and products [9]

Alternate Fuel for Diesel Engine

15. The experimental setup at Indian Naval Academy (INA) was used for the conduct of the experiment consisting of a mechanically governed constant speed, stationary single cylinder Kirloskar Engine 5HP (3.7kW). The engine is loaded mechanically using rope and brake drum. Exhaust gas analysis was undertaken by using a Five Gas Analyser procured from M/s Manatec, Pondicherry. Four varieties of Biodiesel namely Palm oil, Jatropa oil, used cooking oil and Soyabean oil were obtained from M/s SVM Agro, Nagpur and were subjected to test. The effect of biodiesel on specific fuel consumption, brake thermal efficiency and exhaust gas temperature was analyzed. The various blends used in the experiments are listed below: -

(a) B0- Conventional Diesel.
(b) B5- 5% Biodiesel and 95 % Conventional Diesel
(c) B10- 10% Biodiesel and 90% Conventional Diesel
(d) B15- 15% Biodiesel and 85% Conventional Diesel
(e) B20- 20% Biodiesel and 80% Conventional Diesel
(f) B30- 30% Biodiesel and 70% Conventional Diesel

16. Observations of the experiment are as follows:-

(a) **Specific Fuel Consumption (SFC)**. Specific fuel consumption is the measure of the mass flow rate of fuel consumed per unit brake power output of the engine. The graphs obtained for different blends of biodiesel vis-a-vis conventional diesel indicates that the B20 blend of biodiesel for all varieties of biodiesel is the best blend for low SFC in the load range of 40-70%. The reason could be the decrease in the density of the specific gravity of the blend, which is directly related to the SFC. Among the various varieties of biodiesel, Jatropha Oil gives the lowest SFC. It can also be observed that the deviation of SFC for different blends of biodiesel and conventional diesel is less than 5%.

(b) **Brake Thermal Efficiency (BTE)**. Brake thermal efficiency is the ratio of the brake power produced by the engine to the energy content of the fuel. The energy content in the fuel is dependent on the mass and the calorific value of the fuel. It was observed that the brake thermal efficiency of the B20 blend was the highest in the load range of 40-60%. However, the deviation wrt conventional diesel is very marginal (approx 4%). Increase in the brake thermal efficiency can be attributed to the decrease in the calorific value of the blend. Further, Soyabean oil gave the best BTE among the four varieties of biodiesel.

(c) **Exhaust Gas Temperature (EGT)**. Exhaust gas temperature is an indication of the combustion performance of the engine. EGT was observed to be almost same for all blends of biodiesel. EGT for conventional diesel was much lower compared to all the other blends of biodiesel. This clearly brings out the better combustion quality of the conventional diesel.

17. **Exhaust Emissions**. Variation of exhaust emission with varying load measured for various blends of biodiesel is as follows: -

(a) **CO_2 Emissions**. CO_2 emissions (%) were measured for all blends of biodiesel and conventional diesel. CO_2 emissions for all varieties of biodiesel were observed to be lesser than that of the conventional diesel. Among all the blends of biodiesel, B10 and B15 blends were observed to be the blends with the lowest emissions. Reduction in CO_2 emissions indicates better combustion characteristics as compared to conventional diesel.

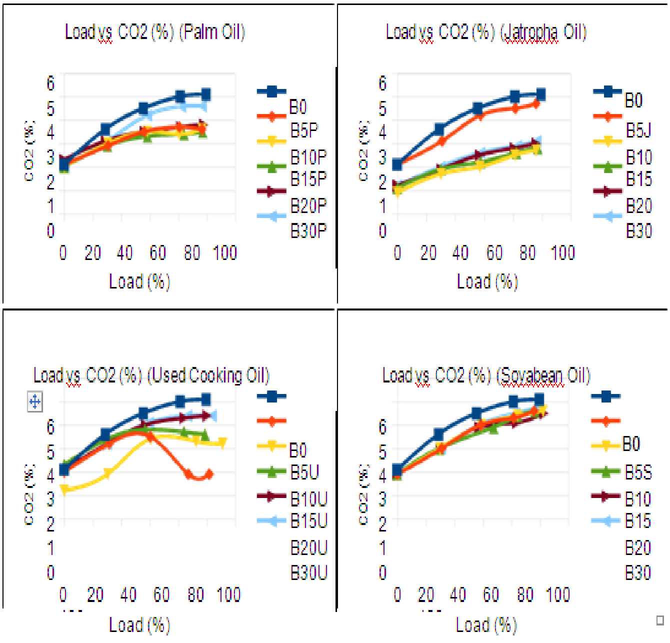

Fig. 4 Load vs CO_2 (%) for Biodiesel Blends [21]

(b) **<u>CO Emissions</u>**. CO emissions reduce to a greater percentage for all blends and all varieties of biodiesel as compared to conventional diesel. It has been observed that B10 and B15 blends of biodiesel are most suited for reduction of CO emissions. B30 blend of Soybean oil showed the minimum percentage of CO emissions compared to all the other blends. Reduction to CO indicates complete combustion of the biodiesel blend as compared to conventional diesel.

(c) **<u>Hydro Carbons (HC)</u>**. Biodiesels have long chain fatty acids, which increases the HC content in the emissions. The HC emissions for all biodiesel blends except for Palm Oil (B10, B15, B20) were observed to be higher than that of the conventional diesel.

(d) **NO_x Emissions**. NOx emissions for all blends of biodiesel were found to be more compared to the conventional diesel. The disadvantage of using a biodiesel is the increase in the NOx emissions. The same trends were observed in the literature survey undertaken by the group prior to the project. Reduction in NOx emissions can be done by using techniques such as Exhaust Gas Recirculation (EGR).

18. Following are the inferences drawn from the experimental study on various blends of biodiesel: -

(a) Biodiesel with blends upto B30 can be safely used in the engine without the need for any modifications to the system. However, as biodiesel is a good solvent, the engine was operated with diesel for ten minutes prior to and post the experiments, so as to ensure that there is no trace of biodiesel in the system.

(b) B20 is the best blend for improving the engine performance parameters, however there is no appreciable change in the performance parameters of the engine. This clearly indicates that the biodiesel neither deteriorates nor improves the performance of the diesel engine.

(c) There is an appreciable reduction of CO (%) and CO_2 (%), however the NOx and HC emissions were observed to be on the higher side. B15 and B20 blends were the best blends observed for reduction of emissions.

19. A similar trial using B20 blend of Jatropha oil was undertaken in Eastern Naval Command during IFR 16 on FIC T-307 and T-311 simultaneously. Similar results were obtained and are discussed in HQENC letter EG/3000/DIESEL dated 25 Jan 16. However, the analysis of emissions were not undertaken during the trials onboard the FICs.

20. Since NOx emissions were observed to be on the higher side during trials at INA, hence another experimental study to analyze the effect of Exhaust Gas Recirculation whilst using biodiesel (blends of cooking oil) was undertaken. The schematic diagram of experimental set up is shown is Fig 11.

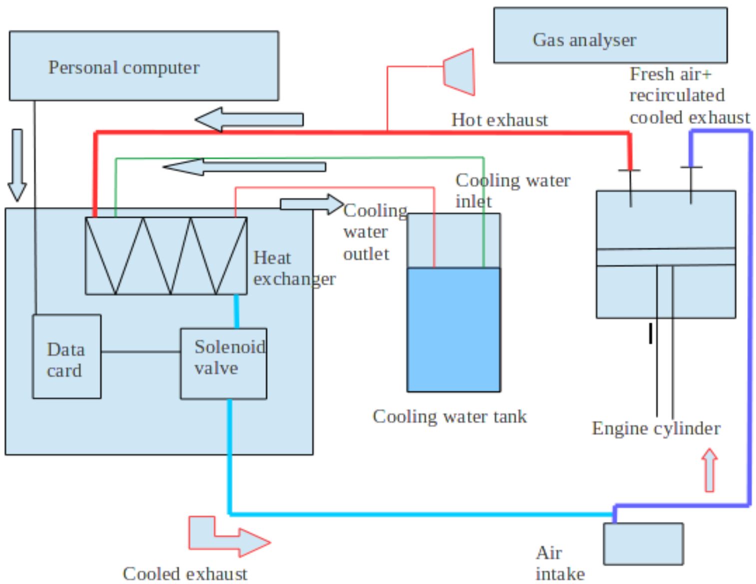

Fig. 5 Schematic diagram of experimental setup

21. The exhaust gas coming out of the engine is passed to an EGR cooler. The exhaust gases from the EC after cooling are passed via valve and digital manometer. The digital manometer is provided in order to find the amount of exhaust gas flow (when the EGR control valve is closed) and valve for controlling the flow. The digital manometer operates with in the temperature range of 10-50^{O}C; this is the reason for cooling the exhaust gas after the EGR system. In the main exhaust line a tapping is provided for EGR system. The exhaust gas from the tapping via a valve and is passed to the EGR cooler, where the exhaust gas is cooled before sending it to the engine. A digital manometer is provided at the inlet manifold of the engine in order to know the flow of exhaust gas to the engine. The specification of engine, load bank and exhaust gas analyser is mentioned in table 2, 3 and 4 respectively.

Ser	Specification	Parameter
(a)	BHP	10kWh
(b)	Speed	1500 rpm
(c)	Manufactured by	Shriram Diesels India
(d)	Engine type	Constant speed diesel engine
(e)	Fuel oil	High speed diesel
(f)	Lube oil	SAE 30/40
(g)	Method of starting	Manual cranking
(h)	Type of ignition	Compression ignition
(j)	Class of governing	B1
(k)	Method of loading	Load bank

Table 2 Engine Specifications [7]

Ser	Specification	Parameter
(a)	Make	Mahesh electrical equipment
(b)	Type	Lamp / resistance/ capacitor / induction load
(c)	Input	230V/440V
(d)	Capacity	60A
(e)	Frequency	50Hz
(f)	Serial Number	276
(g)	Model	Port

Table 3 Load bank specifications [7]

Ser	Measurement Parameter	Range	Resolution
(a)	CO	0-15%vol	0.01%
(b)	CO_2	0 - 19.9% vol	0. 10 %

(c)	HC	0 – 20,000 PPM	1PPM
(d)	O_2	0 – 25% vol	0.0 1 %
(e)	NOx	0 - 5000 PPM	1 PPM
(f)	Measuring gas intake	3 litres / minute	
(g)	Warm-up time @ 25^{o}C & above	< 3 minutes	
(h)	Power supply	230V AC Single phase, 50-60 Hz	
(j)	Power	25W	

Table. 4 Specifications of the Gas Analyser [7]

Procedure

22. The effect of EGR on the reduction of NO_X emissions was studied by varying the exhaust gas mass flow rates for different blends of biodiesel (B5, B10 and B15 blend of waste cooking oil) as well as pure diesel. The procedure followed for analysis was as follows:-

(a) Effect on variation of exhaust mass flow rates for a particular blend at different load conditions.

(b) Effect on variation of load on different blends of biodiesel and diesel at constant exhaust mass flow rates.

(c) Effect of variation of exhaust mass flow rates on different blends of biodiesel at a particular load.

Results Obtained

23. **Effect on NOx Emission at Different Exhaust Mass Flow Rates**. The effect on the reduction of NOx emission were studied for different blends of biodiesel by varying the exhaust

mass flow rates, in order to ascertain the blends of cooking oil biodiesel that gives the best reduction of NOx emissions. The experimental reading indicated that NOx emission was lowest at 75% load for all blends of biodiesel and all mass flow rates of exhaust. Reduction of 58.76%, 58.4% and 61.66% for B5, B10 and B15 blends respectively were observed. The possible reason may be the reduction in the quantity of O_2 molecules available for combustion inside the engine cylinder [6].

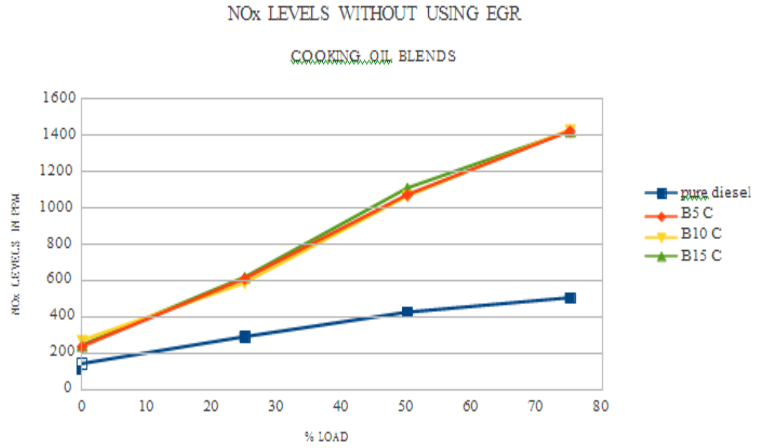

Fig. 6 NO_x level for different blends without using EGR [7]

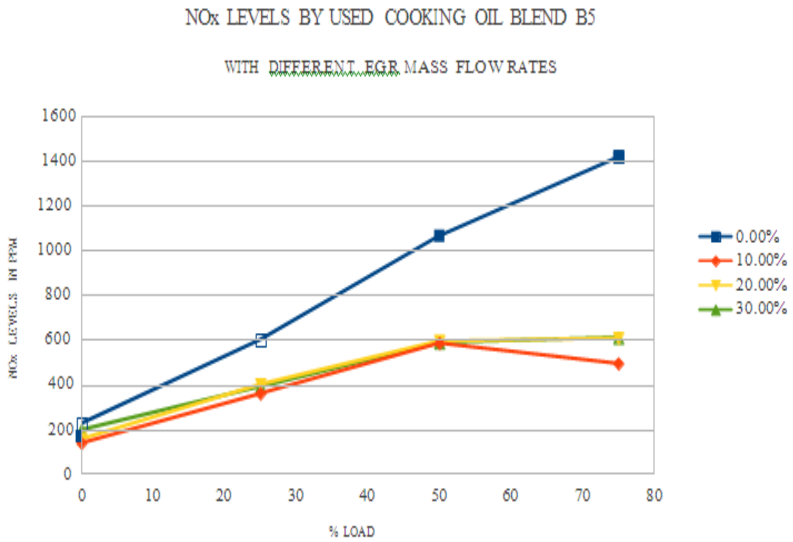

Fig. 7 NO_x level for B5 blend for different mass flow rate of exhaust gas [7]

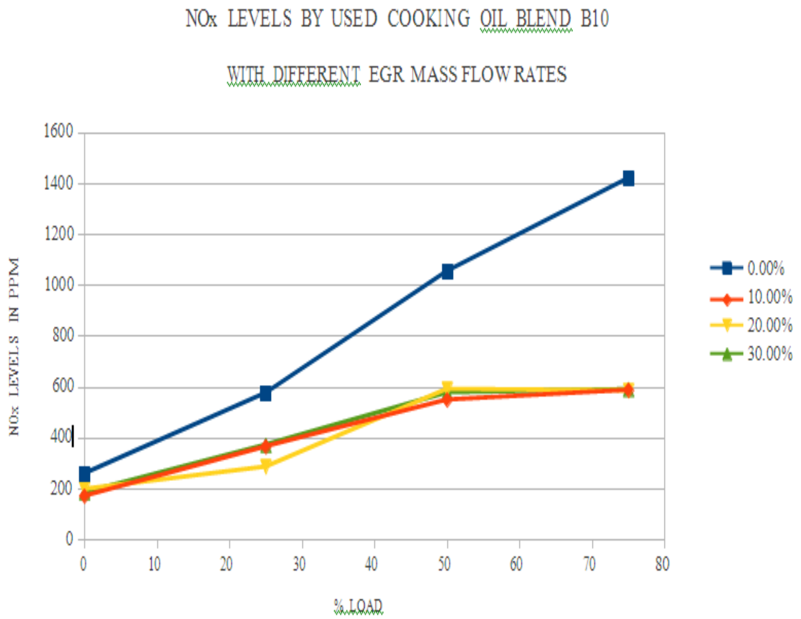

Fig. 8 NO_x level for B10 blend for different mass flow rate of exhaust gas [7]

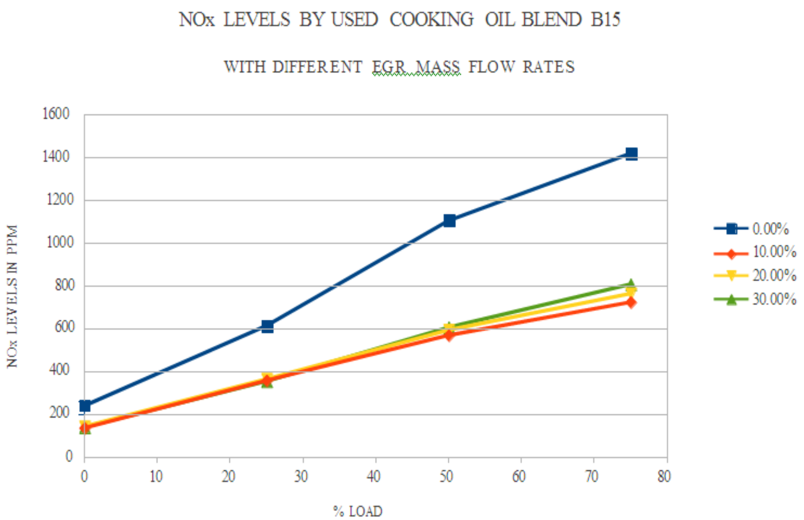

Fig. 9 NO_x level for B15 blend for different mass flow rate of exhaust gas [7]

24. **Comparison of Different Blends at a Fixed Exhaust Mass Flow Rate**, Reduction of NO_X emission for different blends of biodiesel (B5, B10 and B15) and pure diesel were compared for a particular exhaust mass flow rate. NO_X emission were observed to be low for pure diesel for all exhaust mass flow rates. NO_X emission for blend B5 was observed to be lowest for cooking oil biodiesel [7].

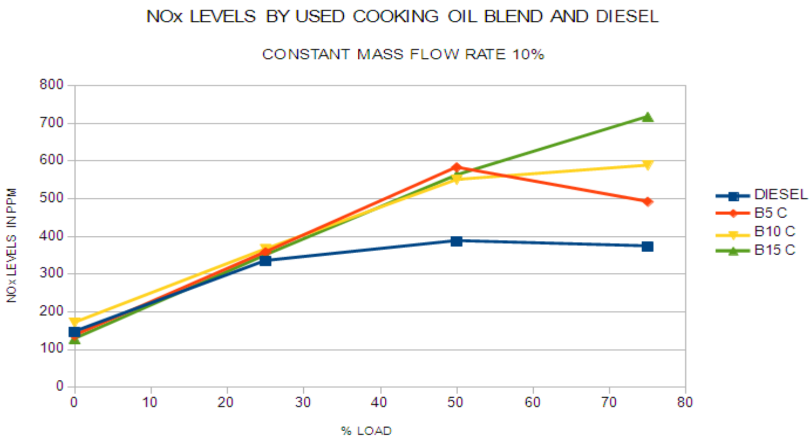

Fig. 10 NO_x level for different blend at 10% mass flow rate of EGR [7]

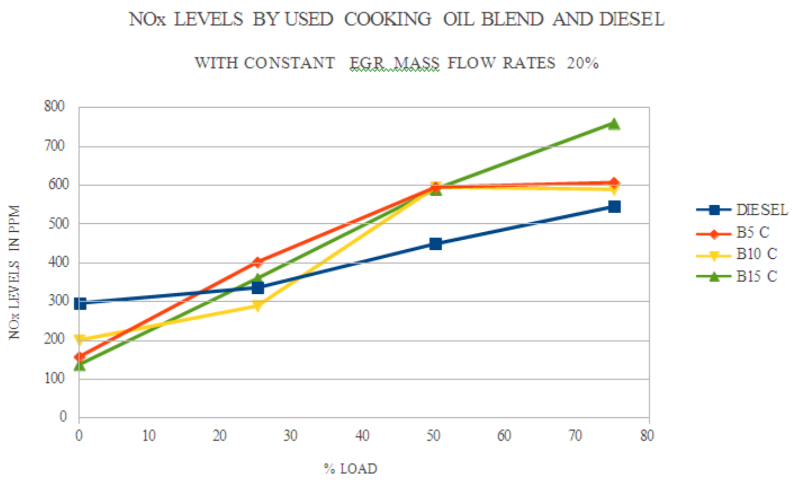

Fig. 11 NO_x level for different blend at 20% mass flow rate of EGR [7]

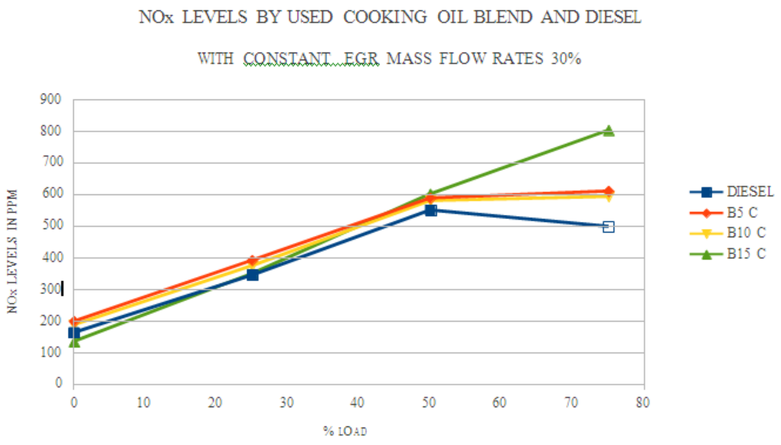

Fig. 12 NO_X level for different blend at 30% mass flow rate of EGR [7]

25. **Comparison of Reduction of NO_X Emission at Different Load**. Comparison of different blends of biodiesel and pure diesel at a particular load for different exhaust mass flow rates was studied. Comparison shows that the NO_X emissions are lowest for pure diesel at all loads and at all exhaust mass flow rates as compared to the blends of biodiesel. However, NO_X emission increases as the load is increased, due to an increase in the temperature which is favorable for the formation of NOx [7].

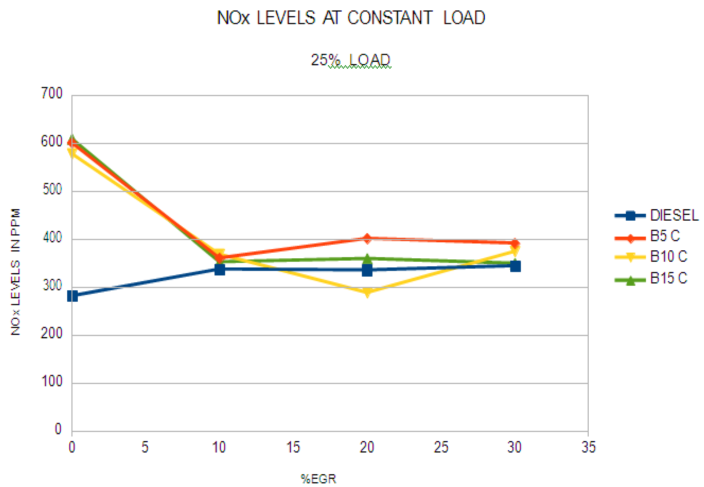

Fig. 13 NO_X level for diesel and different blends of biodiesel at 25% load [7]

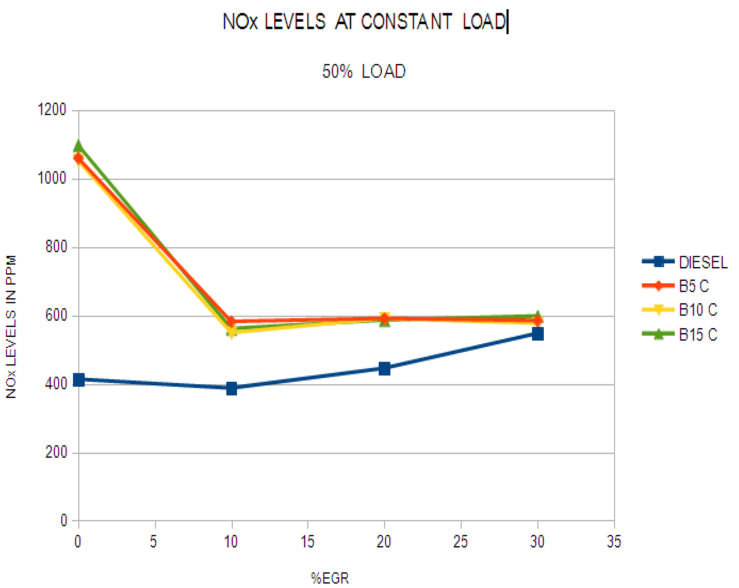

Fig. 14 NO_X level for diesel and different blends of biodiesel at 50% load [7]

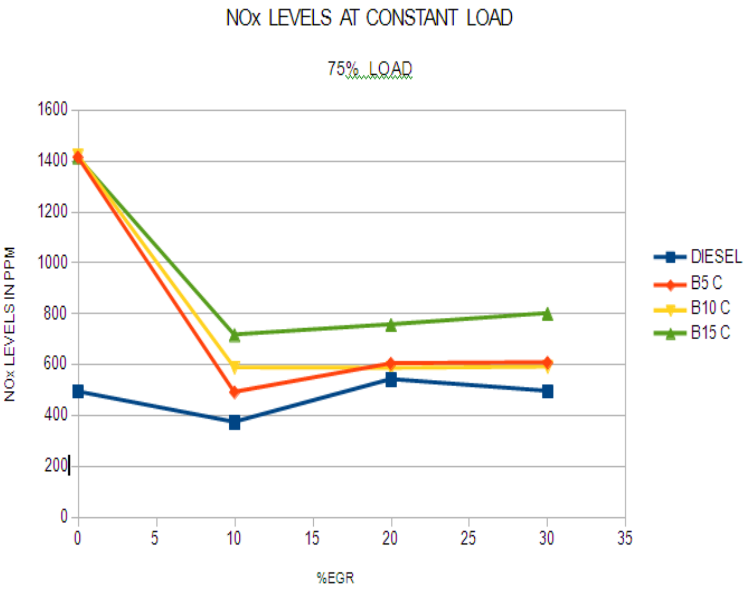

Fig. 15 NO_X level for diesel and different blends of biodiesel at 75% load [7]

26. The above experimental results indicate reduction of NO_X for all loads and exhaust mass flow rates as compared to the emission without use of EGR. Reduction of NO_X emission by approx 59% was observed during the study. This proves that EGR is a promising technique that can be used to reduce NO_X emission. EGR need to be designed using few key parameters like percentage of recirculation, pressure difference between the exhaust entering the cylinder and the intake air and the peak pressure at which engine operates.

Economic Aspect

27. Considering the price of conventional diesel at Rs. 50 per litre (at the time of conduct of experiment) and an ideal blending concentration of 20% by volume, a comparison based on economic aspect of usage of bio-diesel is as follows: -

Fuel	**Cost per litre**	**Cost per litre of B20 blend**	**% increase in cost wrt Conventional Diesel**
Conventional Diesel	50	-	-
Palm oil bio diesel	90	58	16 %
Jatropha oil bio diesel	135	67	34 %
Used cooking oil bio	100	60	20 %
diesel			
Soyabean oil bio diesel	125	65	30 %

Table. 5 Cost Comparison [21]

28. A significant increase in fuel cost has been observed in case of bio-diesel. Palm oil blends are found to be cheaper as compared to other varieties of bio-diesel. Bio-diesel costs are likely to decrease in future with setting up of mass bio-diesel processing plants and with increasing awareness.

Alternate Fuel for Gas Turbine

29. The addition of bio-diesel such as soya methyl ester, canola methyl ester, and recycled rapeseed methyl ester in JET-A fuel for gas turbine have reduced the static thrust and specific fuel consumption, and increased thermal efficiency. The turbine inlet temperature and exhaust gas temperature for all fuels do not show significant changes with the fuel type. CO and NO emission decrease when bio- diesel was used. The bio-diesel– JET-A blends appear promising, while emitting the least amount of pollutant with no significant reduction in static thrust. Higher thermal efficiencies with pure bio-diesel may be attributed to lower equivalence ratios (leaner fuel/air mixtures) and more complete combustion due to the presence of extra oxygen in the bio-diesel. Furthermore, the operation of the turbine with the products of a leaner mixture approaches to the air standard cycle [8].

GTL Fuel from Bio Mass

30. Gas-to-liquid is a process in which gases containing light hydrocarbons are converted into liquid products by binding the short and light hydrocarbons into longer chains. The first method for achieving GTL was the FTS (Fischer Tropsch Synthesis). Synthesis Gas (syngas) can be produced through gasification of biomass. Syngas can in turn be converted into different sorts of fluid fuels through the FTS process [8].

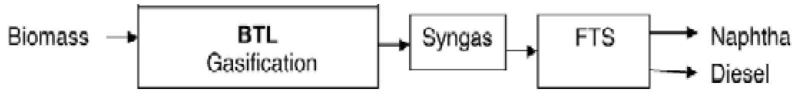

Fig. 16 FTS process [7]

31. The main reaction, from gas-to-liquid, is performed in a flow reactor, at temperatures ranging from 180-360°C and pressures up to 45 atm. The products from this process come in a wide range, from C 1 to C 100 and even higher hydrocarbon chains. The reaction can also produce oxygen containing substances as alcohols, ketones and carbolic acids as well as - at higher temperatures - benzene and other cyclic hydrocarbons

(aromatic compounds). The gasoline produced through FTS cannot directly be used in modern ignition engines because the contents of olefins are too high and the octane number is too low. The product can be used by only adding one production step, where the yield of diesel fraction is radically improved. This is done by focusing the production on paraffin waxes or FTS of syngas from gasification of biomass into SDF (synthetic diesel fraction). SDF has a high cetane number and excellent ecological characteristics; it represents almost pure paraffins containing very few aromatic compounds. It has a higher hydrogen content than standard diesel fuel, hydrogen available in the syngas has a much higher flame propagation speed than the other components, i.e., CO and CH_4, which gives better flame stability and as a result SDF burns better and emissions of CO, NO_X and UHC is much lower. The reductions are 6-18 % NO_X, 18-91 % CO and 40-63 % UHC [8].

Properties	FT Diesel	Diesel
Composition, C, H, O, wt %	85, 15, 0	84-87, 13-16, 0
Density @ 20°C (kg/L)	0.760	0.831
Viscosity @ 20°C (mm^2/s)	3.276	3 - 8
Boiling point (°C)	150 - 350	160 - 380
Freezing point (°C)	-2	<0
Lower heating value (MJ/kg)	43.9	42.6
Flash point (°C)	74	74
Stoichiometric A/F, (by wt)	14.7	14.7
Cetane number	74.8	>45
Aromatics (vol. %)	0.1	~35
Sulfur (wt %)	<0.00005	<0.2

Table. 6 Properties of FT Diesel and Diesel

IN **Roadmaps**

32. The use of vegetable oil in IC engine is not something new. Its usage dates back to 1900 when Rudolph Diesel used peanut oil as engine oil. The major differences between diesel fuel and vegetable oil are that the latter has significantly higher

viscosities and moderately higher densities, lower heating values and higher air fuel ratio. These specific issues can be circumvented by blending the vegetable with conventional diesel in varied proportion. The syndicate carried out a detailed literature review and tried to suggest suitable fuels which have properties similar to conventional fuel and also aids in reduction of pollution/emission. Whilst studying each class of alternative fuels it emerged that these fuels may find its usage on marine platforms but comes with certain specific issues such as storage of these fuels, transportation, specific thermo physical properties, ease of production, changes in engine design and other engine parameters. However, the experimental data obtained from the test conducted at INA and the trials onboard FICs, suggest that the usage of bio-diesel (blend of vegetable oil and diesel oil) may be considered as a viable alternative fuel with minimum/no change in existing systems onboard. The various vegetable oil which can be used are Jatropha oil, used cooking oil, Soyabeen oil and palm oil. However, the major problem encountered during the trials with these fuels was the emission of NO_X. The second experimental test undertaken at INA with EGR indicates reduction of NO_X for all loads and exhaust mass flow rates as compared to the emission without use of EGR. It is recommended that initials trials may be carried out at INS Shivaji and INS Eksila for diesel engine and gas turbine respectively using various blends of bio-diesel for a duration of about 100-200 hrs, the results obtained to be compared with the same engines running on conventional diesel. Post successful trials the use of bio-diesel and EGR be undertaken on a ship for a complete operational cycle to observe the long term effects/benefits of bio-diesel. Post completion of operational period any shortcomings observed during the overhaul of the machinery may be liquidated and the use of bio- diesel may be implemented on large scale in navy. However, it will also involve installation and close monitoring of emissions through exhaust gas analyser for engine running on bio-diesel.

Conclusion

32. The requirement for shifting to another fuel has emerged based on certain premises namely availability of natural resources for production of conventional fuels, harmful emissions from conventional fuels and adherence to emission

norms. The study by the syndicate suggest that usage of biofuels with suitable retreatment of exhaust such as exhaust gas recirculation to avoid NO_X and HC pollutants emission will be a suitable solution and can be used on IN platforms. Though the experiments are still underway to completely eliminate the blending of vegetable fuels with diesel, but still this technology can be adapted in future in our naval platforms.

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HARNESSING INDIGENOUS MANUFACTURING CAPABILITIES

Cdr A Senthil Kumar

"*We had set up the goal of self-reliance some 50 years ago. But still, it is unfortunate that we are importing more than 70 per cent of our defence equipment. We cannot allow this to happen. It is both shameful and dangerous*"

- An Ex Indian Defence Minister

Introduction

1. India, with its strong Non Alignment and democratic values, has always maintained the status as a responsible and peaceful nation. However, changing dynamics in the multi-polar world, have positioned India at the cusp of executing a dominant and pro-active role in world scenario, commensurate to its size and potential.

2. Towards achieving the above goal, the importance of being self-reliant in the defence sector needs no emphasis as it is not only of critical strategic and national importance but also an essential component of the national power. In six decades since independence, the country has made significant progress in achieving this goal. However, much remains to be done and that progress needs to be accelerated by harnessing our national capability in all its forms.

3. The future battle space will be shaped by technology and technological superiority will determine the outcome of future battles. It is therefore essential that technological self-reliance remains the mantra for the future and a collective national effort is necessary to be initiated to achieve this in the quickest possible time ensuring that technological developments are commensurate with our desired military capability.

4. Capacity Building process in the Armed Forces proceeds along a well crafted perspective plan which determine the capability sought by the Armed Forces, which in-turn drive the procurement of platforms and equipment and the technology

required to attain this capability. The plans focus on bridging the capability gaps and building force levels to ensure that the Armed Forces are optimally structured, equipped and weaponised to achieve the desired combat potential across the entire spectrum of conflict.

5. Induction of new weapon systems is cost and time intensive. Building complex platforms like ships, submarines, tanks and fighter jets has a long lead time which is constantly challenged by the race to keep-up with the relentless march of technology. It is therefore imperative that the long term requirement of capability be identified and understood for appropriate technology to be developed indigenously. The technical sophistication of forces, units, weapon systems and equipment is a reflection of the indigenous Defence Industrial Base (DIB) capability and a weak DIB, results in heavy dependence on foreign supplies, which impacts both economy and the operational readiness.

6. Indian industry has made rapid strides in recent times. Developing latest technologies, providing state-of-the-art products to the customer and adopting best practices in management has enabled it to not only hold their own in the global arena but also contribute to India’s emerging status as an economic powerhouse. This coming of age of the Indian industry must find expression in the defence sector as well. Regular interaction between the MoD, individual services, industries is the need of the hour and a growing consensus on the need for greater industry participation in defence sector is of paramount importance.

Situation Post-Independence

7. Defence spending from 1947 to 1960 remained low, at less than 2 per cent of the country’s GDP. The defeat post 1962 Chinese incursion, duly accentuated by lack of military equipment represented a watershed moment for the Indian Defence policy, resulting appropriately, in a focused attention of this vital sector. Comprehending that self-reliance in Defence is of vital importance for both strategic and economic reasons, building a strong DIB therefore, aptly became one of the important guiding principle for theGovernment since Independence.

8. Ordnance Factory Boards (OFBs) and Defence Public Sector Undertakings (DPSUs) rapidly expanded and commenced manufacturing a large variety of military hardware from rifles to tanks and aircrafts. The focus however, remained on production, rather than on design and development. DIB remained an exclusive domain of public sector, until the production of components, assemblies and sub-assemblies was opened to the private sector in 1991. The role of private companies remained however, was restricted to producing low end components, albeit, contributing marginally to the DIB.

9. Government of India over the years assiduously built up capabilities in Defence R&D, Ordnance factories and DPSUs to provide our Armed forces with weapons/ ammunition/ equipment/ platforms and systems that they need for the defence of our country. Industrial and technological growth in the past decades made it possible to achieve this objective by harnessing the emerging dynamism of the Indian industry along with the capabilities available in the academia as well as research and development institutions. However, subsequently, this development process remained restricted to the OFB and DPSUs with the Defence Research and Development Organisation (DRDO) charted with the responsibility of research and development. A two decade long neglect post-independence has therefore had a major impact on the DIB, forcing India today to seek Defence technology from the developed world

Major Importer of Arms

10. Indian Armed Forces today seek, and are generally obliged with, the best weapon/ equipment platforms available globally. India's political stance has allowed easy access to dual use technology, be it the Russian T-90 tank, European fighter aircraft or French Submarines. The Indian Armed Forces identified technologies required to be inducted in development of a future capability and the Defence Procurement Procedure (DPP) has articulated the means of obtaining these either through the 'Buy (Indian)', Buy (Global), 'Buy and Make', 'Make' or the newly introduced 'Buy and Make (Indian)' categories. The country has had to perforce resort to 'Buy (Global)' option in the past due to a host of reasons, which has been an expensive proposition. India therefore, remains largely dependent on

external sources for advanced military technology. It is however note-worthy that over-reliance on imported hardware has the potential to compromise country's defence preparedness in times of crisis, through imposition of technology denial regimes by the supplier.

11. Though self-reliance in arms acquisition has always been the goal of Indian Government for a long time, its achievement continuous to be a distant dream, with the situation continuing to be as it was six decades ago. India continues to import more than 70 per cent of its defence hardware from major arm supplying nations like the USA, Russia, France and Germany. This massive import oriented defence capability is in stark contrast to China which has joined the eliteclub of top five arms exporters with 5 per cent international share.

Statistically Speaking

12. The global defence market is estimated at USD 1800 Billion. India with a spending of USD 51 Billion in the year 2016 has moved up to 4th position from 6th position in the year 2015. India is the largest importer of defence products accounting for 14% of the total global imports in the year 2016. Currently, about 70% of the Indian defence procurements are imported.

13. Indian Defence budget is Rs. 2,62,000 Crore for FY 2017-18, an increase of 5% over the last year budget. The capital acquisitions of defence hardware in next 10 years is expected to be approx. Rs 15 Lakh Crore (Rs 1 Lakh Crore per annum) with the share of Navy being 23%.

14. Indian military enjoys an esteemed status as a professional force amongst the comity of nations. This exalted status which India has been jettisoned to, pre necessitates a credible DIB with the capability to both develop technology indigenously, as well as, taking it to the next level indigenously, rather than seeking upgrades.

Emergence of the DIBs

15. During the pre-liberalisation era, industrial activity was allowed only under license, and imports were controlled by the Director General Technology Development (DGTD) and a cap

was put on the production capabilities. Government policies placed barriers on free trade and insulated the country from rapid technological advances. This resulted in stifling the economic and technological growth across sectors. The post liberalisation era, saw the removal of import restrictions, thus bringing in competition from the global players. Indian industry developed competitiveness despite the policy tilt in favour of imports of finished goods. Over the past decade and a half R&D in private sector came of age, Indian industry evolved and poised to become a global player in Software Technology, engineering and manufacturing. This was realized by the other strategic sectors like nuclear power and aerospace. They collaborated and synergised with private sector R&D for its nimbleness to achieve almost total self reliance in their needs thereby insulated the nation from all kind of sanctions. In the defence sector, however, the production remained reserved for the DPSUs / OFBs. The Transfer of Technology (ToT) from OEMs was limited to manufacturing technologies. The result was that the nation remained a net importer of its security.

16. The DRDO was established with the mandate to conduct research into Defence areas. DPSUs and OFBs were set up with the twin objectives of Productionisation of systems developed by DRDO and produce defence goods under ToT from foreign suppliers and subsequently assimilate the technology. This policy, when formulated, factored in the then state of private sector and also the fact that basic R&D in all nations was needed to be funded by the state. This resulted in investments, over the past decades, in infrastructure and facilities in Defence R&D and Defence Public Sector Undertakings, with the onus to work on technology and product development from the abstract stage to the productizing and hand holding at the production stage.

17. Even in the post liberalisation era, 1991 onwards, local sourcing was limited to component supplies and limited thrust was given to the private industry. Realising the vast potential of the industry, the process of integrating the private sector in the defence industry was initiated in 2001. The policy decisions announced in 2001 permitted 26 per cent FDI in the Defence industry and allowed the Indian private sector to participate in Defence production by obtaining a license. The Defence Procurement Procedure 2002 (DPP 2002) turned out to be the watershed for the Defence industry as it allowed the participation

of the private industry in defence production in-principle. The aim was to enhance competitiveness of the industry with an aim to make them efficient, and achieve global benchmarks essential to compete in the global defence market. The subsequent DPP 2005, DPP 2006 and 2008 incrementally overcame some of those shortcomings and bridged the gaps in the promulgated policy. However, the policy intent is yet to be implemented fully as the nomination of the DPSUs / OFBs still continues.

18. DIB as on date, despite its sustained efforts, has remained in the confines of elementary hardware production and the indigenous technology levels remain far below the contemporary international standards, leading to the import of elementary equipment. Furthermore, the indigenous capability to develop the next generation technology remained largely non-existent. Indian DIB, coupled with lack of competition, has remained restricted to a manufacturing base with weak R&D component.

The Path Ahead

19. Achieving the objective of substantive self-reliance in the design, development and production of equipment/ weapon systems/ platforms required for defence will require conditions conducive for the private industry to take an active role in this endeavour; to enhance potential of Small and Medium sized Enterprises (SMEs) in indigenization and to broaden the defence R&D base of the country. While pursuing the above objectives, the overall aim of ensuring that our forces need to have an edge over our potential adversaries at all times, in immediate terms as well as in sustainability, will have to be ensured. With these in mind, preference has to be given to growth of indigenous design, development and manufacture of defence equipment.

20. Service Headquarters (SHQs), while laying down the qualitative requirements for defence equipment/ weapon systems/ platforms that are to be developed/ integrated/ made, will have to exercise due diligence at all times to keep in view the feasibility and practicability of the Quality Requirements. However, it has to be ensured that the systems/ platforms designed and developed or integrated in the country will provide a competitive edge to our Services vis-a-vis our potential adversaries. Stage-wise process with incremental changes has

to be followed, recognizing the development of complex systems. A review of such developmental projects by the Defence Production Board or Defence R&DBoard will ensure that our equipment, weapons systems and platforms are such that they provide an edge to our forces over our potential adversaries.

21. While examining procurement cases, time taken in procurement and delivery from foreign sources vis-a-vis the time required for making it in the country, can be examined as per the Defence Procurement Procedure, along with the urgency and criticality of the requirement, before deciding to proceed with procurements from foreign sources. Sub-systems/ equipment/ components that are not economically viable or practical to be made within the country may be imported, ensuring their availability at all times. As far as possible, the design and integration of the platform/ system will have to be undertaken within the country and the government will have to build up a robust indigenous DIB by proactively encouraging larger involvement of the Indian private sector in design, development and manufacture of defence equipment. Towards this end, efforts would be made in progressively identifying and addressing any issue which impacts; or has the potential of impacting the competitiveness of the Indian defence industry in comparison to foreign companies.

22. In order to synergize and enhance the national competence in producing state of-the-art defence equipment/ weapon systems/ platforms within the price lines and timelines that are globally competitive; all viable approaches such as formation of consortia, joint ventures and public private partnerships etc. within the Government approved framework will have to be undertaken for which the Academia, Research and Development Institutions as well as Technical andScientific Organizations of repute will have to be involved.Government will have to simplify the procedures under the “Make” category of the Defence Procurement Procedure in such a manner that it enables the indigenous design and development of the required equipment/ weapon systems/ platforms by both public and private industry in a faster time fame.

23. The Direct Offset policy is applicable to all “Buy Global” RFPs valued at Rs 300 crores and above has stipulated a

minimum of 30 per cent of the cost of acquisition to be sourced from Indian defence industry. This policy is aimed not only at ensuring the induction of advance technology in the industry but also to bring in capital investment for the economic growth of the country. Further, introduction of Offset Banking, will enable foreign OEMs to demonstrate their intent for a long term engagement with the Indian Industry. The foundation for the induction of technology, development of infrastructure and making investments attractive for the foreign OEMs is thus, in place.

24. In all cases of Transfer of Technology, all research and production stakeholders will have to be involved in identification and evaluation of requisite technology,and subsequently would be responsible to ensure that appropriate absorption oftechnology takes place in the Indian industry. Thereafter, successive generations of the weapon systems/ platforms can be developed in the country. Upgrades will have to be carried out by the Indian industry as far as possible.

Private Sector

25. Enhanced defence production capability would entail a concerted effort by all competent players in the arena including governmental houses. Both public and private sectors are national assets and harnessing of their potential is essential if self-reliance in defence production is to be achieved. There exists a need for greater appreciation by the government of the potential complementary role of the private sector in augmenting the defence production. A level playing field needs to be provided to all, be it the Indigenous Private Sector or the foreign vendors. The offset clause for all defence procurements above 300 crore, should be exploited optimally to harness the incoming technology and ToT, with an assurance that an indigenous source will produce the same equipment post successful technology transfer, remains mandatory to the cause.

26. While looking at offsets, the consideration seems to be limiting to Transfer of Technology / Knowledge (Low Level). Offsets could also be supply of indigenous systems supplied as part of system of systems being sold by the foreign OEM and may directly be supplied to Indian services (not getting physically exported). Offsets could be delivered by the foreign OEM in the

form of system integration especially where large systems need to be fully integrated and tested in India. This involves passing on the system level know-how that is vital for building industry capability in doing so in India.

The Silver Lining

27. India will have Rs. 86,000 Cr of defence expenditure in the year 2017-18. This will offer large opportunities for Indian Private Sector Defence Companies, given renewed thrust by Government of India towards “Make in India” in the Defence sector. Government of India has undertaken substantial changes in the defence policies with a specific focus on "Make in India" thereby creating a conducive business environment for Private Sector participation for capability and capacity creation / utilization. The Indian defence business opportunities is estimated at Rs 15 Lakh Crores over a 15 year period and currently, the offset export opportunity is estimated at Rs 77,000 Crore. Large private defence players can take the cue and commit to develop a robust defence business ensuring significant contribution to national security and help the country to be self-reliant in defence segment.

28. ‘Make in India’ in defence manufacturing is primarily driven by capital acquisition of defence equipment and other policy measures taken to promote indigenous design, development and manufacture of defence equipment in the country by harnessing the capabilities of the public and private sector. These measures include according priority and preference to procurement from Indian vendors under the Defence Procurement Procedure (DPP) 2016, liberalization of the licensing regime and FDI policy by raising the cap on FDI in the defence sector, simplification of export procedure, streamlining of defence offset guidelines etc. Recently, the Government has notified the ‘Strategic Partnership (SP)’ Model which envisages establishment of long-term strategic partnerships with Indian Private entities through a transparent and competitive process, wherein they would tie up with global OEMs to seek technology transfers to set up domestic manufacturing infrastructure and supply chains. Foreign companies are allowed to have tie-ups with Indian vendors for indigenous production involving Transfer of technology (ToT)

under ‘Buy & Make (Indian)’ and ‘Buy & Make’ categories of capital acquisition.

Defence Public Sector

29. Simultaneous actions at various levels are essential towards improving the existing DIB. The Ordnance Factories should be under the leadership of a competitive management and must have higher accountability for their operations. There must be a concentrated effort of building a consortium of industries around these units, enabling the OFs to play the role of designer and integrator. Acquisition of companies with specialised design skills and expertise either in India or abroad should be pursued vigorously towards their own strengthening.

30. R&D strengthening remains imperative for a viable DIB. From the very basic level of repair & maintenance, to the level of having the ability to system design, develop, manufacture and test, it is a gradual, step by step process based on the technologies and complexities as well as manufacturing and testing techniques involved. There is a need to have a structured R&D setup for innovations, upgradation of existing products, absorption of imported technology and product development. In order to achieve Product development there should ideally be an inherent requirement to spend 5 per cent of turnover in OFs/DPSUs, on inhouse R&D. When achieved, OFs/DPSUs with their vast experience in producing armaments could well become a storehouse of R&D / knowledge in this vital field.

31. Once we have a higher portion of the defence procurement coming from the Indian vendors, we can afford to make a shift in the offset policy towards direct and directed offsets and leveraging the same towards acquiring critical technologies. The issue of direct and directed offsets is already being addressed by the DDP through a new draft offset policy.

32. Presently, there is no mechanism available in the defence sector for testing and evaluation of the products developed by the industry on its own. Defence equipment is necessarily required to undergo qualification tests (environmental, EMI/ EMC etc.) during development stages before being considered for user trials. There is also a strong case to enable smooth and expeditious field / sea / flight trials of

equipment developed by private industry, which they may have developed on their own initiative based on capability requirements projected by the services.

Skill Development

33. Skill development is critical for achieving self-reliance. Aerospace and defence production requires high precision manufacturing which needs a talented pool of personnel having specialized training and certifications. There is a need to strengthen the skilled manpower in the country and introduce formal education institutes and universities in aerospace and defence technology disciplines (like military engineering), upgrade existing Indian training institutes to produce technically sound individuals and formation of Defence Sector Skill Council and institution of Defence Industry Internship program. Subsidising important international accreditations for the SMEs is also a step ahead.

34. Under Skill India initiative, DPSUs have been asked to use Research funds for imparting training to the labour force. They have also been asked to define eligibility criteria for all positions in terms of National Skill Qualification Framework by amending the recruitment rules. This should remove the disconnect between demand and supply of skilled manpower.

35. The Start Up-India, Stand Up-India initiative is designed to encourage entrepreneurship among the youth. It is envisaged that creation of a robust ecosystem will get a boost under this initiative.

36. The provision of 'Make' category of capital acquisition is a vital pillar for realising the vision of the 'Make in India' initiative. Hence it is imperative that 'Make' procedure should be structured to provide the necessary leverage for the industry to take calculated risks, make adequate investments, build the required capabilities and match upto the contemporary and futuristic requirements of the Armed Forces. ‘Make’ category of acquisitions in consultation with Service HQs will not only help in creating eco-system in terms of vendor development, but also kick-start race for technology development and/ or technology acquisition by the industry, which will help the defence manufacturing in the long run. Such indigenously developed

systems will also be available for export to establish India as a global player in defence market.

37. While India is gearing up to upgrade its “ease of doing business” parameters and addressing necessary policy reforms to attract investments under “Make in India”, it is very important to put the highest priority in strengthening its innovation ecosystem, primarily led by industry and in partnership with government, academic and research institutions, nationally and globally. There is also a need to incentivise R&D in defence with innovative funding methods. The significant reserves available with DPSUs could be one such resource to encourage innovation in the MSME sector.

What’s in for the Navy?

38. One cannot refute that 'Make in India' has opened a huge array of possibilities for private partnership in defence which can bolster manufacturing sector. FDI may not have come in as expected yet the ray of hope lies in many Indian companies steering towards indigenous production of defence items. The Indian Navy has unveiled a 15-year plan to achieve full indigenisation in all phases of warship construction, from ship-building to systems to weapons, and aligned it the 'Make in India' dream.

39. For India, the main technological challenge is to reduce the imported content of indigenously produced naval sensors and weapons. While there are plans to build future naval technologies under the ‘Make in India’ initiative, it is unclear if an outright indigenisation approach to technology will be effective. The problem is that even though foreign defence companies are willing to collaborate with Indian manufacturers, they are reluctant to transfer cutting-edge technologies. Equally worrisome, however, is the suboptimal capacity of Indian firms to acquire and absorb foreign technology.

40. The Navy has announced its ship-building ambitions, which it believes will enable India to be a net provider of security in the maritime neighborhood, thus building capability and enhancing capacity of regional partners. Yet, the shortfalls in terms of both Indian R&D and Indian manufacturing remain serious. For maritime managers, the mission involves five urgent

tasks (a) R&D in military sciences and technologies; (b) amalgamation of R&D and the manufacturing sector; (c) bringing about an integration of users, designers and manufacturers; (d) making projects commercially viable, achieving economies of scale; and (e) tiding over technology-denial regimes.

41. The new DPP is likely to have a policy for single-vendor situations. Such a situation is an emerging reality in an industry with limited suppliers for different platforms. Rejecting such proposals for the sake of competition would unnecessarily delay acquisitions. Retracting an RFP has been a common practice in case of a single vendor. This has been done even in cases where more than one bid was received initially but others withdrew at different stages, including after the TEC. Hence, the decision to review its policy for single-vendor situations has been welcomed by the entire industry.

42. In a measure to allow for moving beyond a rigid 'L1' approach, future RFPs are expected to have 'essential' as well as 'desirable' technical parameters or staff SQRs. The essential parameters will have to be demonstrated at the trial stage and will have to be present in the final product. This will reduce the retraction of RFPs. The RFPs will also contain enhanced performance parameters to provide for additional capabilities over and above the essential parameters. Vendors who meet them will be provided additional credit score while evaluating their product cost. This is a welcome departure from the L1 concept and will encourage them foreign and local vendors to go the extra mile in delivering product quality.

Conclusion

43. For a nation of one billion plus with arguably the best knowledge driven industry better than the best in the world, we ought to have done better. Need for the self-reliance cannot be emphasized more than the multiplier effect it will produce for the national economy through manufacturing growth rates and job creation.

44. The way ahead over next 10 to 15 years is to build focused product strategy with commensurate investments in Defence Industry across segments including private sector so that in the long term, the country meets its defence requirements

as much as possible from within the country. A strong DIB is required along with calculated investments in R&D in the core design area with DRDO, DPSUs and OFBs leading from the front and posing challenge to the countries Academia. This will only be possible by allowing the private sector to a play rightful role in product design, development, manufacturing and integration capabilities available in the private sector to augment the capacities built in the Public sector through Public–Private–Partnerships (PPP). The Offset Policy leverages bargaining power to get benefits to the country to build its Defence Industry. The benefits are economic gains, skills development, technology gains, employment generation etc. 'Make in India' initiative has to build world class manufacturing infrastructure in the country so as to reduce dependence on imports and to reduce the cost in the long run. However, this being a long term activity, it is premature to assess its impact on reduction in manufacturing cost at this stage.

"The success of 'Make in India' for the defence industry is in ensuring the success of 'Design in India', thus leveraging the strength of Indian engineers for India's success"

– Pritpal Singh Chhinna, Head, Aerospace and Defence (Strategic Initiatives), WIPRO Limited

Summation

45. Self-reliance in meeting the requirement of defence equipment for the Armed Forces is a strategic necessity. Accelerating this pace of indigenisation is now a priority area for which the active participation of industry, both the public and private sectors, is very important at every stage of the developmental process. Various mechanisms have been introduced to institutionalise this. Positive interaction between all concerned agencies is vital for progress to be tangible and viable. The effort to give fillip to the process of indigenisation is being pursued in right earnest. A ‘Make in India’ policy for the defence sector should ideally aim to reverse the current imbalance between the import and indigenous manufacture without adversely affecting the requirements, capability and preparedness of the user.

46. There are several aspects of this process, the best case scenario being that we have the ability to design, develop, make i.e. the ability to manufacture and integrate, test, maintain and upgrade the defence systems we require and, if possible, export these. Where this is not feasible, we should be able to at least manufacture or integrate the systems within the country with the help of full technology transfer. Given the nature of the defence materials, this may not be possible all the time. In such cases we should at least have the ability to provide a life cycle support i.e. repair and maintenance if not mid-life upgrade.

47. Military modernisation requires innovative thinking, perseverance and sustained commitment to attain self-sufficiency. There exists no option, but to reverse the current high proportion of imports with the indigenous content and steadily reduce thereafter. Vision for India in the next two decades would be flawed if it did not envisage a sizeable, vibrant and sophisticated DIB that is globally competitive and has the capacity to develop advanced technologies.

48. The Government has made indigenous defence production a priority and amply shown its resolve to steam roll all obstructions. This has greatly inspired the DIB, which has now found a new confidence. With concerted efforts of DPSUs, trade, research and development agencies, intellegensitia and the

governmental support, it shall be a matter of time, before India emerges as an Asian powerhouse in defence production.

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VISION OF IMPLEMENTING INTELLIGENT CONDITION BASED MONITORING SYSTEM ON NAVAL PLATFORMS

Cdr A Shrutikar

Abstract. - Conventional CBPM and Integrated Platform Management System (IPMS) are concerned with monitoring the parameters of main Propulsion and Electrical systems equipment onboard Naval vessels. Raw data is collected from ships and is forwarded to the trial agencies for evaluation. Such data is benchmarked against manufacturers' performance data, as well as against vessels equipped with similar equipment, in order to best identify anomalies and to plan remedial maintenance actions. However, Condition Based Monitoring should not be limited to main Propulsion and Electrical systems equipment. To achieve higher survivability, higher equipment availability and optimum operations at lower fuel costs, demands the deployment of an Intelligent Condition Based Management (ICBM) System that predicts and reports the health of the machinery in advance. In addition, ICBM will be having additional situational awareness and fuel saving features to best assist the crew onboard Naval vessels, with appropriate secure interfaces with shore based maintenance centre(s). The above will ultimately result in lower Life Cycle Cost (LCC).

1. **Introduction**. CBPM techniques are designed to help determine the condition of in-service equipment in order to predict when maintenance should be performed. This approach promises cost savings over routine or time-based preventive maintenance, because tasks are performed only when warranted. The main promise of predictive maintenance is to allow convenient scheduling of corrective maintenance, and to prevent unexpected equipment failures. A systematic monitoring and recording with CBPM tools can improve sustainability at high seas, thereby improving the fighting efficacy of a warship.

2. **CBPM Methods**. In order to assess the equipment condition, predictive maintenance uses nondestructive testing technologies such as infrared, acoustic (SBN & ABN), vibration analysis, oil analysis, etc. These methods have been proven to be successful in predicting the condition of the equipment and decide on further exploitation accordingly.

3. **Present Methodologies**

(a) **Vibration Monitoring**. Monitoring the Vibration of an equipment or machinery is similar to the ECG used in medical field. It can be defined as the pulse of a machine. Vibration monitoring technique captures the vibration of an equipment in the form of an accurate time-varying signal with the aid of a vibration transducer, such as an accelerometer. The raw analog data is typically brought into a portable, digital instrument such as SPM T-30. The captured data is later forwarded by the ship to the respective trial agency wherein trend analysis of parameters is being undertaken for respective equipment using software (Condmaster Nova) and analysis report is forwarded to the ship. Moreover in case of special trials *Narrow Band Analysis* of the captured data is undertaken to ascertain the health of the machinery. In case of abnormality remedial measures are recommended to the respective ship.

(b) **Oil Analysis Method**. Oil Analysis is performed during routine predictive maintenance to provide meaningful and accurate information on lubricant and machine condition. By tracking oil analysis sample results over the life of a particular machine, trends can be established which can help eliminate costly repairs. Presently ships are carrying out monthly (basic) and quarterly (SOAP) analysis of oils through authorised labs and forwarding the report to trial agencies for analysis and trending.

5. Machinery reliability and availability is critical for any ship. With machinery failure causing a large percentage of marine accidents hence a substantial reduction in maintenance costs can be achieved by implementing a more efficient Condition Based Maintenance strategy program.

6. **Conventional Onboard Condition Based Maintenance**. The capabilities of conventional Engine/Equipment Health Monitoring System (EHM), Integrated Machinery Control System (IMCS) and Integrated Platform Management System (IPMS) applications have continuously evolved. However, the purpose and product capability of each of the above subsystems are

different and at times not fully appreciated by the end users. In general, conventional IPMS and IMCS products lack capability for providing historical data, detailed diagnostics & advisories for remedial action. They are mainly concerned about main propulsion engines and generators and perform monitoring and reporting functions.

7. As a matter of fact the on board Condition Based Monitoring system ideally should provide all the information required for all sorts of predictive maintenance to the ship staff operating the ship. However, with reduced manning & aging equipment this work against the ship staff. In view of the foregoing, vibration, oil analysis details are forwarded to the trial agencies for evaluation, scrutiny and for recommendations. Moreover, post completion of major routines on main propulsion, auxiliaries and generators; various instrumentation and safety device checks are undertaken in addition to vibration analysis by the trial agencies to evaluate the health of the equipment.

8. **Next Generation Condition Based Maintenance**. Next Generation Condition Based Monitoring system would be an integral part of the Ship's Engineering Control System (ECS) and interfaces with ship subsystems sensors through the ECS data communication network. This facilitates access to sensor data from main Machinery, Navigation (for EEF) & Communication (to import and export engine health to trial agencies) systems. The ECS Interactive Electronic Technical Manual (IETM) provides an added benefit for rapid access to the desired equipment's manuals, drawings, maintenance procedures and diagnostics; all in all providing extra intelligence. In addition, the next generation Condition Based Monitoring monitors and predicts machinery failure modes by taking online (running parameters) and manually (Preset alarms & trips) entered data, it compares the data with established engineering performance criteria/historical data in support of the condition based maintenance philosophy and provides the user an early warning with regard to failure or any deviation from the normal exploiting trend. Individual equipment should be modeled in such a manner that failure modes for each unit are displayed at both the unit level and the system level, and each failure mode can be drilled down to provide actionable information for the user. Equipment readings that are not available on a data bus could be accessed with the aid of an electronic tablet that is

interfaced with condition based monitoring system and can be plugged to a standalone system onboard to undertake analysis.

9. **<u>Intelligent Condition Based Maintenance - Vision 2030</u>**. Implementation of initiatives such as OEM partnering, design improvements, reducing crew size, and remote monitoring there has always been a pressure for reducing ship's Total Ownership Cost (TOC). On similar lines, there is also an increased demand for improved preventive maintenance, fuel economy and efficient identification of potential operational failures, improved recovery from failures based on lower Mean Time to Repair (MTTR), better survivability, and improved situational awareness under damaged conditions. The above has given rise to a new concept of condition assessment system; Intelligent Condition Based Maintenance (ICBM). As a central maintenance management suite, through the Engine Control System and its interfaces, the ICBM obtains information from Vibration Monitoring Systems (VMS), and oil debris monitoring system. Both of these are possible in online monitoring configurations (preferred), or via Portable Data Terminal (PDT) and Portable Data Analyzers (PDA). The PDT is a hand held unit used for manually acquiring engineering plant information. The PDA is a portable, wireless communication (vibscanner), field-use instrument which facilitates machinery condition monitoring by enabling the acquisition and storage of vibration data including vibration spectrum data and other related information.

10. In addition, the ICBM integrates online and offline data sources as well as from plant historians and other reliability applications. In addition, ICBM allows the creation of unique rules and alarm set points for each defined machine state. Any of these data may be trended, alarmed, or used as inputs to rule logic, either individually or in combination, to detect and diagnose machinery failures and drive operational and maintenance decisions. ICBM provides an effective means of observing equipment performance over time, anticipating failure based on historical data and planning maintenance based on material condition.

11. Remote monitoring for a class of ship or a fleet of ships at a central location (Trial Agency) provides the operational and maintenance decision makers with the flexibility to monitor individual ship equipment whilst the ship is at sea. Hence, the

trial agency plays a pivotal role to monitor and provide feedback maintenance recommendations to the ship's crew in a timely manner. Hence with full integration of Condition Based Monitoring functions with the ECS and other mission critical ship systems, optimum Equipment Health Monitoring (EHM) objectives can be achieved.

12. **ICBM Analytics and Rule Set**. The most modular and most essential piece of a scalable, extensible ICBM is the incorporation of "plug-in" analytics or rule sets mapped to individual model operating parameters and configured to the sensors for each ship in which that model is installed. Graphical rule development is characterized by:-

(a) Use of a combination of crisp rule sets and anomaly detection rules to provide early warnings of functional failures.

(b) Rule based logic that can contain but is not limited to time-based evaluation, parameter exceeding limits, and curve-based/parametric performance evaluation.

(c) Historical performance data to set baseline conditions against which all future parameters are compared.

(d) Machine state qualification to ensure only relevant data is analyzed for specific failure modes.

13. The rule sets are self-contained in that they can be modified based on the needs of the customer without modification of the ICBM core software. The land-based (Trial Agency) rule sets take the data provided from the ship and display the data as qualified by the rules in the same manner as in the ship-based system. As sensors are added or removed from a system or operational parameter set points are changed, the rule sets can be modified only by trial agency to process the data as required.

14. **ICBM's Failure Mode**. Each unit which has been configured in the shipboard system should also be available for review and troubleshooting on the land-based system to

troubleshoot potential problems beyond the ability of ship's staff to identify. Hence again the shore based trial agency will play a pivotal role in extending support to ships. A system level "stoplight" type display can provide a quick view for supervisory personnel and can be expanded for more serious pathology of machine conditions.

15. The trial agencies are to be installed with an enterprise tool which is part of ICBM suite to view frequency of failure for each failure mode across all ships equipped with a particular model of equipment. Accordingly, based on the advice from trial agencies, maintenance and lifecycle managers can determine causes for high failure rates on particular ships or for ships deployed to particular areas or even for ships which have had repair work conducted by specific facilities.

16. **Intelligent Land Based Condition Monitoring**. Another feature of the ICBM is the ability for a subject matter expert to review shipboard data, modify status and insert maintenance or repair recommendations/advisories via a report which can be sent directly to the ship and vice versa (through secure, encrypted or secure non-encrypted media). This is clearly a force multiplier since the pool of SMEs (Subject Matter Expert) ashore is much larger than on a ship. Moreover, remote assessment of shipboard equipment by a SME can be a substantial money saver. Onboard Naval ships cost effective Fleet wide Condition Based Management can further enhance Maintenance Management for a Class or Fleet of ships. As a result, the fleet Condition Based Management could compare performance of similar equipment across a Class of Ship or over the complete Fleet as applicable.

17. **Situational Awareness**. As mentioned earlier, it has become essential for navies to have improved visibility on their crew's technical support needs, voyage data, fuel consumption, equipment and systems readiness status, maintenance needs, methods adopted on provision of advisory for ship crew, failures and damage status, etc. However, in most cases today, this data is required to be streamlined which is exchanged between shore base and target ship(s). The data transmission risks and cyber security issues are also fully addressed by solutions that are currently deployed. Furthermore, standalone systems are used with minimum system integrations.

Situational awareness is therefore considered as an integral part of the ICBM. Being an integral part, the ICBM readily obtains intelligence on systems and equipment status and other ship systems through the following:-

(a) Data from Sensors
(b) Manually entered data related to equipment status
(c) Equipment & Systems readiness and availability status
(d) Equipment damaged status, repair status, failures and expected future failures due to cascading effect.
(e) Desired information from Navigation, Communication and Combat systems equipment.
(f) CCTV images related to incident locations and areas monitored by CCTVs
(g) Fuel consumption, fuel reserve and fuel economy related factors.
(h) Equipment Health Monitoring (EHM) data.

18. **Benefits of Increased Fuel & Energy Efficiency for Naval Vessels**. Navies around the world has in the last decade given due importance towards increasing fuel and energy efficiency. In the current world of increasing defense budgetary pressures yet higher operational tempos, fleet leaders are looking for ways to sustain operations at lower cost. Fuel is a significant cost for every Naval Vessel. The most obvious benefit of maintaining and operating equipment to drive energy and fuel efficiency is the reduction in fuel consumption. These direct fuel savings can be measured and attributed to specific actions, whether maintenance or operations.

19. In addition to the cost of the fuel that is saved, there are the costs of delivering that fuel to the vessel. In many situations, this fuel is being delivered to where operations are occurring, potentially via Naval replenishment vessel or to a remote or potentially troubled area. The costs involved in distribution should not be underestimated. The US military estimated that the cost per gallon of fuel to be delivered to remote areas of Afghanistan to be up to $400 per gallon and delivery at sea can cost between five and fifty times the market price. Eventually, a decrease in fuel logistics services demand could lead to lower required capital investment in fuel distribution resources (Naval

supply vessels, etc). A tertiary impact of fuel conservation is the resulting increased vessel range.

20. Towards the same, ICBM will have an added feature of optimizing fuel and energy efficiency which will result in less equipment to be exploited at a particular time (while ensuring appropriate redundancy for mission requirements). This in turn, slows the wear on equipment, enabling deferral of maintenance (and associated cost) and extension of equipment life resulting in greater fleet readiness and higher likelihood of mission accomplishment. Further, implementation of ICBM will increase the fuel efficiency view timely maintenance undertaken based on the prediction resulting in greater redundancy of assets on station or decreased crew deployment time. This increased fuel efficiency provides fleet commanders with increased options for how to achieve mission success while balancing other objectives.

21. **CBPM with IN Perspective**. Indian Navy has adopted CBPM wef 1992 and has thereafter has continuously evolved. The maintenance operating instructions for various equipment promulgated by INSMA to the ships are majorly based on the maintenance schedule promulgated by the OEM and are mostly based on planned preventive maintenance. However, over a period of time there have been amendments in routines as a step towards transition from planned preventive maintenance to CBPM based methodology however still the same is required to be pursued vigorously through revision of MAINTOPs.

22. **Challenges in implementing CBPM**. Even though, literature demonstrates the technically feasible capabilities and benefits of CBPM application, calling for a transition from PPM, however research has shown that the application and acceptance of CBPM in the practical field of maintenance appears to be limited. One example of the same is installation of Onboard Vibration Monitoring System onboard P-17 class of ships during commissioning as part of it’s SOTRs. The system is non operational. Hence challenges encountered in implementing CBPM in totality are as follows:-

(a) All CBPM research is usually undertaken in controlled environments consequently there is a discrepancy between the effects of CBPM implementation reported in literature and the actual effects experienced in practice.

(b) Condition based maintenance requires a heavy investment in measuring equipment and training staff during implementation. Apart from investment and training there is a need for all the stakeholders to understand it's importance and it's wide capability.

23. **Conclusion**. This paper presented the current methodology adopted for CBPM in ***IN*** and presented a stage wise advancement of CBPM from the conventional CBPM system in 2017 to a very advanced CBPM system by 2030 which will have tools such as situational awareness and optimizing fuel consumption under the gambit of CBPM resulting in huge savings to the exchequer. Towards the same, the role of trial agency is also paramount in troubleshooting potential problems which are beyond the ability of ship's staff. The paper also brought out the various modules (ship and land based) of the advanced CBPM system. Finally, in the age of increased defence budgetary pressures, implementation of ICBM by 2030 on all Naval Ships will definitely result in enhancement of fleet efficiency, increased readiness, reliability and it's availability.

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MESC STAFF STUDENT PROJECTS UNDERTAKEN

1. Staff-Student Projects are a vital aspect of the curriculum for the Officers undergoing Marine Engineering Specialisation Course (MESC). The under trainee officers are encouraged to apply their knowledge and skills into practical applications and undertake technically challenging projects. Emphasizing on the engineering aspects and research areas currently in vogue that could be useful for the Indian Navy is the main aim behind this exercise. Selected projects are sent for field trials at Naval Dockyards and Fleet Ships.

2. A brief on Staff – Student Projects under taken by the Officers of MESC recently is enumerated in the succeeding paragraphs.

OIL WATER SEPARATION USING MAGNETITE POWDER

3. Magnetite Powder (Fe_3O_4) has the inherent property of having affinity to oil and this oil - magnetite powder mixture will coagulate and move, if placed in a magnetic field. This phenomenon can be utilized for separating oil water mixture onboard ships and submarines. The coagulated oil-powder mixture can then be further separated when it is made to pass through a selective absorbing agent (prepared foam) under pressure head. Material with superoleophilicity (affinity to oil)/ superhydrophobicity (repellent to water) is used for oil-water separation as they allow oil phase to penetrate through the special materials easily while the water is repelled completely thereby separating oil from water.

4. **Work Undertaken**. As part of the project study, the following tasks were undertaken for designing the prototype model.

(a) Preparation of selective absorbing agent using commercially available Polyurathene foam by treating it with Fe_3O_4, Ethanol and Rust oleum – Actyflon derivative under Ultrasonic apparatus.

(b) Preparation of a suction head using a sealed tank with a vacuum pump and associated fittings and connections.

5. **Construction and Working**. Two glass tanks 2 x 1 x 1 feet and 1 x 1 x 1 feet were designated as the oil-water mixture tank and oil collecting tank respectively. In order to maintain a suction head a vacuum pump of 130 watts was placed on the oil collecting tank. The pump was then connected to the prepared foam using a tube which was then immersed in the oil-water mixture tank as can be seen in Fig1 below. When the system was put into operation the prepared foam selectively absorbed the oil from the mixture and transferred it to the oil collecting tank under suction head. The oil from the collection tank was then drained and discarded as sludge and the left over in the oil-water mixture tank was taken for analysis. The lab analysis revealed that the water remaining in the oil-water mixture tank had a hardness of 80 PPM which suggests that it is moderately hard and the sample for the oil collection tank had only 5.5% water clearly showing that the prepared foam was selectively absorbing in nature and only absorbed oil.

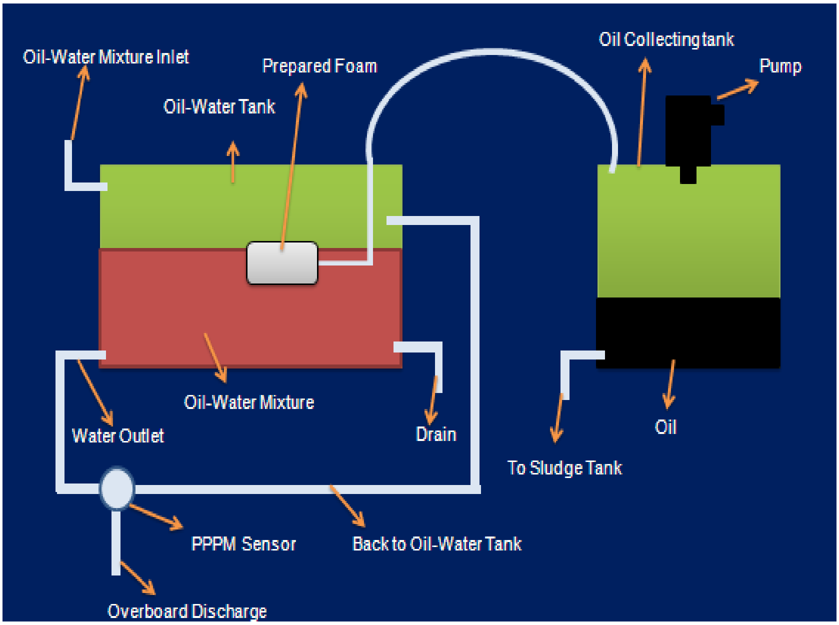

Fig. 1 Working Diagram

6. **End Result**. The projects aim for separating oil-water mixture using Magnetite Powder was successfully tested. Analysis of the separated water was also completed. Based on prototype, designing of an electromagnet and selective absorption foam for the proposed model were undertaken.

7. **Advantages**. The advantages of the proposed design has the following advantages:-

(a) The system is simple in design and requires low maintenance as compared to the OWS presently installed onboard ships and submarines.

(b) All the components are commercially available and is thus financially sustainable.

(c) DI/ DR required no special expertise and thereby ensuring low downtime.

DESIGN AND DEVELOPMENT OF CONTROL BASED TECHNIQUE FOR PRECISE LIFTING OF TALWAR CLASS GT CRADLE

8. Talwar class of ship has two cruise GT's mounted on cradle. The cradle is supported by 96 shock and vibration mounts arranged in three layers of 48 mounts at either end (forward/aft) with each layer carrying 16 shock and vibration mounts between the cradle and bulkhead. The replacement of these mounts is a 10 yearly routine and has never been carried out till date. The prescribed OEM procedure is man power intensive and susceptible to misalignment which necessitates design and development of PLC based technique for precise lifting of the cradle using screw jacks.

9. **Work Undertaken**. A scaled down model for the GT cradle was undertaken after calculations using the available dimensional data. A factor of 22:1 was used to scale down the actual existing model on board. Fabrication of the prototype model was done according to dimensions obtained through calculations. The lifting mechanism was assembled by integrating a servo motor with the screw jack and further with the PLC.

10. **Construction**. It consists of a PLC, servo motor, motor control unit, linear encoder and screw jack along with an HMI touch screen. The mechanism comprises of electronically controlled motor which drives the screw jack with encoders for controlling the precise number of revolutions of the motor. The PLC continuously supplies voltage to the motor and monitor the position of the cradle.

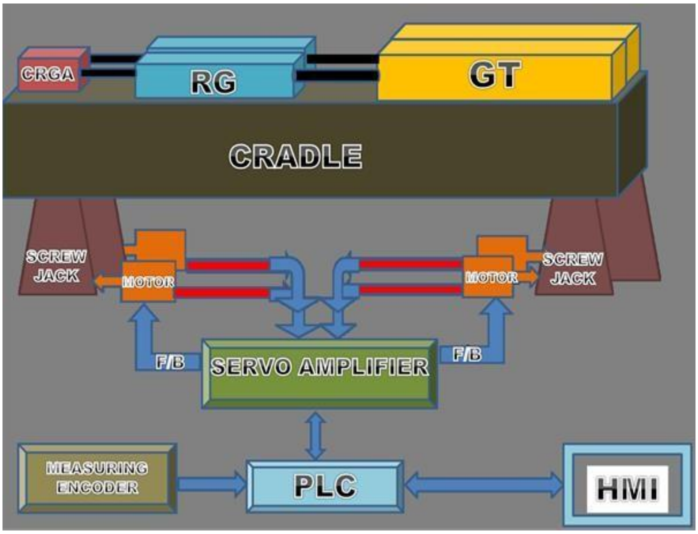

Fig. 2 Working Principle of Lifting Mechanism

Fig. 3 Designed Cradle Lifting Mechanism

11. **Working**. The PLC sends the control signal to the motor control drive unit based on the input value fed into the system through HMI. The motor control drive unit generates corresponding voltage for driving the motor. The feedback is obtained through an encoder which continuously senses the displacement of the screw. When the required vertical displacement is achieved, the voltage supply is cut off, consequently holding the screw jack in its desired position. All the motors are simultaneously controlled through PLC.

12. **End Result**. The project's aim of developing a precise lifting prototype mechanism was achieved upon successful tests on the prototype model. This mechanism can also be implemented on a larger scale for fail safe lifting of heavy platforms in Indian Navy.

OPTIMISED FLOODING SYSTEM USING SHAPE MEMORY ALLOYS

13. The term Shape Memory Alloys (SMA) is applied to that group of metallic materials that demonstrate the ability to return to previously defined shape or size when subjected to the appropriate thermal procedure. Generally, these materials can be plastically deformed at some relatively low temperature, and upon exposure to some higher temperature will return to their shape prior to the deformation. Shape-memory alloys flip back and forth between two solid crystalline forms called Austenite and Martensite. At lower temperatures, they take the form of Martensite, which is relatively soft, plastic and easy to shape. At a higher temperature, they transform into Austenite, which is a harder material and much more difficult to deform.

14. The project utilises the concept of shape memory effect, which is a characteristic property of Ni-Ti alloy wire, to actuate a valve mechanism thereby allowing an extinguishing medium into the compartment. The temperature rise caused due to the fire outbreak is used as the source of heat energy for the SMA wire to actuate.

15. **Work Undertaken**. The specifications of SMA wire used in prototype are 1.0 mm dia Ni-49%, Ti-51%. Ni-Ti stands out from the other SMA's because of greater ductility, more

recoverable motion, excellent corrosion resistance, stable transformation temperatures. The SMA wire is connected to a plunger type valve, which allows the introduction of the pressurised water from the system piping into the compartment. The shape memory wire in the prototype undergoes a change of shape (20mm contraction in length) under the influence of the temperature rise (60-70^0 C) due to a fire. As the temperature of the compartment reduces, the wire returns back to its original shape thereby closing the valve.

16. **Construction**. The isolating valve within the firemain pipeline consists of a rectangular metal block, which is the main isolating element supported by a helical spring. The block can travel up and down within the valve by virtue of two guides. The central supporting rod, which passes through the spring extends downwards and ends at a pivot point which is connected to the SMA spring by a mechanical linkage. The linkage is supported at the centre by a support suspended from the roof. The other end of the linkage is connected to the SMA wire, whose other end is fixed to the ceiling.

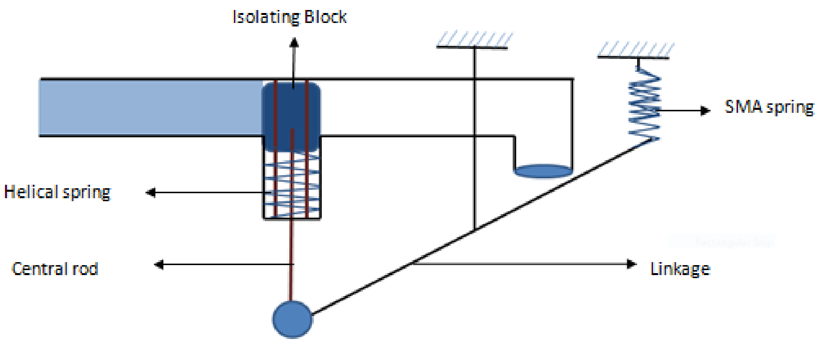

Fig. 6 Actual System Prior Activation of Valve

17. **Working**. As the SMA wire gets heated up due to the fire outbreak, the wire will contract, thereby lifting the mechanism about the pivot point. This will result in the central rod being pulled down, which will lower the rectangular block. As the block moves downwards, it compresses the metal spring and opens the passage, leading to the flow of the extinguishing medium into the compartment. On subsequent extinguishing of the fire, the

SMA wire will come back to its original shape thereby forcing the isolating valve to close.

18. **End Result**. The project's aim of achieving fire extinguishing system using Shape Memory alloys was successfully tested. Calculations for prototype were completed by simulation. Based on prototype calculations and analysis, design for proposed model was developed. Further, SMA spring, helical spring and rectangular valve were also designed based on the prototype calculaptions.

DESIGN OF PART ELECTRIC GAS TURBINE

19. The main aim of the project is to develop the working model of a gas turbine using a turbocharger and subsequently develop the part electric GT model. The conventional GT will be used as a reference for comparing the performance of both the GTs. The part electric GT design will feature the compressor coupled to an electric motor run by a battery which will be charged by a dynamo connected to the turbine. The compressor and turbine will be on two separate shafts as contrary to the conventional GT design. Part electric GT has better efficiency for constant loads and low loads. A simple turbocharger can be used as a gas turbine effectively by installing a suitable combustion chamber between the compressor and the turbine stage. Initially German made TSL turbocharger was used along with flame tube from 1241RE class GT. As the combustion chamber was not matched with the turbocharger, so combustion could not be sustained without the help of external air supply.

20. **Work Undertaken**. During the present project phase, a higher capacity turbocharger (HOLSET HX50 from Cummins NT743 DA) is being used. After carrying out extensive online research, a suitable combustion chamber housing and flame tube has been designed and finally sustained combustion has been achieved without the help of any external air supply. The flame tube and combustion chamber housing have been designed using JetSpecs software and the 3D modelling has been done using Autodesk Solid works. Material used for fabrication is Stainless Steel 316 grade. The fabrication has been carried out in Mumbai and Industrial Training Wing (ITW) in INS Shivaji. The fuel pump operates at a pressure of 8kgf/cm^2. The injector capacity is 9.46 L/hr.

21. **Features**. Some of the salient features of the current model are as follows:-

(a) Sustained combustion without external air supply.
(b) Once the combustion is sustained, only fuel supply is required to get useful power output.
(c) The engine stabilizes at 25000-30000 rpm.
(d) Exhaust temperature at turbine outlet is 750-850^{o}C.

22. **Way Ahead**. The present model is a reference model for comparing the performance of part electric GT model. Further work needs to be carried out to fine tune the system.

(a) Cooling water system for combustion chamber assembly.
(b) Forced lubrication system for turbocharger bearings.
(c) Fuel control system to vary the power output.
(d) Power turbine to get useful work output from the engine.
(e) Design of self-reliant control system to drive all auxiliaries

BRIEF ON INSTALLATION OF PLC BASED CONTROL PANEL FOR STEERING GEAR AT SAX WING

23. The existing facility in SAX wing consisted of a steering gear ex Vijaydurg, which was installed in the year 2003.The control system of the steering gear was non-operational. A syndicate of trainee officers under the guidance of a staff officer undertook a project with following objectives:-

(a) Installation of PLC based control unit for steering gear system.

(b) Integration of control panel with the system.
(c) Proving different modes of operation.

24. **Working Principle**. The present hydraulic system consists of a VSG pump with a swash plate for supply of oil with requisite pressure to the hydraulic ram, which is connected with

rudderstock. The movement of the swash plate is controlled by the drive assembly consisting of servo motor, fixed on top of VSG pump. The position of swash plate decides the direction of rotation of rudder. The PLC generates the control signal depending on the demand received (from push buttons in NFU mode / rudder wheel in FU mode) and the actual position (signal received from position sensor), which are available at the comparator. The control signal is then given to servo motor to achieve movement of rudder. The programming of the logic is done in CODESYS software.

Fig. 4 Steering Gear Setup with PLC based Control Panel

25. **<u>End Result</u>**. This system can be used to impart training on steering gear and its different modes of operation to all the ab-initio courses in INS Shivaji. Also this system can be used as a model to familiarize the trainees with PLC based systems and understand the basics of PLCs.

<u>BATTERY OPERATED SELF BALANCING VEHICLE</u>

26. Battery operated Self Balancing Vehicle is designed to help the user mount the vehicle and facilitate the seamless movement(ahead or astern) based on users orientation. The robot is self-balanced by producing a counter balancing force to the generated inclination of the user.

27. **<u>Work Undertaken</u>**. The following works were undertaken as part of the project:-

(a) Study of high-level computer language and interfacing the gyroscope sensors with microcontroller ATmega328P.

(b) The design and fabrication of PCB and chassis.

(c) Preparation and design of filter for error reduction and integration of sensors using Kalman filter.

(d) Programming on Adruino compiler and boot-loading through Adruino Uno.

(e) Determination of PID control constants from MATLAB.

28. **Construction and Working**. The vehicle consists of three platforms where the topmost is used to mount rider, the second contains the battery and the third has the PCB and control components. Four pillars support each platform and the PCB is screwed down on the plastic frame. Two 300rpm motors, which derive their power from a 2200mAh battery, run the vehicle. If the robot is subjected to a jerk in forward direction, it will oppose the force and balances itself. Similar is the reaction for force from any direction on the robot; it will always try to remain balanced.

29. The designed and fabricated vehicle is a prototype of the initially envisaged vehicle, which could handle the weight of a man riding on it. The inputs to the microcontroller are from a Motion Processing Unit, which has a gyroscope and an accelerometer embedded into it. These sensors work on the principle of piezoelectric effect and generate a voltage proportional to the tilt experienced. The Self-Balancing vehicle consists of an Atmega328P microcontroller, which gives the output of the program to the motors. A PID control system is used to reduce error and achieve a high stability even when the robot experiences a high unbalancing force. The range of the PID values has been calculated using MATLAB software. The constants for P,I,D can be adjusted mechanically by the use of a potentiometer which has been given a separate five pin interface. This PID control gives the flexibility to change the

values depending on the changing parameters of the motor and battery.

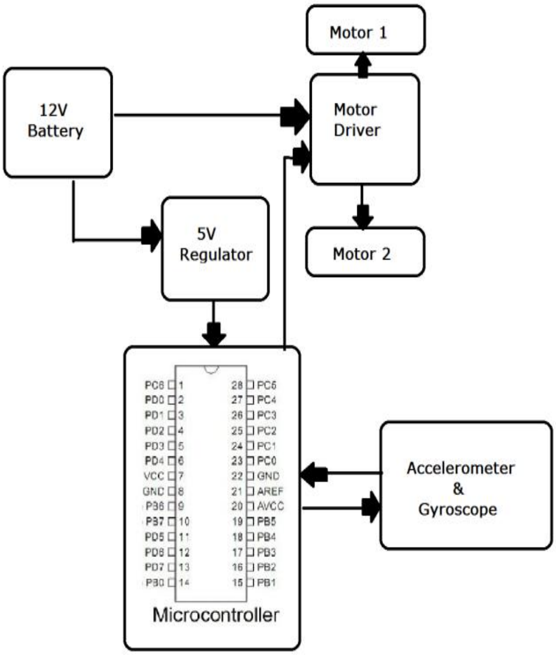

Fig. 5 Block Diagram

30. **End Use**. The future developments of the project can integrate the steering mechanism on a much larger system with enhanced torque and power with longer battery life. The vehicle with appropriate motors and a ruggedized chassis can be used in shop floors, hospitals, large office spaces (Integrated Headquarters) and dockyards where movement of men can be achieved fast and in an efficient way.

KALEIDOSCOPE OF TRAINING ACTIVITIES UNDERTAKEN AT INS SHIVAJI

1. **Training Activities - MESC (60.084)**. Fifty three officers including 32 *IN*, 07 CG and 14 International officers from foreign friendly navies are undergoing MESC Phase II. The course is scheduled to pass out on 06 Jan 18 after a rigourous professional training of 79 weeks. The officers of the MESC are trained on the various aspects of marine, mechanical and control engineering, NBCD aspects, basic electrical engineering, men & material management, military leadership, naval warfare as part of their course curriculum. The officers of the course has actively participated in all training, sports and extra curricular activities.

(a) **Outdoor Training Activities**. Outdoor training activities were conducted to ensure grooming of young officers. Various outdoor activities undertaken during the period include Inter Divisional Football, Jaltaran and Dramatics. The officers have participated as Directing Staff for Camp Aakraman.

Fig. 3 Inter Divisional Dramatics Competition

Fig. 4 MESC officers as Directing Staff for sailor's camp

Fig. 5 and 6 Inter Divisional Sports Events

(b) **Hands on Skill (HoS) training**. HoS training for officers undergoing MESC is conducted in addition to classroom sessions for better appreciation and understanding of functioning of machinery and equipment.

Fig. 7 and 8 Hands on Skill Training

(c) **Guest Lectures**. Regular guest lectures are conducted for the officers undergoing MESC by domain experts encompassing fields such as defence journalism, financial management, Management of Change for overall grooming of officers before taking their first appointments.

Fig. 9 Conduct of Various Guest Lectures for MESC

Fig. 10 MESC officers attending Technical Seminar 17

(d) **Industrial Visits**. For better understanding and appreciation of assembly line manufacturing processes, productivity in terms of output, latest trends in manufacturing industries, officers during their course visit various industries.

Fig. 11 and 12 Industrial Visits

2. **Training Activities – Passing Out of MAAC Course**. On 11 Aug 17, 153 trainees of MAAC XXIV course passed out after successful completion of 117 weeks of training at INS Shivaji. The course comprised of 105 *IN*, 23 *CG* and 25 International trainee sailors. During the entire term of course, the trainees underwent specialized training in internal combustion engine, gas turbine & steam propulsion system. The trainees were also exposed to NBCD training at NBCD School to cover various nuances of damage control, fire fighting, and Nuclear, Biological and Chemical warfare methods. The ceremonial parade on the occasion was reviewed by Commodore KP Arvindan, VSM Commanding Officer, INS Shivaji. He reiterated that continuous efforts need to be put in by trainees to keep acquiring knowledge and serve the Navy in an utmost professional manner. PK Sahoo, U/NVK (ME) was adjudged best all round trainee of the course. Course passing out Barakhana was organized with Commanding Officer on 09 Aug 17 at Drill Shed. The Commanding Officer interacted with the Trainees and stressed upon the technological advancement by the Navy.

Fig. 13 Award Ceremony and Passing Out Barakhana of MAAC XXIV Course

3. **Training Activities – Passing Out of DEME Course**. 225 trainees of DEME Course 60.939 including 177 *IN*, 38 *CG* and 10 international trainees passed out after successful completion of 25 weeks training on 08 Sep 17. A passing out Barakhana with Commanding Officer was organized for the course on 07 Sep 17 in Drill Shed. The Commanding Officer interacted with the trainees and stressed upon the future

prospects of the passing out trainees. The principal focus of this ab-initio course at Shivaji was to prepare the sailors to be worthy professionals and exemplary leaders in the engine room departments of their respective warships. In addition to academics, the sailors have been exposed to sports, adventure and co-curricular activities namely cycling expedition, day treks to various forts of Chattrapati Shivaji, visit to Symbiosis International School of Arts and Monsoon concert. This course had the opportunity of participating in the Maiden camp for DEME trainees, Abhyaas-17 which was introduced with this course to give them a feel of military training and outdoor living.

Fig. 14 Passing Out Parade of DEME Course

4. **Independence Day Barakhana**. Independence Day Barakhana with Commanding Officer was organized on 15 Aug 17 in Drill Shed. 60 trainees from DO (T) participated in the event. Commanding Officer interacted with DO (T) trainees and advised trainees to update their professional knowledge to handle the equipment fitted on board newly inducted ships in Indian Navy.

Fig. 15 Independence Day Barakhana

5. **Badge Distribution Ceremony**. Badges were distributed to International trainees from the following courses during the period:-

(a) Badge ceremony for LME'Q' (08), CHERA'Q' (04) and MAAC XXVII (01) Course was held on 17 Jul 17.

(b) Badge ceremony for 10 International trainees from DEME (60.940) course was held on 20 Sep 17 and 26 Sep 17.

Fig. 16 Badge Ceremony for International Trainees

6. **Independence Day Celebrations**. On occasion of 52nd Maldives Independence day, 47th Fiji Independence day and 57th Nigerian Independence day, Commodore KP Arvindan, VSM, Commanding Officer INS Shivaji handed over congratulating letters to the senior most trainee from Maldives,

Fiji and Nigeria. Officer-in-Charge, CMET interacted with international trainees from Maldives, Fiji and Nigeria and enumerated regarding warmth in relationship amongst two countries and congratulated all trainees on the occasion of their Independence Day.

Fig. 17 Maldives Independence Day

Fig. 18 Nigeria Independence Day

7. **Proficiency and Cash Awards**. On the occasion of Independence Day, proficiency and cash awards were awarded to DO(T) staff and trainees in Drill Shed. Divisional Chief Sudhagad, MR Mishra, CHERA and 12 trainees were awarded the proficiency awards by Commanding Officer. Commanding Officer reiterated on continuous efforts to be put in by trainees to keep acquiring knowledge and skill and serve the Navy in utmost professional manner.

Fig. 19 Proficiency and Cash Awards

8. **Outdoor Training Activities**. A host of training activities were undertaken for trainee sailors of DO (T) to ensure good military bearing and better physical fitness of over 2500 young budding trainee sailors including almost 100 international trainee sailors. Various outdoor activities undertaken during the period included trek to saddle point, various Intra DO (T) sports championships like table tennis, carom, handball and Camp Joshila. In addition, intra DO (T) Quiz and Hindi debate competition, Rainbow Night-17, and club exhibition were organized. Some of the activities are as follows:-

(a) **Trek to Saddle Point**. A trek to Saddle point was conducted on 26 Aug 17. Senior Divisional Officer flagged off the trek at 0630 hrs in front of Gomati block. 188 trainees from DO (T), one medical assistant, one divisional chief and 02 assistant divisional officers led by Lt Sudeep Bhattarai participated in the event. All participants completed the trek successfully.

Fig. 20 Trek to Saddle Point

(b) **Sports Championships**. Trainees participated in following sports championships :-

(i) **Table Tennis**. Intra DO (T) Table Tennis Championship was held from 05 Jul 17 to 07 Jul 17 at Betwa block recreation room. Lohagad division emerged as winner division.

Fig. 14 Table Tennis Championship 2017

(ii) **Carrom**. Intra DO (T) Carrom Competition commenced on 23 Aug 17 at Gomati rec. room. The aim of the competition was to develop analytical skills, enhance the level of competitiveness and encourage logical analysis and development of thoughts amongst the Trainees. Korigad division secured the first position.

Fig. 21 Carrom Competition 2017

(iii) **Handball**. Intra DO (T) Handball Championship commenced on 03 Oct 17. All trainees contributed their best in the championship. Korigad division won the championship.

Fig. 22 Handball Championship 2017

(c) **Camp Joshila – 17**. A four day training camp Joshila-17 was flagged off on 20 Nov 17 at 0630 hrs by Capt. Sumeet V Shidore, Officer-in-Charge, CMET, in which 141 trainee sailors of MAAC-XXVI participated. A Camp fire was organised at the camp site for MAAC XXVI course at 1830 hrs on 22 Nov 17. Commodore KP Arvindan, VSM, Commanding Officer, INS Shivaji was the chief guest for the event. Commanding Officer emphasized on importance of being physically fit and mentally tough to the trainees. The camp got culminated on 23 Nov 17 after the main Josh run. Officer-in-Charge CMET, presented the participants with prizes and emphasized on importance of camping activities. Sudhagad emerged as champion division whereas Lohagad was runners up.

Fig. 23 Camp Joshila – 17

(d) **Industrial and Educational Visits**. As an effort to acquaint trainees with best practices of the industry, visits to following institutions were organized :-

(i) M/s Refractories and Shapes Ltd., Pune on 08 Nov 17 for 169 trainees of MAAC XXVI course.

(ii) M/s Symtronics Automation Pvt. Ltd., Pune on 23 Sep 17 for 78 trainees of MAAC XXVI ICE II class on 06 Apr 17.

(iii) M/s Perci Forge and Gears Ltd., Pune for 40 trainees of MAAC XXV class.

(iv) M/s Mazgaon Dock Private Limited and Bhabha Atomic Research Center of MESC officers on 18 Oct 17 and 28 Nov 17 respectively.

Fig. 24 Industrial Visit

(e) **Monsoon Concert – 17**. Monsoon Concert was conducted at Menaka Auditorium for DO (T) Trainees and staff members. Commodore KP Arvindan, VSM, Commanding Officer INS Shivaji was the Chief Guest of the event. Commanding Officer interacted with all the participants and appreciated their effort to make Monsoon Concert a grand success.

Fig. 25 Monsoon Concert

(f) **Swachh Bharat Abhiyan**. Maha Shramdan on occasion of Swach Bharat Abhiyan was organised on 17 Sep 17 and 02 Oct 17 at DO (T). All divisional Officers, DO (T) staff and trainees participated in the event.

Fig. 26 Swachh Bharat Abhiyan

(g) **Aero Modeling Show on Air Force Day**. Aero Modeling Association of India, Pune chapter conducted Aero modeling show at parade ground on occasion of 85th Air Force Day on 08 Oct 17. 200 Naval SCC Cadets and 100 DO (T) trainees participated in the event. 13 members of Aero Modeling Association of India also participated in the event. The event was conducted by Lt. Sudeep Bhatarai assisted by M R Mishra, CHERA.

Fig.27 Aero Modeling Show

ON THE HORIZON

1. To remain abreast with constantly evolving technology, the training methodology at Shivaji for Naval Engineers is also updated to sustain high confidence levels whilst operating new induction ships and state-of-art technologies. Shivaji has always strived hard to impart quality training in Marine Engineering to officers and sailors. Training methodologies have evolved from theoretical instructions to use of Live Equipment for Maintenance Oriented Training (MOT), Computer Based Training Technologies, Simulators, Modern Tools / Test Equipment and Reference Systems.

2. "On the Horizon", attempts to appraise the technical fraternity and the Naval Community on ongoing activities and future plans of team Shivaji.

3. **Management of Machinery Controls Onboard**. Towards re-aligning the responsibility of upkeep and maintenance of Engineering machinery systems, a new approach of single point responsibility was implemented onboard ships by IHQMoD(N) in May 17 and accordingly personnel are being trained in phased manner to undertake the mandate promulgated by IHQMoD(N). Accordingly Officer's PCT, Control ERA and ME courses were commenced at INS Shivaji.

(a) **Officer's PCT**. Post completion of PCT at PCT school, INS Shivaji, the Officers are attached to SECON wing for a period of four weeks to undergo Control oriented PCT for equipment fitted on board respective classes of ships. The four week Officer's PCT was divided into two parts. The first part of two weeks was aimed to orient officers on ship specific control systems undertaken through circuit tracing and identification of components whereas two weeks were utilized for type specific training by OEMs, as arranged by IHQMoD(N)/DME.

(b) **Control ERAs**. Maiden control ERA course commenced at INS Shivaji we.f. Jul 17 for duration of 21 weeks with a borne strength of 24 ERAs. The training of control ERAs was divided into two phases. While the initial phase was dedicated to orient the trainees on basics of electrical and electronics components, the later phases were used for learning the nuances of deciphering drawings, circuit tracing and live control panels. The practical training started with basics of usage of INCRETE equipment like multimeter, tong tester, EMC meter, megger, digital storage oscilloscope etc and soldering/ desoldering of components, the later half was used to gain confidence and expertise towards fault diagnostic capability. The trainees were exposed to all training sessions conducted by OEMs for the officer's PCT classes and were additionally sent on two industrial visits. While one visit was to M/s L&T where the firm reps gave an overview of IPMS being installed on P-15B ships, the other visit was conducted onboard Tarkash where training on live system was undertaken. In addition, two trainees were sent for five day capsule course for MCS-V training at Mumbai.

(c) **<u>Control MEs</u>**. The first batch of control MEs commenced on Aug 17 with a borne strength of 75 MEs. The trainees underwent nine week extensive training on machinery controls and instrumentation. The course was conducted with special emphasis on maintenance of basic electrical safety and hygiene, utilisation of CRETE equipment and store management of engineering controls spares and record keeping for defects/ repairs.

Fig. 1 HoS undertaken by Control ERAs/MEs

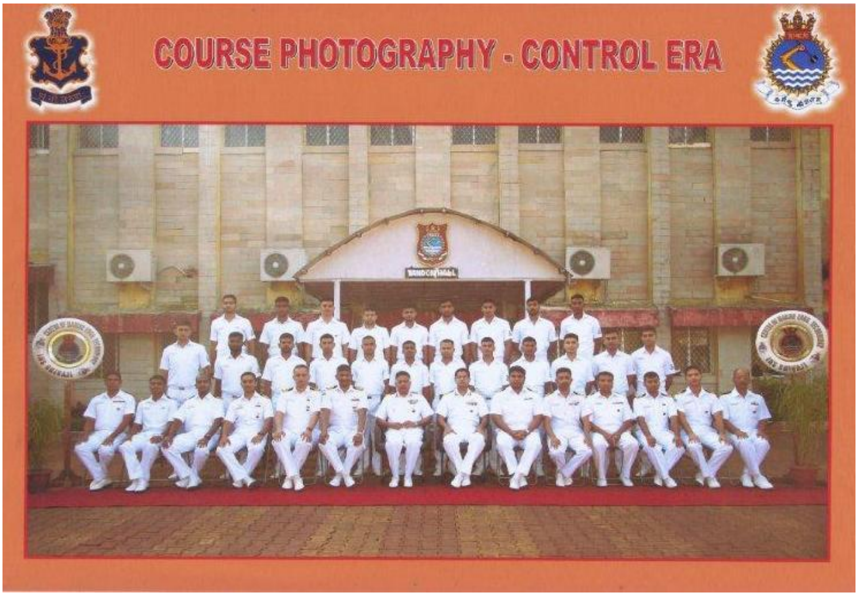

Fig. 2 Course Photography of Control ERA Course

4. **Commencement of Bridging Engineering Course**. The maiden Bridging Engineering Course (BEC) approved by IHQ MoD(N) commenced at INS Shivaji wef 26 Dec 17 as an additional MESC phase. The course would comprise of 20 weeks of training at INS Shivaji followed by three weeks of afloat attachment and three weeks of leave as per ATP. With the implementation of this course, the conduct of the MESC shall spread over three phases; Bridging Engineering Course as MESC phase I, present MESC phase I as MESC phase II and present MESC phase II as MESC phase III. The course being marine engineering oriented is being conducted by Centre of Excellence (ME), as a prelude to equipment focused training during the subsequent MESC phases. Three PG instructors have additionally being appointed at CoE for ensuring smooth conduct of the course. Preparation of course syllabi, lesson plan and other activities towards commencement of the course has been completed and forwarded for approval. HQSNC vide fax TR/8432 dated 18 Dec 17 has accorded approval for implementation of block and master syllabus for Marine Engineering Specialisation Course.

5. **Grading of Officers and Sailors for Instructor Potential**. Grading of trainee officers and sailors for instructor potential is being carried out i.a.w. HQSNC training directives for MESC, CHME and CHERA courses. The trainees have been graded according to their instructor potential and the gradings are forwarded along with course analysis report. The grading will help to identify potential officer and sailor instructors so that they may be posted in training establishments.

6. **Creation of Pratigya Sthal**. An Ashoka Stambha has been installed at the inner gate of INS Shivaji and offers an inspiring first view as one enters the portals of the premier technical training establishment. The unveiling ceremony was undertaken on 13 Nov 17 by Devendra Kumar from XVIth Merged Artificer Apprentice Course in presence of Vice Admiral AR Karve, AVSM, Flag Officer Commanding-in-Chief, Southern Naval Command, Vice Admiral GS Pabby, AVSM, VSM, Chief of Materiel, Integrated Headquarters, Ministry of Defence (Navy) and other dignitaries. The area has been named as 'Pratigya Sthal' which comprises of the Ashoka Stambha, which stands tall at 20 feet, a 'Prerna Bhiti' (wall of inspiration) and statue of Chhatrapati Shivaji Maharaj, the great Maratha warrior after which the establishment has been named. Establishment of the 'Pratigya Sthal' against the backdrop of Ashoka Stambha shall instill the core values of duty, honour, courage and patriotic fervour to the trainees of the establishment. All trainees who pass through the portals of the institution annually will be taking oath of allegiance to the nation at this solemn place henceforth. The installation will provide the much needed symbolic value during various scheduled visits/ inspections and cultural events, when both military and civilian dignitaries and guests would be in the establishment with a view to enhancing the element of pride and patriotism amongst one and all.

Fig. 3 Establishment of Pratigya Sthal at Inner Gate

Fig. 4 Installation of Ashoka Stambha and Prerna Bhithi

7. **Renovation of Motivation Hall**. The motivation hall at INS Shivaji was renovated in the month of Nov 17 prior commencement of Techsem – 17. The renovation of museum includes up gradation of entrance canopy, cladding of main entrance partition, provisioning of custom made 3-D 'niches', fitment of false ceiling, fitment of modern stainless steel signage and operationalisation of lights and sounds show. The Museum was registered under Society Registration Act (1860) as the Naval Engineering History Society (NEHS). The motivation hall, established on 15 Feb 1995 during Golden Jubilee Celebration has been renovated to provide facelift to the "Hall of Fame". The

renovated motivation hall was inaugurated by Rear Admiral RJ Nadkarni, VSM, Chief of Staff, Southern Naval Command. The renovation work includes external wall cladding with water proofing and redesigning of six rooms including the alleyways and staircase with the streamlined flow of information. The six sections of the motivation hall are Shivaji Room, Torch Bearers Room, Ship's Activity Room, Naval College of Engineering and the Cadets Training Section.

Fig. 5 Inauguration of Renovated Motivation Hall

8. **Construction of 200 Men Trainee Block with Galley – 'Shivalik'**. In order to cater accommodation for increased annual throughput of trainees and to improve their living standards, it was proposed to construct a 200 men trainee block with dining hall and galley. The 200 men trainee block was sanctioned under AMWP 2013-14 and contracted by CE(NW) Kochi to M/s Duwell Agencies, Pune in Nov 2013. The sanctioned amount for the project was 741.24 lakhs and the contracted amount is Rs 664.94 lakhs. The work is still in progress and is expected to complete by early Jan 18. Following are the salient features of the project:-

(a) Living Accommodation Floor Area – 3272.69 Sq Mt (G+3)

(b) Dinning and Galley Floor Area – 485.2 Sq Mt

(c) Partitioned dormitories thereby giving each trainee his own space.

(d) Introduction of the concept of central study room delinking living spaces from study spaces.

(e) Usage of renewal energy in line with the nations' aim of going green. This block being the first trainee block at the station fitted with solar panels for water heating.

(f) Towards interconnecting and integrating various trainee blocks and dining halls, this building has been designed with covered interconnecting passages thereby ensuring easy movement for trainees even during peak monsoons.

9. **Conduct of Embedded Technology Course.** Control systems onboard ships are getting more sophisticated with better reaction times, reduced operator errors and user friendly features to enable complete platform management. Therefore, to give an insight on the engineering control systems, Linux operating system, microcontrollers and introduction to embedded & Real Time Operating Systems, a certificate course on Embedded Technology for 25 Engineers (officers and sailors) was conducted at INS Shivaji from 07 Nov - 26 Nov 16 through CDAC, Chennai. Based on the positive feedback, a MoU between INS Shivaji and CDAC Chennai for conduct of Certificate Course in Embedded Technology was signed on 05 Sep 17, wherein, 25 Engineers would be trained every year till 2022. Accordingly, the second course has commenced wef 07 Dec 17 with participation from all commands including civilian dockyard workers.

Fig. 6 MoU with CDAC for Conduct of Embedded Course

Centre of Excellence (Marine Engineering) - Recent Activities

10. Centre of Excellence (Marine Engineering) since its inception on 31 Jul 14 has come a long way and is further gearing up to expand horizons in the field of Marine Engineering. A gist of major activities progressed at CoE (ME) over the last six months, are enumerated in succeeding paragraphs.

Professional Domain

11. **Preparation of Specifications/ SOTRs/ SQRs**. Following SOTRs were drafted and forwarded to Professional directorate:-

(a) SOTR on Lube oil and Fuel oil Centrifuge – Jul 17

(b) SQR repair/ test facility for HP air compressors – P75 - Jul 17

(c) NSQR on Breakable Spool Coupling – Jul 17

(d) SOTR on 1500 KW Turbo Generator-Vikramaditya – Aug 17

(e) SOTR on Oil Turbo pump (OTP) for MTGA and TBU for INS Vikramaditya - Aug 17

(f) SOTRs for F/W and S/W pumps – Oct 17

(g) SOTR for Plate Type Heat Exchangers – Nov 17

(h) Draft SQR for repair / test facility for MAN 12 PBA -200 SMDs engine used on P-75.- Nov 17

(j) Draft SQR for repair / test facility for AC and refrigeration plant make SNORI used on P-75.- Nov 17

(k) Draft SQR IPMS, steering console reference system extended D-level maintenance repair facility for P-75 - Nov 17

12. The following Professional Studies were undertaken and detailed study reports forwarded to IHQ MoD (N)/ DME and HQSNC/ CEO:-

(a) **Air Conditioning / Cooling Techniques for Engine Rooms**. The Engine Room temperatures onboard ***IN*** warships have been observed to be high due to running machinery and associated ventilation system issues. The provision of cooling for the engine rooms as well as air intakes of major prime movers would not only enhance machinery performance but also human comfort. A detailed study was undertaken by the Centre of Excellence (ME) in accordance with the promulgated terms of reference and in consultation with IITs, various OEMs engaged in R&D in the said technology. A comprehensive literature survey referring some of the recent research papers published in International Journals in relevant fields was undertaken to get an insight about the various technologies which are in vogue/ under development. A detailed study report has been prepared and forwarded to IHQ MoD (N)/ DME in Nov 17 highlighting various alternative non-conventional cooling systems developed/ being developed in India and abroad; for eg. thermoelectric, vapour absorption/ adsorption, thermo-acoustic, supercritical/ trans-critical CO_2 based power (Brayton Cycle) and cooling (Vapour Compression) systems, panel heat exchangers etc. along with pros & cons, practical feasibility of usage as retro-fitment or for new induction and suitable way ahead in adopting these technologies onboard IN ships.

(b) **Effective Utilization of Torsionmeters**. A study was undertaken of the existing fit (make & model), operational status, repair and maintenance aspects of Torsion Meters to identify causes for in-effective utilization, lacunae in utilization pattern and recommend suitable way ahead to ensure effective utilization of the Torsion Meters. A comprehensive report recommending way ahead for effective utilization of torsionmeters was forwarded to IHQ/ DME in Aug 17. During the course of the study, it was observed that in majority of the cases, the torsion meters were non operational due to following reasons:-

(i) Lack of OEM support.

(ii) Non availability of Spares.

(iii) In-adequate operator and maintainer level training at Ship/ Yard.

(iv) In-adequate repair facilities / expertise.

(v) Non standardization of Torsionmeter models view varied makes/ models.

(vi) Non integration with ship's main propulsion plant monitoring and control system.

(c) **Preparation of Revised Formats for Service Log Books for Diesel Engines**. Centre of Excellence was tasked to prepare a draft format for 'Diesel Engine Service Log' for inclusion in future contracts/ SOTRs vide IHQ fax ibid. The revised service log formats was prepared with an aim to make a single reference document which can be used throughout the engine service life (womb to tomb) and contains all pertinent information required to understand the history and provide a holistic information about maintenance, in-service exploitation, defects observed and design modifications if any undertaken on the engine. Two separate 'Diesel Engine Service Log' formats one for propulsion and one for power generation applications inclusive of following critical aspects and other essentials considered necessary for data and record keeping has been compiled and forwarded to IHQ MoD(N) / DME:-

(i) Recording of critical engine parameters like exhaust back pressure, air intake restriction, blowby measurement, boost pressure of TC, pressure drop across charge air coolers, temperature drop across Heat Exchangers etc.

(ii) Record of safety device checks.

(iii) Record of coolant and POL analysis.

(iv) Record of SV mounts defections.

(v) Recording of peak pressures.

(vi) Record of advance engine health monitoring including combustion and Narrowband analysis.

(vii) Record of valve tappet setting.

(viii) Record of valve and fuel injection timing data.

(ix) Engine preservation and packing certificate

(x) Engine alignment readings.

(xi) Service power deduction and de-rating graphs.

(d) **Capability Study of Industries & Institutes**. The present day industrial evolution and economical challenges of the modern times have propelled the Indian industries to take on research and development activities in emerging technologies to meet the requirements of diversified global customers. This has led to engaging multiple collaborations with individual industries catering to a specific field of engineering thereby helping various OEMs to advance their R&D activities and release innovative products in a short time-frame. The collaborations not only result in efficiency improvements, but also enhance product design and development besides reducing cost. As a result, various government sectors/ PSUs have also adapted this methodology to enhance their capability and competency for undertaking R&D activities. Accordingly, INS Shivaji/ CoE in consultation with IHQ / DME is engaging with various industries / institutes / academia of repute to harness their capabilities towards development of mission worthy marine engineering equipment, as an exercise to address and resolve field level issues and as a precursor for induction of new cutting edge technologies. To date, detailed capability study reports along with major highlights and recommendations in respect of following institutes / industries have been forwarded to IHQ /DME and HQSNC / CEO:-

(i) Crucible for Research and Innovation [CORI], PESIT, Bangalore

(ii) Indian Institute of Science [IISc], Bangalore

(iii) M/s Resin & allied Products, Vijaywada

(iv) Naval Science and Technology Laboratory, Visakhapatnam

(v) BHEL Heavy Plates and Vessels Plant, Visakhapatnam

(vi) M/s Zeus Numerix, Pune

(vii) M/s Knowledge Stream, Pune

(viii) Tata Consulting Engineers Ltd, Pune

(ix) National Chemical Laboratory, Pune

13. **MoU with IIT(B) for Research Collaboration, Technology Development and Technical Solutions**. An umbrella MoU has been concluded on 15 Dec 17 with IIT Bombay for Research Collaboration, Technology Development and Technical Solutions post obtaining approval from IHQ MoD(N)/DME letter EG/1308/CAM dated 20 Oct 17. The MoU would give an impetus to Naval organizations / Units towards evaluation of technologies, assessment of equipment, promote academic cooperation, resolving recurrent and critical issues experienced in their relevant fields. The MoU would also facilitate research under the Indian Naval Technology Board (INTB) to undertake R&D activities for naval applications in mutually

beneficial areas. The broad spheres of study as part of the MoU would include the following:-

(a) Various fields of Engineering such as Mechanical, Electrical, Civil, Electronics and Communication, Computer Science and Engineering, Bio-Science and Bioengineering including Medical applications, Design, Aerospace Engineering, Education Technology

(b) Propulsion and propulsion systems

(c) Steel Technology, Metallurgy and Material Sciences, and Corrosion Science.

(d) Systems and Controls, Instrumentation and Sensors.

(e) Environmental Science and Engineering, Energy Science & Engineering

(f) Management – Technical and Logistics

(g) Industrial Engineering and Operational Research

(h) Nanotechnology and MEMS (Micro Electro Mechanical Systems)

(j) Any other Engineering discipline/ Branch of Science/ subject of mutual interest.

Fig. 7 Signing of MoU between *IN* and IIT Bombay

Academic Domain

14. **Technical Seminar on ‘Main Propulsion Systems – Roadmap towards Self Reliance’**. A two day Technical Seminar “TECHSEM 2017” was conducted at INS Shivaji on 13 and 14 Nov 17 on the central theme ‘Main Propulsion Systems-Roadmap towards Self Reliance’. Vice Admiral AR Karve, AVSM, Flag Officer Commanding-in-Chief, Southern Naval Command was the chief guest for the Seminar and delivered the inaugural address wherein he highlighted the inclusion and importance of ‘Design’ category along with ‘Move’, ‘Float’ and ‘Fight’ categories in our efforts towards building true Self Reliance with indigenization as its key pillar. The sub themes on the sidelines of the central theme included the following:-

(a) Harnessing Indigenous Manufacturing Capabilities

(b) Development of Indigenous Propulsion System Integration Capability

(c) Self Reliance in new Induction Main Propulsion Systems – Challenges & Way Ahead

(d) Integrated Full Electric Propulsion – Challenges and Way ahead

(e) Advancement in Health Monitoring Systems for Effective CBPM

(f) Emission Norms, Alternate Fuels & IN Roadmap.

Fig. 8 Release of Compendium and Delegate Photography of TECHSEM 17

15. The seminar aimed to bring together diverse stake holders from various fields to share experiences and present viable models in tandem with the National Maritime Military Strategy and included participation of *IN* reps from IHQ MoD (N) and all commands, representatives from academia, Indian Defence Industry Sector, Ship Repair Industries, Foreign/ Indian OEMs. Over 50 papers were received from authors ranging from *IN* Officers to Indian/ Foreign Industry Reps, out of which 20 were included in the Seminar Compendium and a total of 14 technical papers were presented in a span of five sessions during the two day seminar.

(a) **Session I - Self Reliance on New Induction Main Propulsion Systems – Challenges & Way Ahead**. Two papers were presented on this sub-theme; first one by Capt Anup Menon from IHQ MoD(N)/DME and the second paper by Mr. SM Mujumdar of M/s KOEL, Pune. The first speaker brought out present initiatives of Naval Headquarters to harness technology and plan for future interaction between academia and labs for solving field level problems. The second speaker highlighted on aspects of self reliance in indigenous manufacture of diesel engines for Indian Naval applications.

(b) **Session II- Integrated Full Electric Propulsion Challenges and Way Ahead**. Three papers were presented on this sub-theme. In the first presentation, Mr. Brian Pope from M/s L3 adequately surmised the application of electric propulsion in both commercial and naval fields. In the second presentation, Capt CK Singh brought out advantages of using IEP onboard Naval platforms and highlighted the suitability to meet environment norms. In the third presentation, Mr. Salter from M/s GE brought out the practical implications of the technology and the challenges faced with the help of the aircraft carrier HMS Queen Elizabeth.

(c) **Session III- Self Reliance – New Induction Main Propulsion System**. Two papers were presented during this session; first one by Lt Cdr Sahil Kapila from WOT (Mbi) wherein he highlighted various facets related to achieving indigenization in main propulsion system. During the second presentation, speakers from M/s

Vericor and M/s Triveni presented the technical features of the marine gas turbine TF 40 that finds application as prime mover for marine generator.

(d) **Session IV- Development of Indigenous PSI Capability**. In the first presentation by Capt V Ganapathy, it was brought out that Marine Propulsion System Integration requires a systems engineering approach towards formulating a comprehensive solution for the design, identification of requisite hardware, simulation, integration, commissioning and deployment. The second speaker Mr. Mahabaleshwar from M/s DCNS brought forth the challenges associated with naval propulsion system and how they can be mitigated by an experience Propulsion System Integrator. During the third presentation, Mr. Bernd freidrich from M/s MAN Diesel had brought out that PSI requires an interdisciplinary approach where in mechanical, electrical and hydrodynamics needs to be combined and integrated to achieve the overall optimum plant.

(e) **Session V- Energy Efficiency, CBPM & Acoustics**. Four papers were presented during this session. In the first presentation, Cdr R Prakash from IHQ MoD(N)/DME had aptly brought out the need for synergy amongst all the involved agencies to collaborate for flow of information and technology towards design of energy efficient propulsion and power generation systems. In the second presentation, Mr. Juergen Mueller from M/s MTU presented various measures to reduce magnetic signatures using state-of-the-art techniques as wells as propulsion systems that aid in reducing magnetic signatures. In the third presentation, Capt. Jasvir Singh from MTU(Mbi) had brought to fore the significance of an effective acceptance testing program to avert any inheritance problems by the plant. In the last presentation, Capt. Giriprasad from MTU (Vzg) had highlighted the importance of noise reduction from shipboard machinery to sea water towards achieving stealth feature.

16. **Continuous Education Programmes (CEPs)**. One week Continuing Education Programme (CEP) on 'Nuclear

Technology for Warships and Submarines' was conducted from 28 Aug to 02 Sep 17 at CoE (ME), INS Shivaji. The CEP as a technology update course was designed with an aim to provide the participants with insight into the various aspects of latest technologies which are in vogue and which are likely to be used in future in respect of nuclear propulsion. The major topics covered as part of the programme included an overview of naval nuclear program, basics of nuclear science, types of nuclear reactors, reactor physics, marine nuclear power plants, nuclear fuel management and safety aspects, ship building considerations, challenges of setting up of nuclear propulsion plant, nuclear reactor operations and development of Indian Nuclear Industry to name a few.

17. The CEP was attended by 22 Naval officers from various commands and guest faculty comprised of specialists in the nuclear related field, from Academia, Industry, R&D and senior *IN* Officers. RAdm Atul Khanna, VSM, ACOM (NSM) was invited as part of the CEP programme and delivered a lecture on the topic "Management of Nuclear Technology- Challenges and Opportunities".

Fig. 9 R Adm Atul Khanna, VSM, ACOM (NSM) delivering lecture

18. Other prominent speakers who graced the CEP included *IN* Officers from ATVP (Vzg), SBC and INS Satvahana/ SAUW, faculty from academic organizations such as BARC and IIT (Bombay), Indian Industry Firms from M/s Pune Instruments and M/s Walchand Nagar Industries Limited.

AWARD WINNERS – OFFICERS
MESC (60.084)

Award/ Prize	For	Awardees
The Hammer & Book Prize	Best 'All Round Officer'	SLt Amardeep Singh Jaswal, 43786-N
CNS Rolling Trophy & Book Prize	First in Order of Academic Merit	SLt Priya Ranjan, 43797-N
Book Prize	Second in Order of Academic Merit	SLt Harith Lal M, 43774-K
Rolling Trophy & Book Prize	Best Project Syndicate Design and Development of portable & wireless emergency SOS push button for engine room watch keepers and implementation pan Navy/CG ships	A/C Dhanasekar S, 4306-L A/C Nekuri Nikhil, 4309-Q A/C Rahul Prasad R, 4308-P Lt MPP Fernando, NRE 3113
Commodore's Trophy & Book Prize	Positive Living	SLt Rahul Sharma, 43794-F
VAdm Daya Shankar Trophy	Best in Sports	SLt Sohrab Mohammed K, 43768-Y
DGCG Rolling Trophy	Best CG Officer	A/C Dhanasekar S, 4306-L
FOCINC (South) Rolling Trophy	Best International Trainee Officer	Lt LDTKD Lokudadalla, NRE 3088

AWARD WINNERS – SAILORS
FIRST IN ACADEMICS

Course	Stream	Awardees
MAAC XXIV	ICE GT STEAM	P K Sahoo, U/NVK(ME), 11106-S Mohit Bhatt, E/A, 504365-K Ishwar Singh Panwar, LME, 232289-F
Commodore's Rolling Trophy	Best Sportsman	Utkarsh Bhardwaj, E/A, 504149-W
International Trainee	ICE	Imukusi Edwin, CPO, 17276840
International Trainee	Best International Trainee	Ahmed Mohamed, SGT, 4835
DEME (60.939)	ICE GT STEAM	T Pavan Kumar, DEME, 244306-T Deepak Singh Mahar, DEME, 244817-B Kamaljeet Singh, DEME, 244890-W
DEME (60.939)	Best Sportsman	Sachin Singh, DEME, 245509-A
International Trainee	ICE	Majaliwa Godlove Zakayo, LS, MT79226

BEST ALL ROUND SAILOR		
Course	**Stream**	**Awardees**
MAAC XXIII	DEDH Mech/NEA/E/A	A Mahapatro, YTK (E/R), 40154-P P K Sahoo, U/NVK(ME), 11106-S
DEME (60.938)	ICE, GT, STEAM	Kamaljeet Singh, DEME, 244890-W

KIND ATTENTION TO AUTHORS
PLAGIARISM

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The thin line between permissible literary and impermissible source code Plagiarism is finally left to the maturity level, morality, integrity and honesty of the author. In short, authors are requested to adhere to the guideline. ***If you did not write it yourself, you must, at least, give due credits.***