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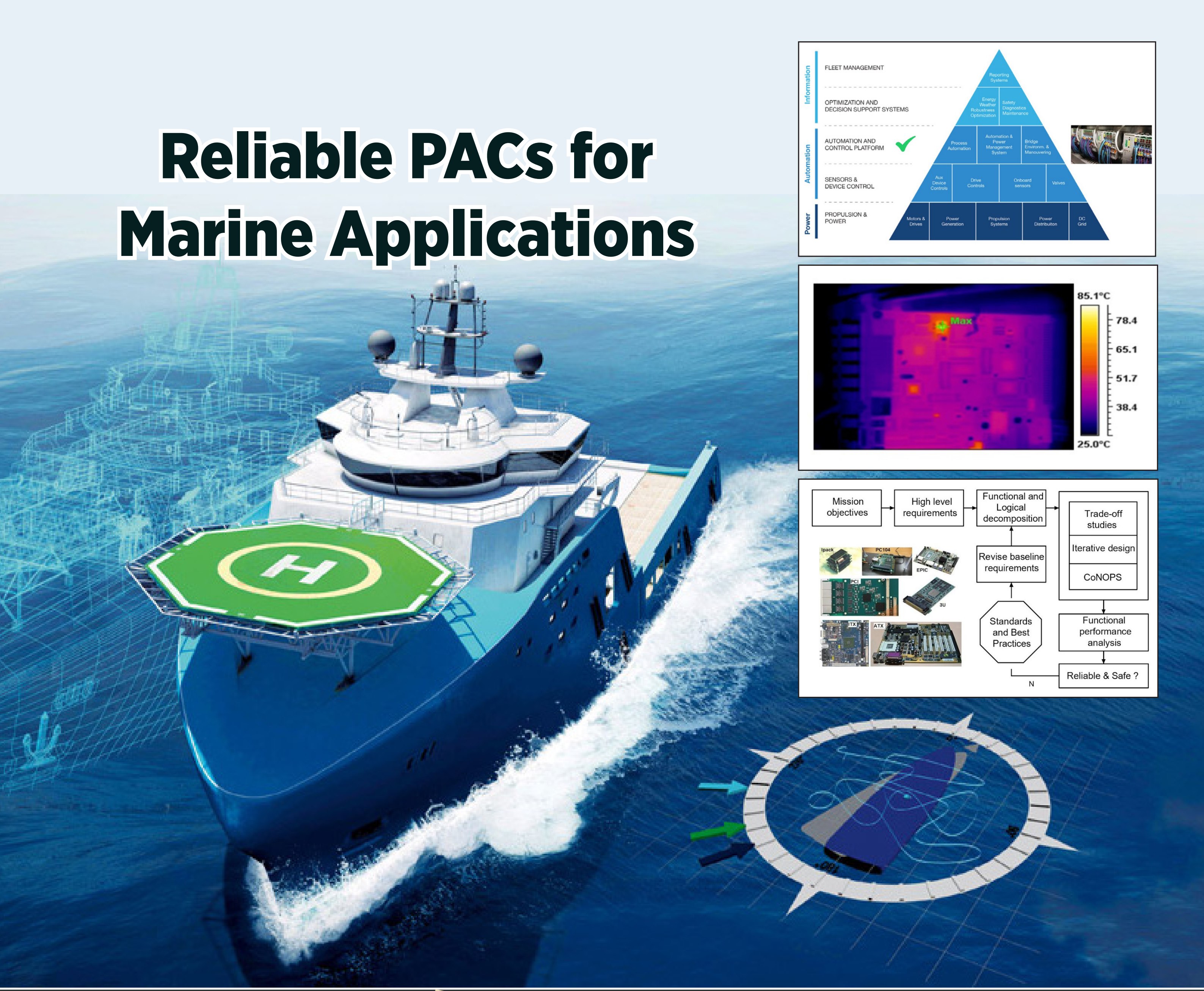
Reliable PACs for Marine Applications



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EDITORIAL

Our success has really been based on partnerships from the very beginning.
- Bill Gates

The recently held follow-up event on the Global maritime India Summit (GMIS) 2030 has more to discern than the optics which go with such events. The seriousness brings in accountability along with action lest the MoUs and projects fall into desuetude. GMIS had drawn a mammoth investment potentials valued at INR 10 lakh crore and memorandums (approx. 360) with indicative investments of over INR 8 lakh crores. There were additional investments also in sector-focussed areas of port development, fuels, shipping business and knowledge sharing.

This GMIS Stakeholders meet had the presence of the Ministry, the Ports and also the industry. There were deliberations on issues voiced by the executors (industry/ports). The occasion saw the release of the Guidelines for National Benchmarking of Ports (Sagar Aankalan) and keywords of Maritime Amrit Kaal 2047 and India's maritime potential got mentioned. Though these were fewer than what would emerge from such projects, they were not token words either. The need for land and infrastructure and freeing the project from bureaucratic bus stops are typical hurdles.

A noticeable technology chase was on gearing for alternative fuels and Green Hydrogen and Ammonia were the twins which featured under many port-projects across the country. Deendayal Port, on the western waterside reported on an e-auction for about 3600 acres of land for development of a Hydrogen Hub. Under the same head of Hydrogen Hub, the VOC Port from the southern side reported on about 200 acres of land being handed over to developers with more to come.

A significant deal the event saw was the M.Tech in Dredging Engineering (IIT-M+IMU+DCIL). This is a welcome academia-industry partnership with Dredging Corporation extending the crucial apprenticeship/field exposure. This philosophy must extend to the other efforts on Hydrogen, Ammonia etc. There should be a synergy of academia and industry (or ports) for all moves on sunrise technologies. If one would look at the roads crossed by developed countries of USA, Japan and Germany, a symbiotic growth (of academia and industry) could be recognised. A partnership with academia is as imperative as with the industry, from the beginning of the thought and word. Hope we see more of this in the coming times.

In this issue...

We start with Dr. Veda's exposition on Programmable Automation Controllers (PAC). PACs have a healthy presence in a wide range of marine control applications. It is imperative that these have a high degree of reliability and probability of failures must tend to zero. Dr. Veda explains this in the initial section of the article and proceeds to explain how ambient temperature affects ICs. The discussion gets interesting and lucid with the thermal images. Failure modes in multi redundancy feature (alternate path in case one path fails) and cooling solutions with explanations on heat pipe add value.

Following this is a discussion on fuel cells. Cmdt. Sudeeptho Ghosh explains a few trends under sustainable energy technologies in focus for marine applications. After nominal descriptions on wind, Solar PV, nuclear (pros & cons), bio fuels etc., the Author pitches for fuel cells. The interesting takeaways are the indigenous designs registering success and acceptance. This is an informative read.

Next, Venkat Krishna discusses condition based monitoring (CBM). The discussions revolve around employing ML for predictive functions. The Author then goes on to explain CBM using Pattern Recognition algorithms. The interesting parts to the practicing marine engineer are the examples discussed herein from the offshore industry. This is an easily digestible read.

The Competency Corner has Elstan Fernandez explaining ways to troubleshoot alternator problems. The MER Archives of March 1984 has a few good takeaways which would relate with engineers from the eighties-era.

We shall soon march into the second quarter of this leap year to witness another festival of democracy. As we await the General Elections, here is the March 2024 issue...

Dr Rajoo Balaji
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Realizing Reliable Programmable Automation Controllers Configurations for Time-Critical Marine Applications

N.Vedachalam, V.B.N. Jyothi, R. Ramesh

Abstract

Operational reliability and on-demand availability are the key requirements for Programmable Automation Controllers (PAC) used in time-critical marine applications. The article describes the methodologies for determining the failure-rate of PACs comprising of power supply, control processor circuit board and rotary cooling fan, the influence of ambient temperature on PAC, multi-redundant PAC configurations required for achieving fault-tolerance, as well as meeting the reliability requirements and statutory safety compliances. Emerging trends in cooling and thermal management of electronic devices are also discussed.

Introduction

Programmable Automation Controllers (PAC) are widely used in marine and offshore industrial applications including dynamic positioning of ships and platforms, propulsion, power plants, offshore wind energy systems, system protection, emergency control, active magnetic bearings, subsea intervention systems including manned and unmanned systems, submarines, offshore observation systems, floating and subsea hydrocarbon production and processing.

Depending on the criticality of the application and safety demands, various PAC configurations have evolved over time. They include dual, Triple Modular Redundancy (TMR), Quadruple Modular Redundant (QMR) and Flexible Modular Redundancy (FMR) configurations.

These multi-redundant fault-tolerant PAC configured with cold/hot standby modes and synchronization features are used to the meet process-specific HSE (Health, Safety & Environment) Safety Integrity Level (SIL) demands. Based on the specific process application, fault-tolerance is achieved through either Hardware Implemented Fault-Tolerance (HIFT) or Software Implemented Fault Tolerance (SIFT). With the present technological maturity, TMR or higher configurations with voting gates reduces false alarms/trips, as well as helps to achieve lowest Probability of Failure (PoF).

Ambient environmental conditions (such as temperature, temperature variations, humidity, vibration and dust) have significant influence in determining the PoF of the PAC. Hence ambient conditions are to be considered in computing the PoF of the PAC, and multi-redundant configuration required for meeting reliability requirements and statutory safety compliances. The article describes the methodology for determining the PoF of PAC (comprising of control processor circuit board, power conditioner and cooling fan) based on discrete component and FIDES approach, influence of ambient temperature in the PoF of PAC, reliability and safety integrity models for multi-redundant PAC architecture based on HSE needs **(Figure 1)**.

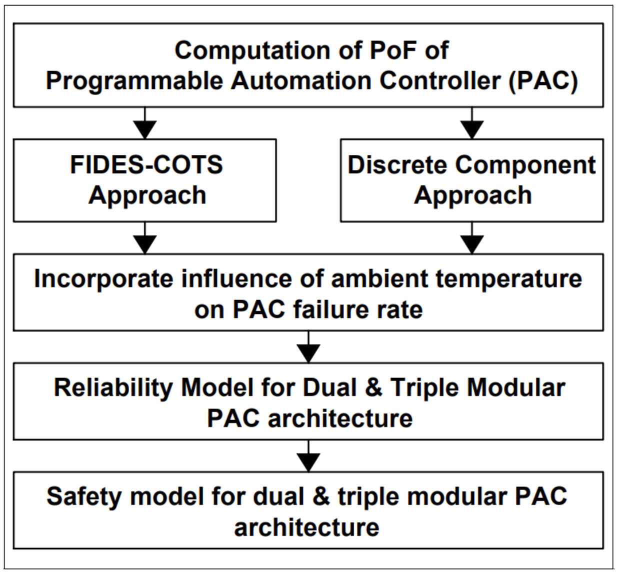

Figure 1. Approach to determine redundant PAC configurations

Determining failure rate of PAC under various ambient temperatures

According to industry reports, 80% of all field failures can be correlated to three major factors, with temperature, vibration, and humidity contributing 55%, 20% and 19%, respectively. A typical PAC includes control processor circuit board, input power conditioner and a cooling fan. The control processor board incorporates discrete components including resistors, capacitors, diodes, transistors, voltage regulators, Integrated Circuit (IC) chips such as Complex Programmable Logic Device (CPLD), etc. The input power conditioner used to regulate the input voltage/power for the PAC could be of AC/DC or DC/DC converters. The cooling fan used for circulating the air through the control processor circuit board and the power conditioner normally operates on 24VDC power supply.

The PoF of the PAC for a defined operational period could be computed based on the failure rates of the discrete components. These are published in MIL and Failure-In-Time Determination for Electronics Systems (FIDES) standards. FIDES is evolved by a consortium of companies (Airbus, Eurocopter, Nexter electronics, Thales group, etc) under the supervision of the Directorate General of Aviation (DGA) for estimation of reliability for electronic components and systems, considering the mission and environmental conditions. Component failure models incorporate physical, technical, production and operational conditions, including operating cycle (On/Off), operating ambient temperature, amplitude and frequency of temperature cycles, vibration amplitude, relative humidity, ambient pollution level, exposure to application-specific accidental over-stresses, subcomponent procurement and production quality procedures.

The PoF of the PAC for a defined operational period could be computed based on the failure rates of the discrete components

Influence of ambient temperature in PAC reliability

Discrete components

The reliability and useful life of the electronic systems depends on the ambient temperature, and the number of thermal cycles experienced. The Arrhenius law used to model the acceleration of electronic system failures, due to operation in increased ambient operating temperatures is,

$$\mathrm{AF} = e^{\frac{E_a}{K_B}\left(\frac{1}{T_1}-\frac{1}{T_2}\right)}$$

where AF = acceleration factor; E_a = activation energy;

K_B = Boltzmann constant = 8.617* 10^{-5} eV/K;

T_1 =Design temperature in °C; T_2 = Actual operating temperature°C.

The Norris-Landzberg model is used to model the fatigue induced failures due to thermal cycling. This model is derived from the Coffin-Manson model, used for thermo-mechanical fatigue studies, the acceleration factor being,

$$\mathrm{AF} = \frac{24}{N_0} * \left(\frac{N_{cy-annual}}{t_{annual}}\right) * \left(\frac{min(\theta_{cy},2)}{min(\theta_0,2)}\right)^p * \left(\frac{\Delta T_{cycling}}{\Delta T_0}\right)^m * e^{1414 \cdot \left[\frac{1}{273+T_0} - \frac{1}{T_{ambient}+273}\right]}$$

where $N_{ey-annual}$: annual number of thermal cycles; N_o number of reference cycles; θ_{ey} : cycle duration in hours; θ_o : reference cycle duration; $\Delta T_{cycling}$: thermal amplitude of the cycle; ΔT_o : reference thermal amplitude of the cycle; Constant 1414 corresponds to an activation energy of 0.122eV; $T_{max\text{-}cycling}$: the maximum temperature reach during the cycle; T_o : reference temperature; m : fatigue coefficient and P = , acceleration power of the duration factor.

The sensitiveness of the PAC discrete electronic components to ambient temperature and thermal cycling for 300 cycles/ year is calculated based on FIDES standards and shown in **Figure 2.** In the case of aluminium electrolytic capacitors, the Failure-In-Time (FIT in billion hours) increases by 10 times when ambient temperature is increases from 10°C to 40°C. To show the importance of thermal management, cases are included for a component (High-density IC Chip) and system's (PAC) sensitiveness to ambient temperature.

High-density Integrated Circuit Chip

Electric power is required to operate Integrated Circuits (ICs). The

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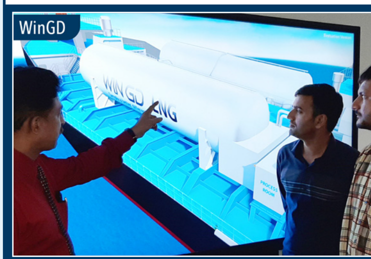

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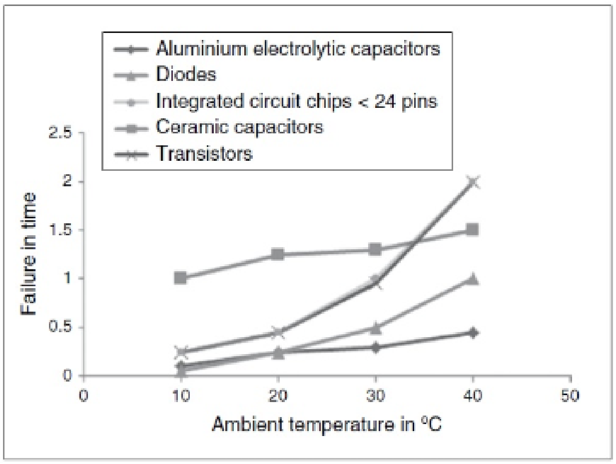

Figure 2. FIT of electronic components for various operating temperatures

consumption of energy creates heat, which results in an increase in the semiconductor junction temperature. The junction temperature is a function of the heat produced by the IC, heat from neighbouring circuits, airflow, IC packing material, IC packing technique, printed circuit board materials and ambient temperature. Ambient temperature (T_A) dictates the minimum junction temperature at which the device can operate. Thermal resistance is the ability of a given device to dissipate the internally generated heat and is usually expressed in ° C/W. When the junction to ambient thermal resistance θ_{jA} and the ambient temperature T_A are given, the junction temperature of the IC chip is calculated as follows,

$$T_{jA} = p_d \theta_{jA} + T_A$$

P_d = Processor core power + Input and Output (I/O) device switching power,

I/O switching power = α ∗ f ∗ CL ∗ V^{2*}(number of switching I/Os).

where, α = activity factor; f= operating frequency; C_L=external load capacitance; V is the output voltage swing.

For a 100 pin Static Random Access Memory (SRAM) Thin Quad Flat Package (TQFP) with a thermal resistance is 28.66 ° C/W with zero airflow and operating at 100MHz with a 40Pf capacitance load and all I/Os switching, the power dissipated is calculated as 1.56 W.

The junction temperature is thus calculated as follows,

"The reliability and useful life of the electronic systems depends on the ambient temperature, and the number of thermal cycles experienced"

Ambient temperature (dictates the minimum junction temperature at which the device can operate

$T_j = T_A + (\theta_{jA} \times p_d)$

$= T_A + 28.66°$ C/W x 1.55W) $= T_A + 44.71°$ c

when T_A is 35°C, T_j = 35° C +44.71°C =80.71° C

when T_A is 10 °C, T_j = 10 ° C + 44.71°C = 54.71° C

The IC device's FIT at different ambient temperatures and operating clock speeds is calculated and plotted in **Figure 3.**

Based on the defined relationship, it is found that, an IC chip operating at 500 MHz can have a failure rate of 80 and 1500 FIT when operated with a junction temperature of 54°C and 80 °C, respectively. To overcome this challenge, the device could be operated at a reduced clock speed, so as to have reduced failure rates. This results in under-utilisation of the hardware, which is not desirable. Thus, it can be seen that ambient temperature plays a significant role in the performance, reliability and life of ICs.

The thermal image of a typical PAC control processor board (obtained using IR camera) is shown in **Figure 4**. In the circuit board design stage, thermography can be performed to visualize the excessive heating of circuit components. This can be caused by a range of defects, which include improper design, electric short circuits, incorrectly mounted component and insufficient tin during soldering.

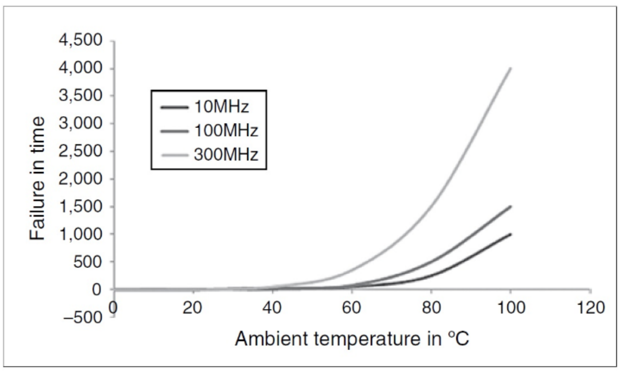

Figure 3. High density IC FIT as a function of ambient temperature and clock speeds.

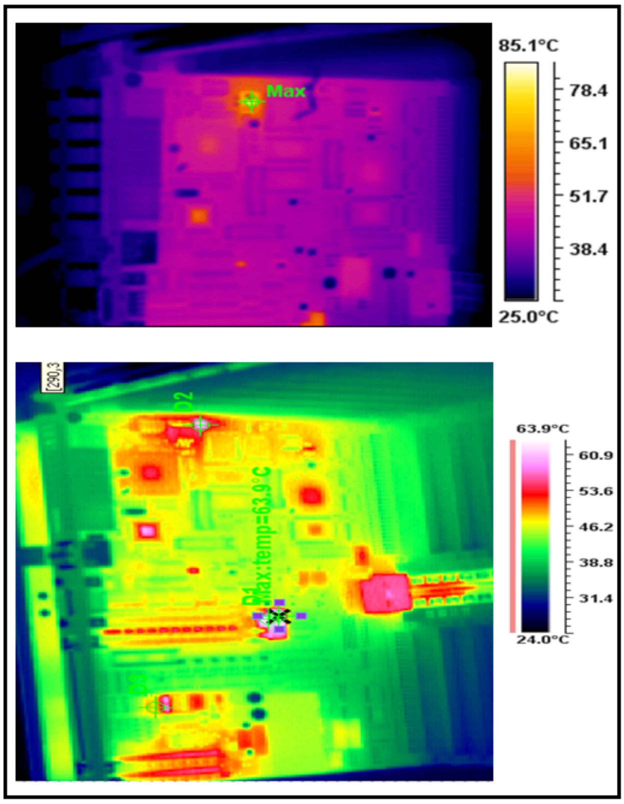

Figure 4. Thermal image of a PAC control electronics board

Determining PoF of PAC subsystems – COTS approach

Control processor circuit boards

FIDES COTS-board model is used for estimating the PoF of off-the-shelf boards that perform standard electronic functions, when

(a) Manufactures have not provided failure data.

(b) Operated in environments other than those for which the manufacturer have defined the reliability (MTBF).

(c) Board components are obtained from different sources and quality factors for component suppliers are available.

Based on FIDES-COTS approach, PoF is calculated for the PAC control processor board when operated at different ambient temperatures. The features of the PAC considered for analysis are summarized in **Table. 1**

It can be seen from **Figure 5** that the FIT of the PAC control processor board increases from 669 at 10°C to 9000 at 60°C. This corresponds to failure probabilities of 3.1% and 32.6%, respectively, in a five-year period. Thus ambient temperature plays a major role in the operating life and reliability of PAC.

Circuit boards used for developing PAC are available in various dimensions (**Figures 6** and **7**). The form factor (FF) is the product of the board length and breadth. The Ipack type is used for embedded system packaging

Table 1. Details of the PAC considered for reliability analysis

Feature	Details
Circuit board dimension	100 x 100 mm
Clock frequency	100MHz
Boot memory	8 MB
Storage memory	1024 MB
Dynamic RAM	512 MB
Static RAM	512 MB
Ethernet interfaces	2
Analog inputs	10
Serial inputs	2

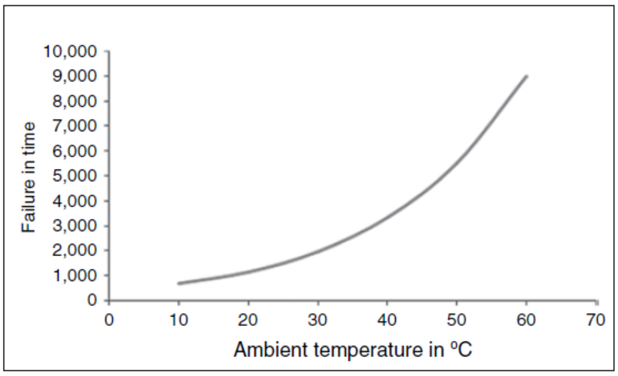

Figure 5. PAC failure rate as a function of temperature

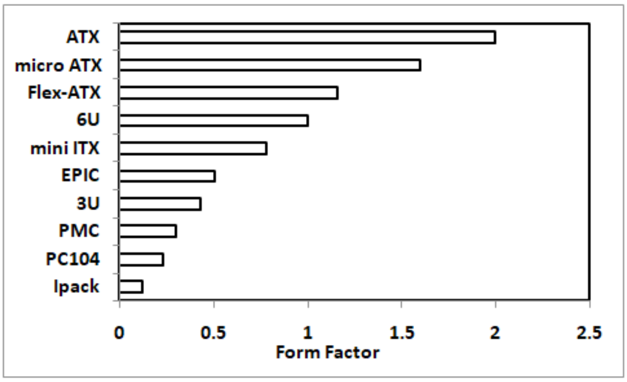

Figure 6. Form factors for various circuit board families

assemblies which provide a common board size for stacking. A 10-pin connector is used to enable inter-board connection. The PC 104 size is of 90mm × 96 mm dimension with mounting holes at all four corners of the board. The PCI Mezzanine card or PMC is used to extend the connectivity or function of a compatible computer system, typically for the VME bus, Futurebus+ and other computer systems supporting the PCI specification. The EPIC board is almost exactly halfway between the area of the PC 104 form factor and the EBX form factor.

The term 'Eurocard' describes a single standardized size of printed circuit board of dimension100mm x 160mm. The symbol 'U' used in Euro-card descriptions/ sizing refers to 'units', with 1U being 44.45mm in height - equivalent to the height of one 19-inch rack unit. Mini-ITX is commonly used in small-configured computer systems. Originally, they were a niche product, designed for fan-less cooling with low-power consumption architecture. The ATX (Advanced Technology eXtended) is a motherboard and power supply configuration specification with improving standardization and interchangeability of parts. The view of various boards is shown in **Figure 7**.

Based on FIDES-COTS approach, the PoF is calculated for circuit boards for various form factors when operating at ambient temperatures 5°C -50°C, and the results are plotted in **Figure 8**. The bottom envelope in red corresponds to I Pack board and the successive envelopes correspond to PMC, EPIC, 6U and ATX formats.

Rotary cooling fans used for removing the heat from the circuit board assemblies by circulating air (convection) have failures mainly due to the wear out of the bearings

Rotary Cooling fan

Rotary cooling fans used for removing the heat from the circuit board assemblies by circulating air (convection) have failures mainly due to the wear out of the bearings.

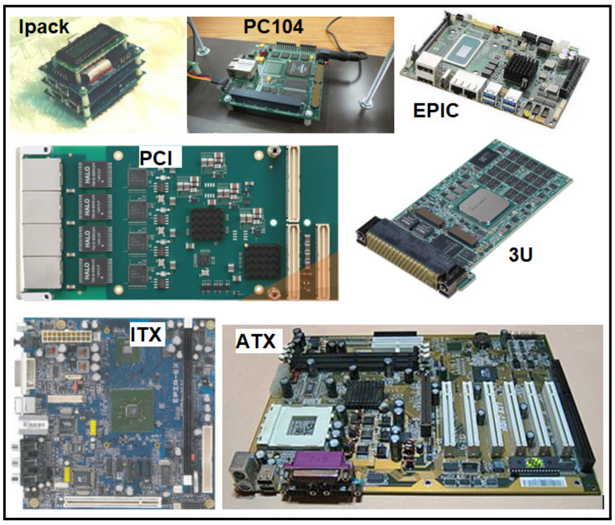

Figure 7. Various COTS circuit board families

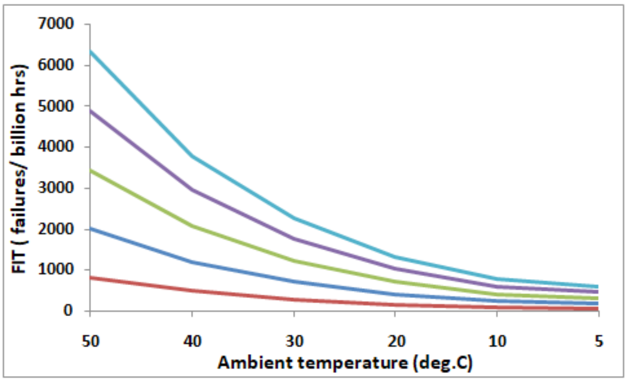

Figure 8. Failure rate of COTS boards as function of temperature

Fan technologies vary differently, and thus it is preferable to use manufacturer's data, usually accessible in the form of operating life (L_{10}). The reliability and operating life of the cooling fan depends on the operating temperature. FIDES has provision to model the failure rate of the cooling fan taking into consideration of the bearing type (including sealed sleeve, ball and ceramic types), ambient temperature, ambient temperature variation frequency, operating hours, revolutions per minute (rpm) and noise levels. The failure rate of the PAC rotary cooling fan (with speed in the range of 1500–5000 rpm and noise level ranging 10–90 dbA) when operated at various temperatures is calculated and plotted in **Figure 9**.

Power supply conditioners

The PAC circuit board assemblies and cooling fan are normally operated using 24VDC. Based on the system architecture AC-DC or DC-DC converters are used for deriving the operating the operating voltage. Based on FIDES component model, the failure rates identified for power conditioners for temperatures ranging 10°C –60°C are summarized in **Table. 2**.

Reliability of multi-redundant PAC configurations

For computing the PoF of various PAC TMR configurations (**Figure 10**) based on the identified PAC

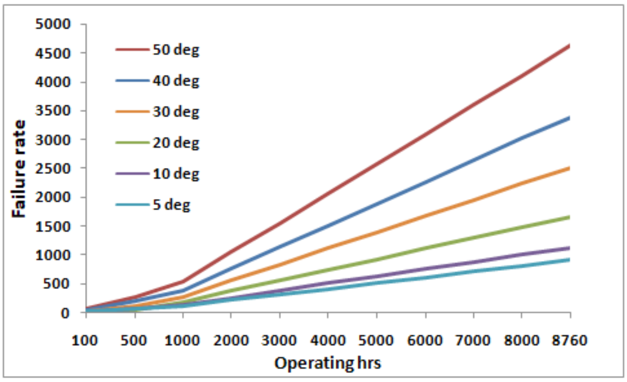

Figure 9. Failure rate of cooling fan as function of temperature

Table 2. Failure rate of power supply packages

Type	FIT (/billion hrs) at			
	10°C	20°C	40°C	60°C
PCB-mountable < 1W DC-DC converter	11	19	55	140
AC-DC packaged power supplies < 500W	64	114	325	910

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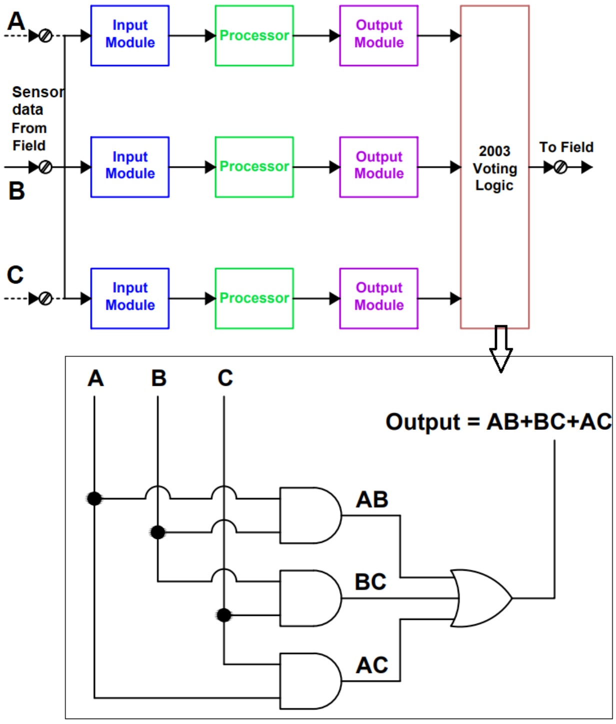

Figure 10. TMR with voting scheme (HIFT)

subsystem failure rates, failure trees (FT) are modelled and simulated using TOTAL-GRIF reliability analysis software. The PAC configuration includes a control processor circuit board with FF=1, cooling fan of 5 W and a 50W AC-DC power supply unit. The exponential law is used for defining the degradation pattern over the simulated period of 1 year. The FT's shown in **Figures 11** and **12** correspond to PAC system failure rates of 1000 and 10000 FIT, respectively. The results are summarized in **Table 3**.

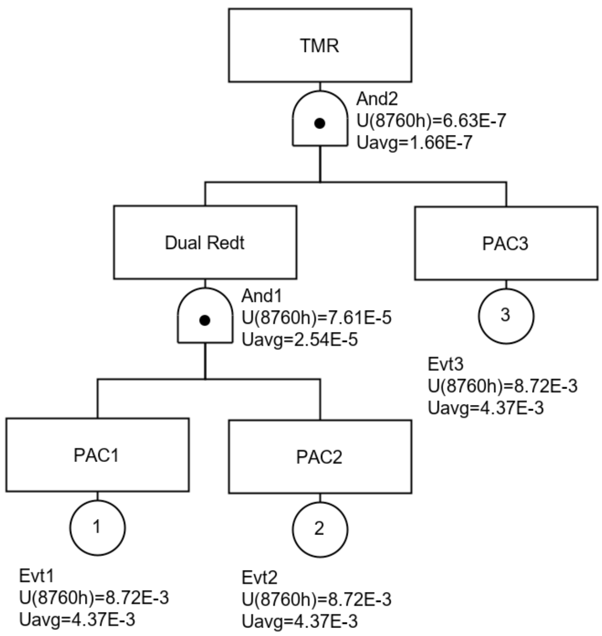

Figure 11 PoF of multi-redundant architecture with PAC1000FIT

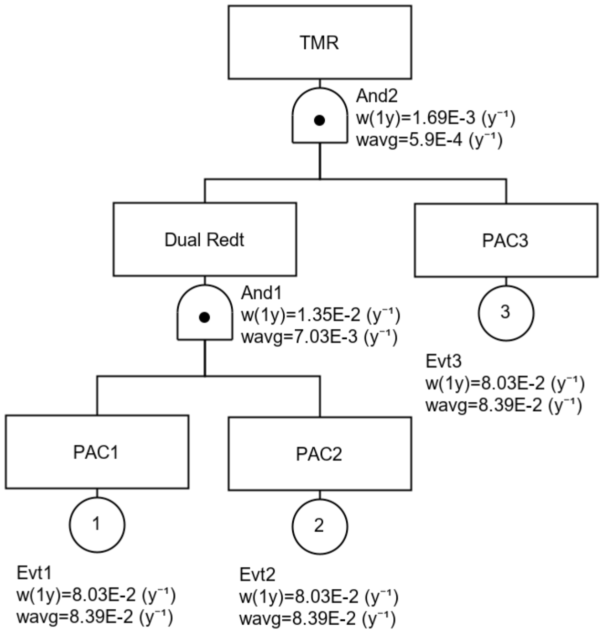

Figure 12. PoF of redundant architecture with PAC10000FIT

Table 3. PoF in 1 year for multi-redundant PAC

PAC FIT / Configuration	PoF for redundancy level		
	Single	Dual	Triple
1000 FIT	0.8 %	7.6 x 10^{-3} %	7.6 x 10^{-5} %
10000 FIT	8 %	0.76 %	0.17 %

Safety compliance of multi-redundant PAC configurations

IEC 61508/11 is a standard that provides a framework for implementing instrumented safety systems, using the principles of the safety life cycle and Safety Integrity Level (SIL) concepts. The SIL defines the degree of safety protection required by the process and, consecutively, the safety reliability of the system necessary to achieve the function. SIL has four levels, 1 to 4, with the higher number meaning the safer the system. The SIL requirements are computed taking into consideration the risk consequence, alternative safety instrumented function (SIF) in place, human occupancy and the demand rate for the SIF. The PoF on demand (PFD) for a low-demand system (when the demand on the PACs is < 1 per year) and the probability of failures per hour (PFH) for a high-demand system (when demand is >1/year) are summarized in **Table 4**.

Based on the identified failure rates, TOTAL-GRIF SIL module is used for computing the SIL compliance. The SIL graphs shown in **Figures 13** and **14** correspond to PAC system failure rates of 1000 and 10000 FIT, respectively for a high demand system. **Table. 5** summarises the time in various SIL zones. It is identified that a TMR with PACs with a failure of 1000FIT shall meet SIL4 compliance. But a PAC with a failure rate of 10000FIT can comply with SIL2 compliance only.

Table 4. PFD requirements for SIL-rated configurations		
SIL	PFD per year	
	Low demand (PFH)	High-demand (PFD)
1	$10^{-6} - 10^{-5}$	$10^{-2} - 10^{-1}$
2	$10^{-7} - 10^{-6}$	$10^{-3} - 10^{-2}$
3	$10^{-8} - 10^{-7}$	$10^{-4} - 10^{-3}$
4	$10^{-9} - 10^{-8}$	$10^{-5} - 10^{-4}$

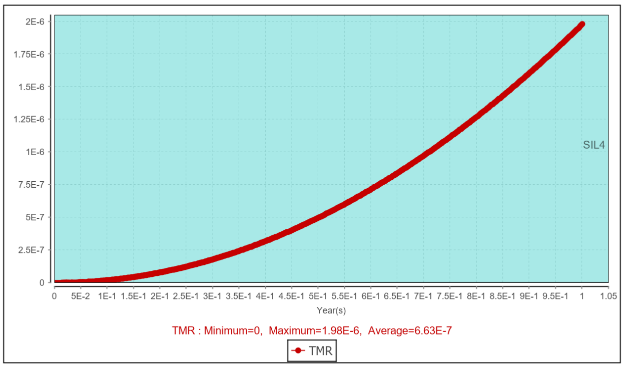

Figure 13. SIL zones for TMR with PAC failure rate of 1000FIT

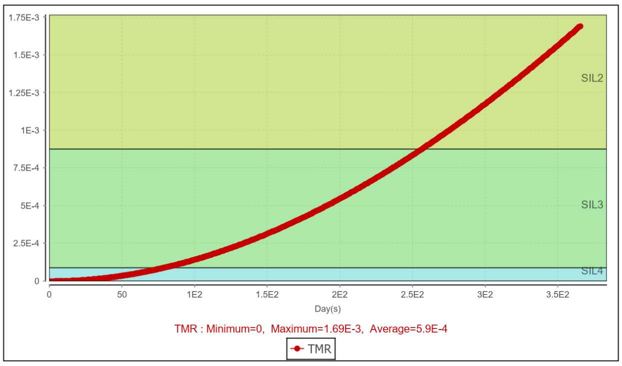

Figure 14. SIL zones for TMR with PAC failure rate of 10000FIT

Table 5. SIL compliance for TMR PAC for various FIT

PAC FIT / Configuration	SIL zones (in months for TMR architecture)		
	SIL4	SIL3	SIL2
1000 FIT	12	-	-
10000 FIT	1.6	8.4	12

Emerging cooling and thermal management technologies

Futuristic electronics systems involving large heat flux demands effective cooling and thermal management for ensuring reliable, efficient operation and extended life-time. Based on the industry field-failure reports, ~55% of are temperature-induced. The efficacy of electronics cooling and thermal management depends on the heat transfer mechanism involved. The range of heat flux density handled by conventional methods include, radiation and free convention (10^2-10^3 W/m^2), forced air cooling ($1x10^3$-$2x10^4$ W/m^2), forced liquid cooling (10^4-10^5W/m^2) and liquid evaporation (10^4- $2x10^6$ W/m^2). The development trend in the electronic system miniaturization over the past 2 decades (1000 times increase in transistor counts) has resulted in 3.5 times increase in chip power and heat flux (**Figure 15**). The International Technology Roadmap for Semiconductors (ITRS) has predicted that the number of transistors in high-performance processors to cross from 1 billion to 150 billion, with transistor size decreasing from 40 nm to 6 nm within the year 2026.

With the continuous miniaturization and rapid increase of heat flux of electronic devices, development of high-efficient direct and indirect cooling, flexible thermal management solutions and corresponding design tools are in the uptrend. Challenges in strategic cooling systems include effective removal of high heat flux, non-uniform power dissipation (e.g., hot spots), and confined space constraints (3D stacked packaging). Direct cooling consists of air cooling, spray and jet impingement cooling, immersion cooling, and droplet electro-wetting. Indirect methods include use of microchannel, heat pipe, vapor chamber, thermoelectric and Phase Change Material (PCM) (**Figure 16**).

In direct contact cooling, liquid cooling has attracted more attention due to its better heat dissipation than conventional air cooling. Spray cooling method atomizes droplets through high-pressure pumps and nozzles,

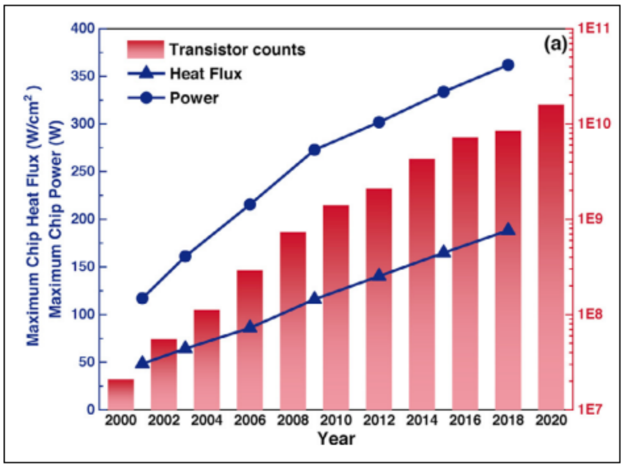

Figure 15. Trends in electronic miniaturization and heat flux

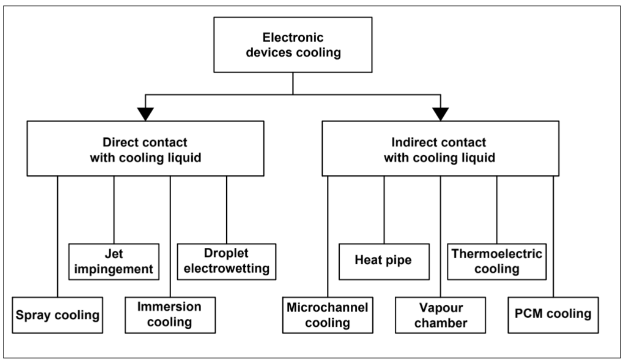

Figure 16. Strategic high heat flux handling systems

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and covers the entire insulated heating surface of an electronic device. Spray cooling has the advantage of high heat transfer capability (> 100 W/cm^2 using fluorinerts and >1000 W/cm^2 with water), excellent temperature uniformity, and sizeable cooling area. Nozzle parameters, cooling fluid characteristics (alcoholic liquid, surfactants solution and nanofluids), heating surface properties, phase change regimes, flow patterns (Nusselt number and Reynolds number) and bubble nucleation process play a key role in the effectiveness of this spray cooling method.

Jet impingement cooling having heat transfer capability of >200W/cm^2 is similar to spray cooling, but does not need droplet atomization. Compared with conventional convection cooling by confined flow parallel to the cooled surface, the use of jet impingement produces increase in the heat transfer coefficients that could be 3 times higher, at a given maximum flow speed. The study on jet impingement heat transfer enhancement focuses on optimizing jet parameters, liquid characteristics, heat transfer coefficient, flow pattern (Reynolds and Nusselt number) and heating surface structures.

In droplet electro-wetting (to control hot spots of electronic devices) technique **(Figure 17)**, droplet motion (on mm or μm scale) is controlled by adjusting the surface wettability using an electric field. The electro-wetting action is controlled by numerous electrodes that were sequentially activated. Micro-fluidic technology based nanoparticles with sizes in the range 10–1000 μm has the advantage of precise manipulation of a small amount of liquids. Such ultra-high removal heat flux up to 2000 W/cm^2 has been achieved using impingement jets with liquid-metal micro-fluidic cooling systems. They offer promising solutions for on-chip or in-chip cooling which could be effective for 3-D IC packaging.

Unlike direct contact cooling, indirect contact cooling needs to consider the contact thermal resistance of external heat sinks, in which Thermal Interface Materials (an effective medium that fill the gap between the surfaces and provide better heat transfer) play an important role in the thermal management. The performance of high heat transfer capability (~1000W/cm^2) compact microchannel heat sinks (attractive for suitable for small and high-power electronic devices) depends on microchannel structure parameters ,material, size, flow channel layout, liquid characteristics (thermal conductivities of water and a typical liquid metal are 0.6 and 40 W/m-k) and phase-change (critical heat flux) process involved in the heat transfer. Considering the fine size of the micro-channels within the heat sinks, the clogging phenomenon and agglomeration of nanoparticles are important concerns, particularly the case for larger solid volume fractions of nanoparticles (>1.0 vol.%).

The heat pipe and vapor chamber have similar working principles like wick structures and two-phase flow **(Figure 18)**. They are attractive because of their simple structure, high reliability and efficient heat transfer

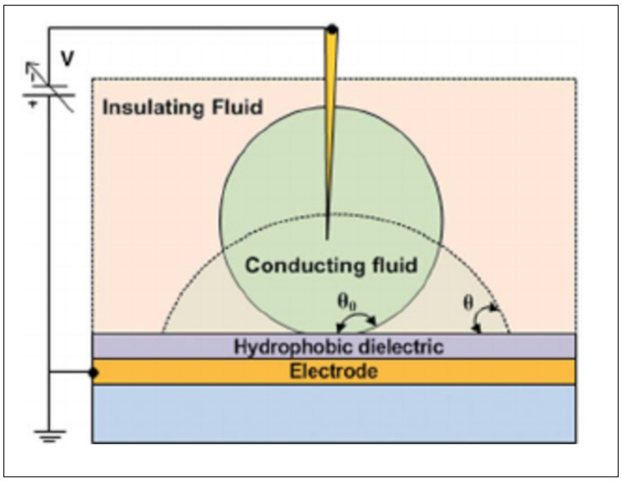

Figure 17. Droplet electro wetting cooling principle

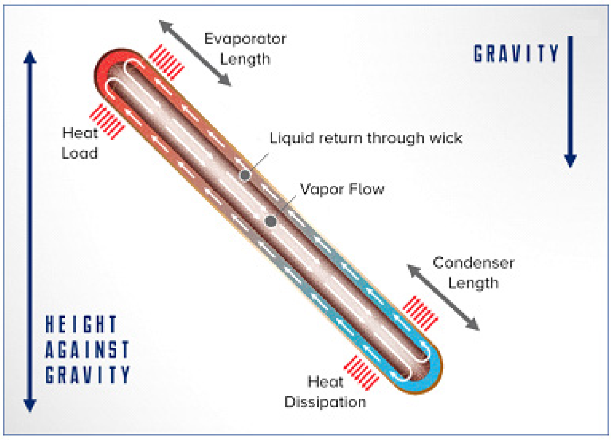

Figure 18. Working principle of a heat pipe

capability (500W/cm^2 for flat heat pipe). The liquid evaporates in the hot end, and vapor condenses in the cold end, then the liquid is back to the hot end through the wick structure with the help of capillary force. The heat transfer characteristics in the heat pipe and vapor chamber involve1-D heat transport and 2-D heat spreading.

In thermo-electric (TE) cooler, the flat plate at one side of the TE device absorbs heat (cold side), and the other side will generate heat (hot side). The TE devices have the advantages of zero-noise, high reliability, longer operating life (~30 years) and heat transfer performance (upto 200 W/cm^2), and its performance is independent of gravity. The phase change material (PCM) cooling based on the principle of latent heat storage, maintains the temperature constant with the high energy storage density. For electronic devices with pulsed heat flux density, the PCM-based heat sink can effectively absorb the heat during pulse operation and return to the device for devices during low-temperature operation, maintaining a stable operating temperature. As nanofluids (based on TiO_2, Al_2O_3, magnetic and CNT) with larger thermal conductivities can provide higher rates of convective heat

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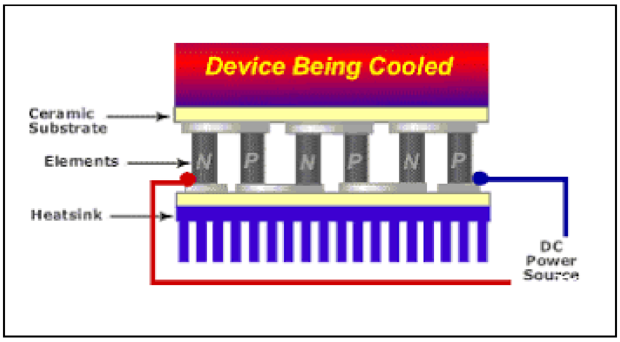

Figure 19. Operating principle of a TEC

transfer in comparison with pure fluids, extensive research are ongoing in the application of nanofluids in heat pipes, ordinary parallel channels, jet impingement, double layer liquid blocks and corrugated channels.

Conclusion

The article presented the methodology based on FIDES to compute the failure rate and reliability of the commercially-off-the-shelf programmable automation controllers, when the failure rate is not available from the manufacturer and when operated in ambient temperatures below and beyond the range mentioned by the manufacturer. With the computed PAC failure rates as inputs, reliability and safety modeling is done using quantitative fault tree analysis and Safety Integrity Level modules, and the reliability and on-demand availability for multi-redundant PAC architectures are presented. The results could serve as a ready-reckoner/guideline for marine control and automation system designers in identifying PAC configurations required for complying with the desired level of operational reliability and statutory safety compliance. Technological trends in next generation cooling and thermal management systems are also discussed.

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Transition to Fuel Cells Energy Onboard Ships – An Imperative for Future-proofing against Oil Crisis

Sudeeptho Ghosh

Abstract – Adverse climate changes resulting from Global warming have been attributed to higher consumption of fossil fuels.[1] This has led to increased Greenhouse gas (GHGs) emissions and carbon footprint and also, high energy prices. Accordingly, the Paris agreement of 2015 necessitated a drastic reduction of the GHGs emission by 2050. Further, studies indicate that all known global oil reserves will deplete between 2052–2075. India is heavily relied (80%) on conventional fuels for its overall energy needs, with 86% of the total oil being imported from Gulf countries and Russia (12%). Furthermore, recent events such as COVID-19 pandemic, Russia-Ukraine[2] war etc had led to unprecedented supply chain disruptions, which could bring countries/ organisations, which are heavily dependent on oil imports for energy needs, to a standstill. This has led to shift in India's energy policy towards low carbon strategy by means of exploring the alternate sources of energy.[3] However, the green energy technologies have not matured enough yet and substantial amount of time is required to introduce, stabilize and migrate to a new technology. Hence, the research aims at establishing the need to migrate to sustainable energy sources operational platform, deliberating on various options available and undertaking feasibility study towards introduction of Fuel cells for power generation/propulsion requirements onboard ships for Coastal Communities.

The paper aims to analyse and appraise the criticality of the impending oil supply crisis and its effect on the *Shipping Industry.* Further it seeks to establish the need for swift transition to sustainable energy sources onboard ships. In doing so, the paper has assessesed effect of rapidly depleting global oil reserves, emission norms and factors such as geo-political issues,[4] supply chain disruption etc on India's energy requirements. Secondly, this paper also establishes the over-dependence of *marine industry* on fossil fuels and various methods to mitigate it.

I. INTRODUCTION AND METHODOLOGY

India is extensively dependent relied on fossil fuel for functioning of its operational platforms. Presently, marine platforms doesn't have any surface platform which does not rely on fossil fuels for power generation/ propulsion. Thus, India is presently not ready for the inevitable reduction in availability/ consumption of fossil fuels due to various factors such as depletion of reserves, geopolitical issues, environmental norms, supply chain disruptions etc. Thus, overdependence on fossil fuels constitutes to the primary problem. The secondary problem entails identification and proving of most suitable sustainable energy technology, which can reliably meet all the marine requirements. Tertiary problem is formulation of a concrete roadmap and effecting the tectonic transition from conventional energy sources to sustainable energy sources onboard existing/ future marine platforms.

Background

(a) Depleting Global Reserves. Reserves-to-production (R/P) ratio is used to predict the time for the depletion of known oil reserves. If the reserves remaining at the end of any year are divided by the production in that year, the result is the length of time (years) that those remaining reserves would last, if production were to continue at that rate. Petroleum Planning and

Analysis Cell (PPAC) report of 2021,[5] indicates that the total known reserves of the world are 244.4 K Mil Tons / 1732.4 K Mil Barrels. At the current rate of yearly consumption, these known reserves will last for 53.5 years as per BP annual report.[6] However, if we consider the actual rise in the rate of fuel consumption every year, the reserves are estimated to deplete by 2052.[7]

(b) **India's Oil Dependence.** India is a net importer of oil, which constitutes 1/5th of India's total value of imports (3.9% of real GDP of 2021). Further, out of India's total oil requirements, 85.5% oil is imported and only 14.4% is domestically produced. In case of oil supply shortage/disruption, country can issue oil from its Strategic Petroleum reserves (SPR).[8] On 14 Mar 22, the Minister of State for Petroleum and Natural Gas, Rameswar Teli said in a written reply to a question in Lok Sabha that, "India maintains of 5.33 million tonne, or equivalent of about 9.5 days of crude oil requirement. In addition, oil marketing companies (OMCs) currently have a capacity of 64.5 days."[9] Thus, India can sustain for a maximum duration of 74 days in case of complete disruption of oil imports.

(c) **Effect of Geo-Political Issues on Oil Imports**. When an economy excessively relies on imports for its energy needs, geo-political issues become a major point of concern. The majority of Indian oil is imported from Gulf countries and Russia (12%).[10] In the recent past we have witnessed the equivocal support of gulf countries (OIC/OPEC) to Pakistan over revoking of Article 370 in Kashmir.[11] Thus, even if India does not have a direct confrontation with the OPEC (Organization of the Petroleum Exporting Nations) nations in the future, any altercations with Pakistan can adversely affect the supply of oil to India from these countries.

(d) **India's Dependence on Fossil Fuels**. Presently, *IN*'s active and under construction strength of ships and submarines is 150 and more than 50 respectively[12]. As guardian of nations' maritime interests, *IN* employs ships, submarines and aircrafts, which are mechanized platform. It is pertinent to note that propulsion / power generation systems employed onboard all Naval ships are either diesel engine, gas turbine or steam engine, which are all dependent on fossil fuels (with exception of the Nuclear submarine). Thus, it is evident from above, that in case of disruption in oil imports, *IN* may be able to operate for a maximum duration of 74 days (SPR- Strategic Petroleum Reserve) or less, subject to Military fuel needs being given priority over critical civilian needs, which seems unlikely.

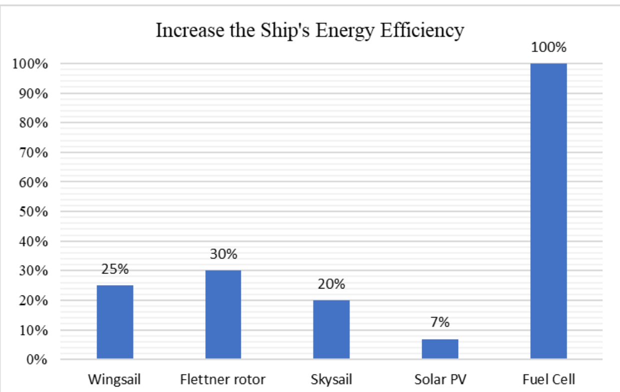

Figure 1. Increasing the Ship's Energy Efficiency

Methods of Data Collection

(a) **Type of Research**. The research encompasses aspects qualitative, quantitative (interview), strategic and analytical research. The paper attempts to analyse the effect of shortage of fuel oil on the functioning of the Indian Navy/Coast Guard as a result of any geo-political event or Pandemic. Further, an attempt to assess the benefits accrued from migration to sustainable technology based power generation/ propulsion to the the marine Industry . The diplomatic/ strategic advantages gained by mass production/ export of the indigenous sustainable technology based equipment have also been explored.

(b) **Literature Survey**. The sources for undertaking the study/analysis for the paper include various research papers, publications, reports, periodicals, etc., published by Subject Matter Experts (SMEs) in respective fields. Reports of government institutions and global organisations such as UN, PPAC, and British Petroleum etc have been referred for the data pertaining to fossil fuels. Further, the data pertaining to Indian Navy/Indian Coast Guard has been obtained from past correspondences, reviews and reports from relevant professional directorates of the Navy.

(c) **Methods Adopted for Data Collection**. The data available on open domain has been sourced primarily from official websites of reliable online sources. Detailed deliberations were undertaken with the subject matter expert on the indigenously developed PAFC technology fuel cell technology.

II FINDING AND ANALYSIS

Sustainable Energy Sources Suitable for Maritime Applications. New energy technologies for ship power systems have been widely developed by researchers and have also been implemented on a prototype scale. The current focus of renewable energy application in shipping is solar energy, wind energy, biofuels, wave energy and fuel cells. Alternative energy for ships using wind, solar PV and fuel cells can increase the efficiency of the ship's energy needs. For example, wind energy technology using Wing sail can increase energy efficiency by 25%, Flettner motor 30% and Skysail up to 20%. Large ships that use Solar PV energy mainly to reduce the main energy needs that use fossil fuels and increase energy efficiency by 6.9%. Compared to wind, solar Photo Voltaic (PV) requires a large panel area and only depends on the time of day and sunny eather. Meanwhile, wind energy in the sea can be captured as an alternative energy source at any time as long as there is a wind speed that can capture its energy. Meanwhile, fuel cell energy for ships is more directed at replacing 100% fossil energy or building new ships and not for additional ship energy. Furthermore, **Figure 2** shows about increasing the ship's efficiency energy.

Wind Energy. Wind energy has become a consideration for alternative fuels to reduce emissions and to increase ship power and reduce fuel consumption. Wind energy is abundantly available at sea such was traditionally harnessed by sail ships. Energy crises concerns have kindled renewed interest in Wind Assisted Ship Propulsion (WASP). Example of WASP include Walker Wingsail ships, Flettner rotor sail ships and skysail ships; soft-sails, such as Greenheart's 75 dwt freighter, B9 Shipping's 3 000 dwt bulker and Dykstra/Fair Transport's 7 000 dwt Ecoliner; fixed-sails, such as in the UT Wind Challenger and the EffShip's project; Flettner Rotors, such as in the Alcyone and Enercon's 12,800 dwt E-Ship; kite sails, such as in the MS Beluga Skysails.[13]

Solar Photovoltaic (PV) and Hybrid Systems. Solar energy is readily available at sea and has low maintenance costs. Furthermore, solar energy can be used as the main energy source, especially for the main engine of small ships, while for large ships; it can be used to meet electrical energy for lighting, navigation systems and communication devices. These are mainly in hybrid models with other energy sources on small ships such as NYK's Auriga Leader and Solar Sailor by OCIUS Technology etc. The largest solar-powered ship and has completed 60,023 km circumnavigation without using fossil fuels in 2012 is the ship "Turanor Planet Solar".[14]

Biofuels. Biofuels are a relevant alternative for replacement or blending with fossil fuels and are compatible with existing engine systems and infrastructure, with modifications/ redesigning in systems if required. Biofuels can be used in the form of biodiesel, bioethanol, biomethane, straight vegetable oil (SVO), dimethyl ether (DME), pyrolysis oil, hydrogenated vegetable oil (HVO) or some other derivation.[15]

Alternative (Non-Fossil Fuel based) Energy Sources

Nuclear Energy - Pros. Alternative energy technologies can also be considered as a substitute to the conventional fossil fuels. The most proven and effective alternative technology in maritime/naval domain is Nuclear energy. Presently, over 160 ships/submarines are powered by more than 200 small nuclear reactors.[16] If the nuclear technology is also inducted onboard ships, it would provide commonality of spares and support expertise/ infrastructure with the submarine application. Nuclear power is particularly suitable for naval vessels which need to be at sea for long periods without refueling, due to its non-intermittent capacity and high energy load.

Nuclear Dilemma - Cons. However, there are technological challenges that must be overcome for effective implementation. Decommissioning of nuclear plants and managing nuclear waste is not sustainable. Increased nuclear energy usage will lead to rapid depletion of already scarce reserves and will require multiple nuclear waste disposal/storage facilities[17]. Nuclear plant projects are costly, from erection through life-cycle, with added costs of decommissioning. Safety and reliability of plant performance of nuclear plants in the marine domain has been overall acceptable.

Fuel Cells the Most Suitable Sustainable Option for Ship A fuel cell is a device that uses a chemical reaction to produce electricity that can be used to do work. These have been primarily employed on submarines for increasing underwater endurance and researchers/ industry are trying to realize fuel cells to become the main propulsion of ships or hybrid systems. Onboard the United States warship USCGC "Vindicator",[18] all four diesel generators have been replaced with fuel cells, for development and proving of FC performance onboard ships.

Advantages of Fuel Cells (FCs) in Marine. The fuel cell is comparatively superior to other systems with respect to net efficiency and capability to operate at low temperature. Fuel cell system, in contrast to the others, reaches its maximum net efficiency at partial load. The higher cost of fuel cells can be offset by the reduction in maintenance and emissions. Ever tightening emission legislation, and the modifications required to meet them, could seriously erode the competitiveness of diesels. Fuel cells have a low acoustic signature and are ideal for slow speed operations. Also in the low megawatt power range, fuel cells will be competing with the new high-speed gas turbine generators in near future. FCs can also aid in vision of lean manning with reduced operator/maintainer requirements.

Fuel Cells Vs Diesel. The long lead time for indicates that it will be at least 10 years before a ship is built that is designed specifically for fuel cells, as a consequence the first fuel cell systems will be fitted as replacements for existing generator sets in the 0.5 – 2MW range. Studies have shown [19] that Proton Exchange Membrane Fuel Cells (PEMFC) and Molten Carbonate Fuel Cells (MCFC) can compete with diesel generators in this range in terms of volumetric and power density. These diesel replacement units are envisaged as individual self-contained plants each with its own fuel reformer etc. Installation of fuel cells in this power range has many attractions. The higher cost of fuel cells can be offset by the reduction in maintenance, noise, and emissions. Ever tightening emission legislation, and the modifications required to meet them, could seriously erode the competitiveness of diesels.

Fuel Cells vs GT. In the low megawatt power range fuel cells will be competing with the new high-speed gas turbine generators. The main advantages of fuel cells here is the small ducting required, flexibility in sizing and excellent part load performance. Fitting a fuel cell plant into the volume vacated by a diesel generator/GT does

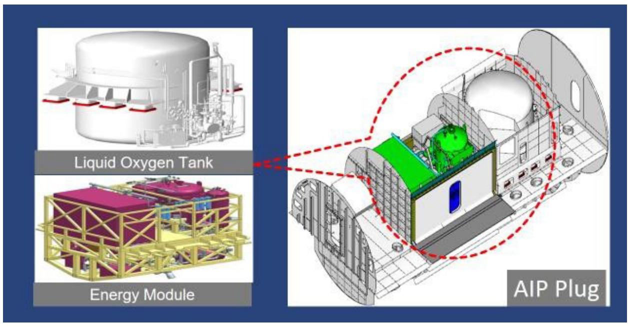

Figure 2. DRDO PAFC

not permit exploitation of all the benefits a fuel cell offers, this will only come when a ship is designed specifically for a fuel cell power plant. Replacement of main (or boost) prime movers is a more radical step. It is less likely that this can be achieved in an existing ship and will be preferable in new construction ship. Even then, for small ships that are volume critical and for large power production, gas turbines are likely to remain the engine of choice for the time being. However, in future, high temperature FC with co-generation may compete with the GTs.[20]

Phosphorus Acid Fuel Cells (PAFC) Most Suitable Option Among Fuel Cells PAFCs are the most commercially developed fuel cells for the non-space application and can be considered a mature technology. With the exception of the direct- methanol fuel cell the 42.7% efficiency average here is the lowest of any fuel cell. the need for transformation to sustainable energy sources has been established and various option available globally have been deliberated. It has been understood that among the various options, Fuel cells have substantial potential for ship borne application and the PAFC has certain advantages over other types of FCs. Hypothesis states that the Fuel cells can be inducted onboard *IN* warships for power generation/ propulsion and as a proof of concept, PAFC is being considered for installation onboard *IN* ships.

Development of Indigenous PAFC. Recently, Indian Navy with the help of DRDO / NMRL (Naval Materials Research Laboratory), achieved a major feat by indigenously developing the maiden Land Based Prototype (LBP) of PAFC for propulsion onboard P75 class submarine. The performance LBP has been ascertained, proving the concept of research. Presently, development of full scale engine required onboard the submarine is in progress. Concurrently, de-risking trials of LBP in various modes are in progress and the Engine is planned to be fitted onboard a P75 submarine in 2024-26.

Justification for PAFC Application Onboard ship. High level of confidence exists in the organisation regarding success of design, development and performance of PAFC for the submarine application. PAFC can certainly be employed for ship based application, albeit some modification will be required which are quite feasible. The justification of employing FCs onboard warships would be slightly different from commercial application, which are oriented towards commercial and environmental norms[21]. Most significant advantage of PAFC is that it is indigenously developed. Hence, the expertise and flexibility of design modification exists locally and not required to be dependent on foreign sources. Multiple options of drive train can be employed and design/ development can be tailor made for marine requirements. FC (and PAFC in particular) offer high degree of reliability, robust performance, damage resilience, and flexibility, higher efficiency vs cost ratio and high endurance which are key requisites for warships. Warship is also suitable for FC application due to its multiple fuel carrying capacity and higher space availability as compared to submarines.

Most Advantageous for Employing PAFC – Electric Propulsion. Maximum benefit of a fuel cell can be derived by its application in conjunction with Integrated Full Electric Propulsion (IFEP). Retro-fitting the existing engines with Fuel cell will accrue only limited benefits of 20-30% rise in efficiency. Output of fuel cells is DC voltage this opens the argument of DC versus AC for the main bus. Electric propulsion is better suited to ships with volume to spare as the motors, power converters, switchgear, transformers and gen-sets are all relatively large and heavy, meaning that they are not a good fit for small high-performance platforms. An arrangement of fuel cells and auxiliary diesel engines charging batteries during light/heavy loads respectively can be made. Electric ships such as US Queen Elizabeth class42 and Indian Dhruv/Anvesh ships are examples suitable for FCs. Using a FC based IFEP has substantial advantages. Firstly, the flexibility of machinery layout as the FC can be located anywhere onboard ship and only the electricity is required to be supplied to the motor in the aft section of the ship which drives the propeller via gearbox. FC based electric propulsion also has distinct advantage for navy due to substantial life of motors with minimal maintenance and noise, as against conventional mechanical components / transmission.

Effective Configuration for Onboard Application of PAFC.

IFEP is the most efficient configuration for employing FC. Maximum benefit of FCs can be extracted via a hybrid configuration, wherein, FCs can be employed as primary source for full ship load or auxiliary power source (along with bio diesel engine) in the cruising condition of the ship. Additionally, other sustainable sources such as solar power (Photovoltaic cells), wind power (fixed/foldable sails, flettener rotors, wing sail etc) can be installed as ancillary power source. Warships have a distinct advantage, most of the prolonged deployments consists of low power operations such as patrolling, transit at economical speed, drift-ex etc. During such operations, the ancillary sources can produce and store energy, which can be stored in batteries. These sources can together act as micro grid, with all sources contributing power to grid and nominal loads being catered by ancillary sources and PAFC for other ship loads. This energy can also be used to produce hydrogen via fuel processor system which can be further utilized by Fuel cell or direct injection of hydrogen in an engine, which produces high amount of energy.

III ROAD MAP FOR INDUCTION OF PAFC

(a) **Fuel Flexibility.** In order to meaningfully achieve the goal of transition to sustainable energy in a time bound manner, the marine shipping companies will first require to decide on the fuel flexibility onboard ship. The type of fuels required to be stored onboard can be decided by homing-on to a single/combination of sustainable technologies such as FC, Bio Diesel etc. This can be achieved by deliberate all available options and freezing the engine combinations for power generation/propulsion. All electric is undoubtedly the most suitable choice, given the advantages of low maintenance, fuel flexibility and tactical aspects such stealth, damage resilience, efficiency etc. Once, the combination is finalised, focused development of required technology should be concurrently progressed with detailed ship design and production.

(b) **Platform for Installation.** The second step is to determine the platform where the fuel cell is to be installed. This would help determine the purpose and requirements of the FC. Currently, the fuel cells presently have low power density and the performance over prolonged duration is not yet proven. Thus, the PAFC can be considered for installation onboard a non-combat ship of medium, such as a tug or ferry. PAFC can also be used in place of auxiliary / emergency DA onboard bigger ships.

(c) **Nomination/Design of Platform**. It is evident from above, that space and capacity is to be carefully considered while replacing conventional power generators with fuel cells. The complete benefits of fuel cells are less likely to be witnessed in case of retro fitment of FC, in place of existing power source. Designing a ship with FC in mind would be a better option, yet a costly and with long lead time. Hence, in the meantime, FC can be installed and tested on a ship of suitable size, which is about to be decommissioned. This ship can be converted as a platform for equipment testing.

(d) **Purpose of Application**. The next consideration for installing FC onboard ship would be to decide upon the purpose it needs to meet. Renewable energy applications can be primary propulsion, auxiliary propulsion, or ancillary power substitution. Fuel cells could be initially installed to generate electric power to either sustain the hotel load, i.e. other miscellaneous loads, or to aid another generator to share the ship's load. This would determine its capacity, material requirement, parameters etc. Capacity of fuel cell is affected by its fuel stacks and has direct bearing on its volume and weight, as discussed above.

(e) **Prototype and Full Scale Development**. Once above factors are consolidated, suitable firms can be approached for developing a prototype under the 'Make in India Scheme'. The ship design/ production can be progressed subsequent to successful proving of the prototype, or even concurrently, given the long time required for ship building. In case of the PAFC, the land based prototype has already been proved. Proving of the full scale model can be undertaken on a non-combat ship of suitable size, such as tug or ferry. In case of PAFC, installation/ proving of full scale model will be undertaken within 2024-30 onboard submarine.

IV GAP ANALYSIS

In order to formulate an effective action matrix, post research and deliberations, it is prudent to undertake the 'gap analysis' between the current and desired end state of induction of PAFC onboard ships

V CONCLUSION AND RECOMMENDATION

GOI is on mission mode with Atmanirbhar Bharat initiative and has laid special impetus on reducing defence imports and increasing defence exports. Further, Indian government has adopted the Green Hydrogen initiative and is firmly resolved to reduce the carbon footprint. Marine Industry could play a leader's role in both of these initiatives by progressively migrating to green technologies over the next two decades. The tactical level benefits of migrating from conventional to Green energy techs include silent machinery, electric propulsion, reduced thermal signature, increased fuel economy etc. resolve to reduce CO_2 foot print vis-à-vis electric propulsion.

There is sufficient evidence and argument to support the hypothesis of this paper pertaining to feasibility of employing PAFC onboard ship. It has been qualitatively (maritime application and deliberations with experts) and practically (proving of LBP) substantiated. Sustainable/alternate energy sources can be optimally employed onboard ships with substantial benefits and same can be extended to other arms of services and power sector. Hence, all out efforts are required to be pursued at the highest level with due diligence and determined vision.

Fuel-cells offer substantial economic, political, environmental and operational advantages. Further, Militaries across the world have been pioneers of latest technologies. It relies on the foresight and adaptability of India, how swiftly we migrate to green technologies, especially PAFC, in order to be future-proof against imminent crunch of conventional fuels. India have been presented with a unique opportunity to be world leader in PAFC technology. Large scale transition to PAFC will go a long way to contribute towards National Vision of Atmanirbharta, Green Initiative, Defence Diplomacy by production/exports and Naval vision of silent, green, lean manned and efficient ships.


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"You Get to Make Your Own Choices, but You Do Not Get to Choose Your Consequences"

"It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of Light, it was the season of Darkness, it was the spring of hope, it was the winter of despair, we had everything before us, we had nothing before us, ..."

Charles Dickens comes to our minds as we reflect upon the state of shipping today. Juxtaposed between Trade Wars, Galloping Technology, Regulatory Challenges and Climate Change issues, we could be looking like a deer caught in the headlights, unable to comprehend where our future lies.

The Lehman Brothers crisis of September 15, 2008, now close to 15 years ago; yet we have not been able to overcome its impact, just as we have never been able to avoid the odd bout of flu every winter, and of course the Covid-19. There has been a continuous stream of regulations, in the wake of galloping technology, escalating political gamesmanship across nations, safety management continuing to be an issue, and duty of care towards crew remains questionable.

Is it the first choice industry for an entrepreneur? For the hopeless romantics, it is!

We would like stakeholders in the industry to come forward to make a case for Shipping, We invite you to Chennai and fearlessly present views to make the industry safe, environment friendly and investor supportive. In Chennai, one of India's largest cities and its cultural capital, you would find the rhythm and the beat to speak your mind, with an unwavering conviction and unfounded joy.

On behalf of the Organising Committee and The Institute of Marine Engineers (India), Chennai Branch, we extend a warm invitation to you and your organisation to actively participate and support the three day event, between December 4-6, 2024 in Chennai. We provide you in attachment, a copy of the canvas, and we hope to engage you in cool pre-winter periods in India.

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PAPERS

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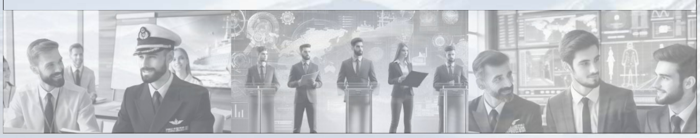

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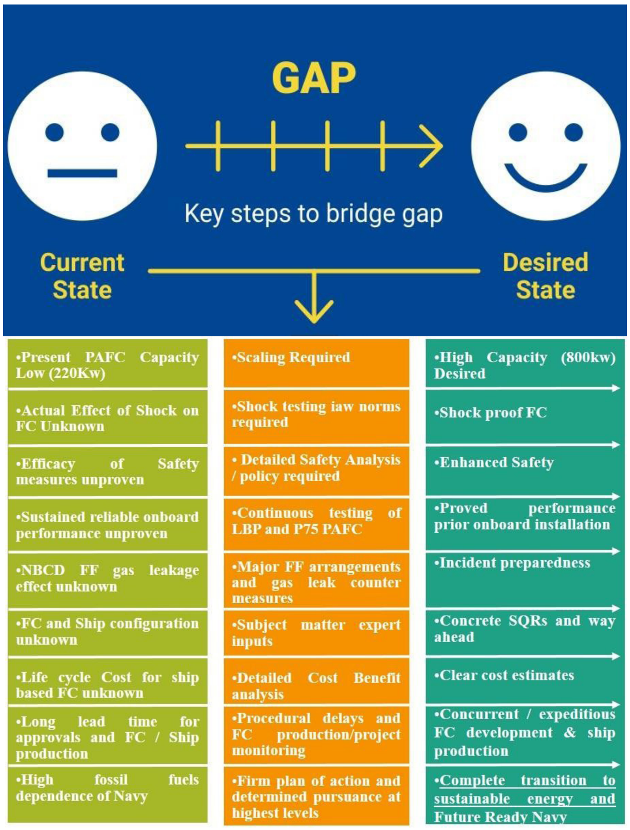

Figure 3. Gap Analysis

About the author

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

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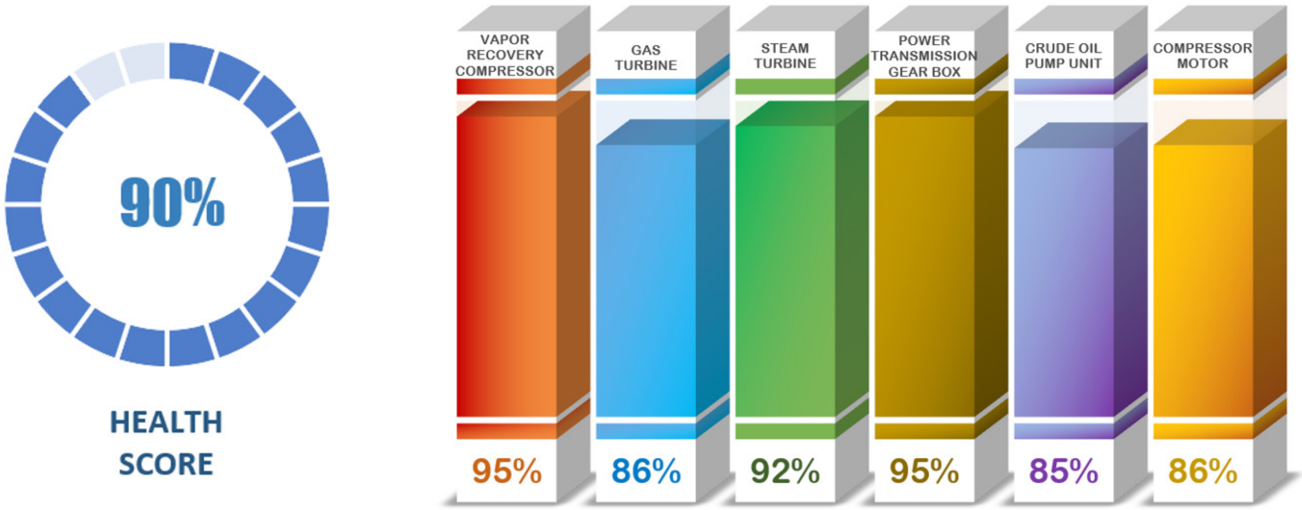
Condition Monitoring Using Predictive Ml Applications



S. Venkat Krishna

Abstract

A most common method to perform Condition monitoring is to note sensor measurements in specified durations and impose a maximum and minimum limit to it. This can help classify the equipment as 'Healthy' or 'Unhealthy'. Anomaly detection or Outlier detection is identification of rare items, events or observations which raise suspicions while observations differ significantly from majority of data. Predictive ML models like 'Pattern Recognition' is an algorithm that identifies the patterns in historic data, and then uses these learned patterns to detect changes in on-going plant operating data that arise from a developing problem. These methods require limited knowledge about the process because the model will learn and infer them directly from the data. As a result, Pattern Recognition can be applied to many types of process variables and process variations, such as operational changes and ambient condition changes. Some typical examples are cases of some compressors from Oil and Gas industry, which have been presented using Pattern Recognition. Similar predictive ML methods can be applied in Marine industry for monitoring machineries on board vessels.

1. Introduction

Any machine or component with or without any moving parts will eventually reach a point of poor health. This may not be an actual failure or shutdown, rather it is one in which the equipment is no longer functioning in an optimal state. This signals a requirement for maintenance activity to restore the equipment back to full operating potential.

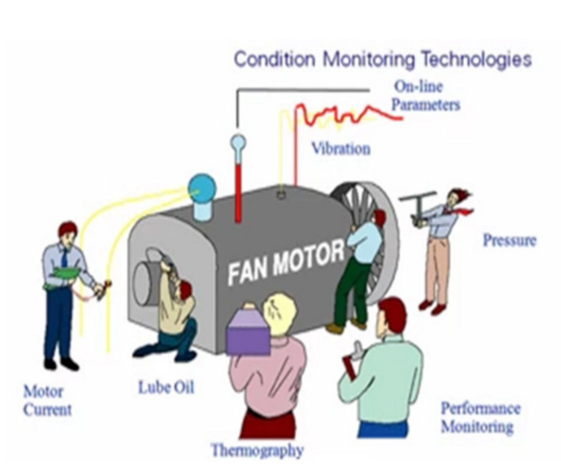
In simple terms identifying the "health state" of the equipment is the scope of Condition Monitoring.

An illustration of applying conventional methods is shown in **Figure 1.**

Most common method to perform Condition monitoring is to note sensor measurements in specified durations and impose a maximum and minimum limit to it. This can help classify if equipment is 'Healthy' or 'Unhealthy'.

Problems with conventional condition monitoring:

Anomaly detection or 'Outlier' detection as shown in **Figure. 2** is identification of rare items, events



Courtesy: National Instruments

Figure 1. Condition monitoring technologies

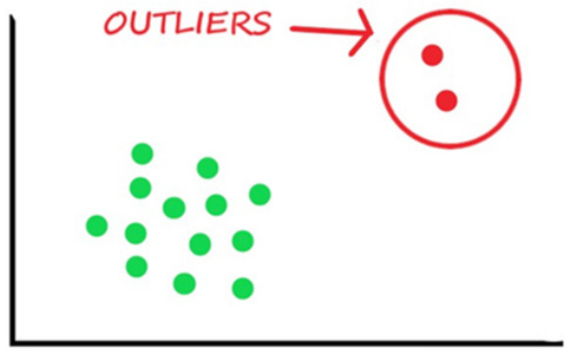


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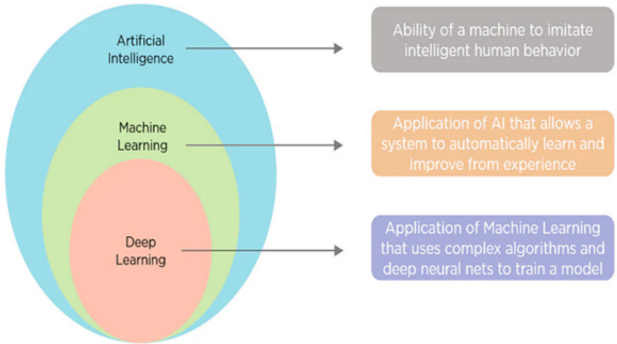
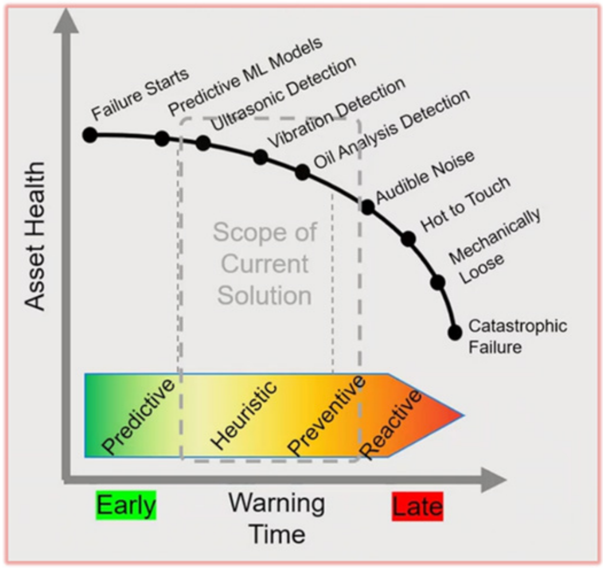
Figure 2. Anomaly detection using Outliers



Courtesy: Studocu

Figure 3. AI-ML-DL fundamentals



Courtesy:Honeywell

Figure 4. CBM and detection levels

or observations which raise suspicions by differing significantly from majority of data. Imposing such hard-coded alarm limits is known to generate a large number of false alarms, i.e., alarms for situations which are actually healthy states of the machine. There are also missing alarms, that are problematic or critical, but not notified. The first one wastes time and effort along with non-availability of the equipment. The second one is more crucial as it is leads to real damage with associated repair cost and lost production or process.

In case of two-dimension data (X and Y) it becomes quite easy to visually identify outliers. But if the dimensions/variables increase say 10-100, it becomes quite complicated.

Solution

The health of a complex piece of machinery or equipment cannot be reliably adjudged based on analysis of each measurement or parameter alone. It is rather achieved by a combination of various measurements giving a true picture of the situation. Machine learning methods for Pattern recognition can be based on both supervised and unsupervised learning.

The models using various AI-ML-DL fundamentals as shown in **Figure 3,** are chosen on the basis of the dataset and variables (parameters) available. It is most important to check correlation between the variables before choosing the correct methodology. Some commonly used ML methods used are Multi Linear regression, Random forest, Gradient Boost Regressor, XGBoost etc., Deep learning models like ANN, LSTM etc., are also most widely used.

Machine learning methods for Pattern recognition can be based on both supervised and unsupervised learning

2. Methodology: Pattern Recognition (Predictive ML model)

As shown in **Figure. 4** various conventional condition-based monitoring (CBM) methods detect the anomaly much later and thus provide very little time to react or take corrective actions.

The conventional methods can be classified as Heuristic, Preventive and Reactive, all of which are later stages of anomaly detection.

Predictive ML model starts detecting as soon as the failure trend presents itself, starts progressing and provides early warning to the operator. This provides sufficient action time to mitigate the abnormal situation and optimize process / machinery operations.

Pattern Recognition (PR) is an algorithm which is a predictive ML model, that identifies the patterns in historic (training) data, and then uses these learned patterns to detect changes in on-going plant operating data that arise from a developing problem.

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PR does not use mathematical, physics or first principle models for predictions.

The conventional methods can be classified as Heuristic, Preventive and Reactive, all of which are later stages of anomaly detection

Empirical methods are used to model the expected performance variable values that include the true process value plus any measurement uncertainty and operational variance.

These methods require limited knowledge about the process because the model will learn and infer them directly from the data (Machine learning). As a result, PR can be applied to many types of process variables and process variations, such as operational changes and ambient condition changes. Typically, existing data from the data historian is used to create statistical relationships between relevant signals that can describe key performance, operational or reliability characteristics for key components. Once these relationships or prediction models are derived, they can be used to accurately estimate the predicted values of the various signals while the component is known to be operating normally.

The Predicted signals at 'normal' conditions can then be compared to the actual Observed values in real-time by calculating the 'Residual' as shown in **Figure. 5.**

Residuals = Observed or Actual value 'minus' Expected value.

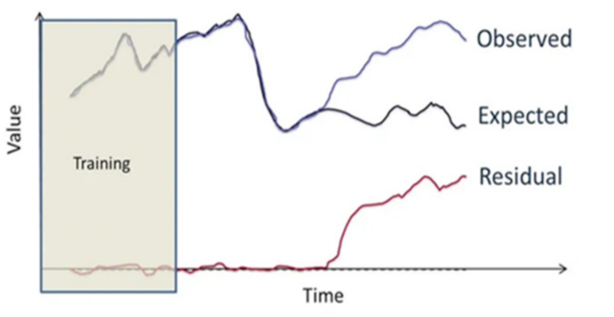
This Residual should, over time, be statistically zero under normal conditions.

If the residual begins to statistically deviate over time, this is a 'highly sensitive' and accurate means for early detection of an 'anomaly' that would lead to a failure.

The thresholds of predictive alerts high and low, for a parameter being monitored are configured based on operator's confidence levels. It depends on how early or later a predictive alert should be triggered.

Asset Health Monitoring and diagnostics

As a general practice it is observed that operators rely more on Maker's allowable limits or traditional limits and assess the machinery condition on the basis of fixed alert condition.



Courtesy: Powerplant performance

Figure 5. Pattern recognition fundamentals

As long as the machinery is operating within those limits, it is generally deemed to be operating normally.

It is important to recognize that the machinery may still be not running optimally or normally. It may be deviating from an expected operating condition, though it still appears to be operating within the traditional limits.

This remains one of the most important reasons for the onset of failures for any machinery. Identifying the condition when a machinery starts deviating from the expected condition is the most important diagnosis of condition monitoring that could indicate process or machinery degradation.

Conventional methods have these limitations, where predictive ML models have a great advantage.

By observing patterns of operating machinery and comparing it with expected values in real time it is easy to diagnose the fall out in machinery performance and efficiencies.

A comparison between heuristic and predictive health monitoring methods is shown in **Figure 6.**

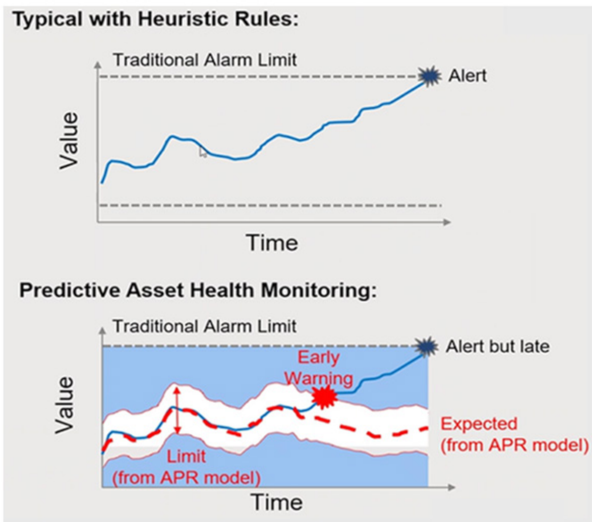
The key differences are mentioned below.

Heuristic rules

Sensor alarm limits or Traditional alarm limits must be set outside of normal operating range to cover all possible conditions.

Predictive Asset Health Monitoring

a. Advance Pattern Recognition (APR) Machine learning trained models.



Courtesy: Honeywell

Figure 6. Heuristic and predictive method comparison

b. Compares observed behavior to expected behavior.

c. Provides early warning of sensor issues and equipment degradation.

d. Can identify very subtle condition changes to identify anomalies.

e. Makes subject matter experts aware of abnormal conditions and supports the decision-making process.

3. Results and discussion

The concept of Pattern Recognition is best explained by exhibiting some use cases from Oil and gas industry. The industry relies heavily on pattern recognition for their condition monitoring.

The idea of showcasing Oil and gas industry is that several such projects have already been successfully implemented and being utilized effectively by the refineries worldwide to monitor thousands of static and rotating assets. Similarities can be drawn from such methodologies for developing identical projects for the Marine industry. Important terms are explained below in reference to the use case trends.

Actual value: Current operating value of machinery parameter

Expected or predicted value: Reference value obtained from past historic data using predictive ML model

HLim: Predictive diagnostic alert- Higher limit configured as per operator's confidence level.

LLim: Predictive diagnostic alert- Lower limit configured as per operator's confidence level.

Maker's HL: Alert suggested by Maker based on maximum allowable value for a parameter.

Maker's LL: Alert suggested by Maker based on minimum allowable value for a parameter.

Applications of Pattern Recognition:

A. Equipment: Tandem (Dry) Gas seals for Propylene Refrigeration compressor

Parameter monitored: Primary vent gas flowrate (Driving end)

Trends in **Figure. 7** show a deviation in Primary vent gas flowrate for dry gas seals of a propylene refrigeration

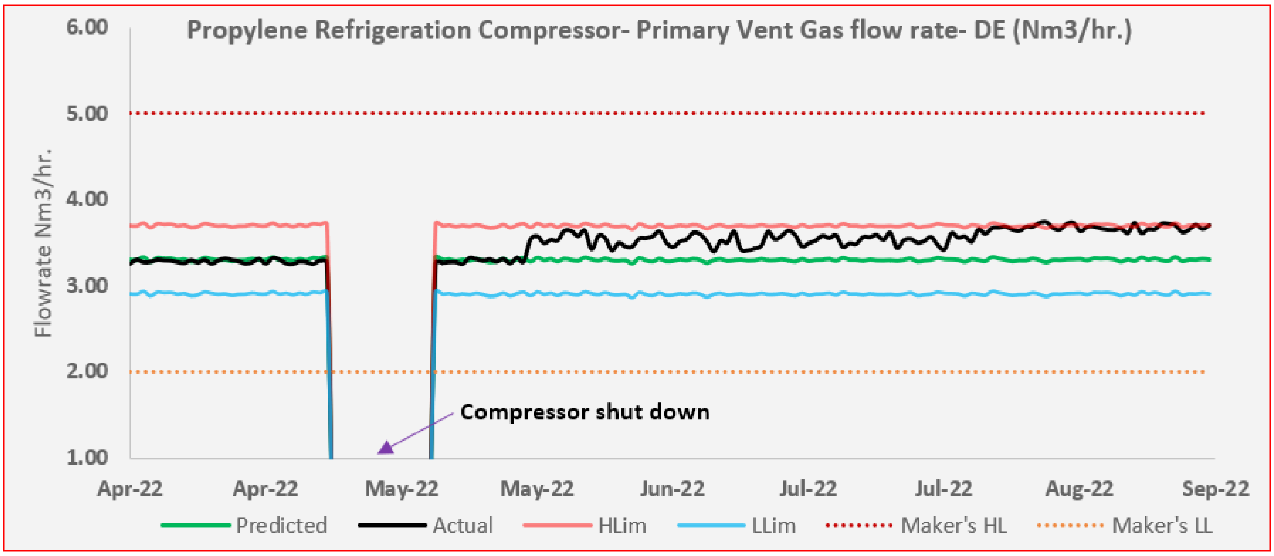


Figure 7. Primary vent gas flow rate DE deviation from predicted values

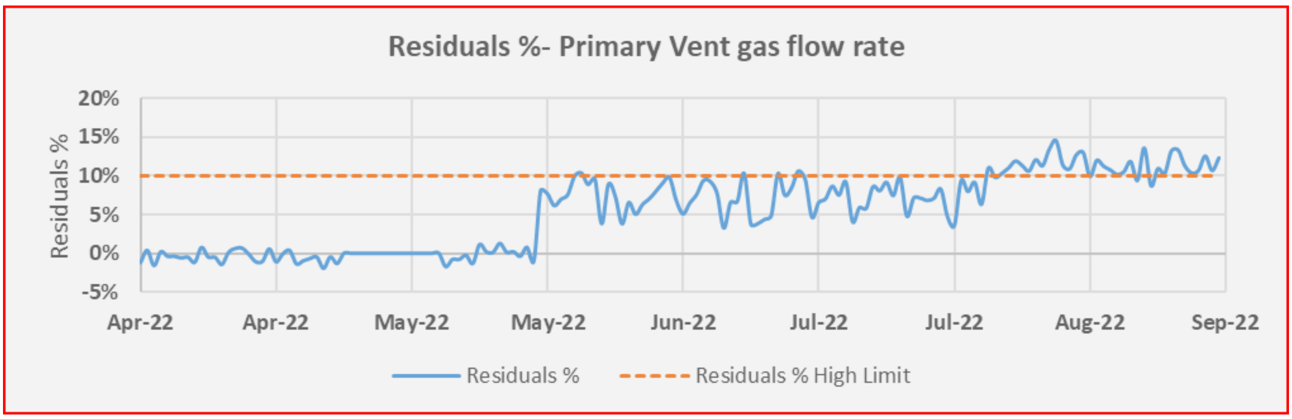


Figure 8. Residuals % change between predicted and expected values (PVG flow rate)

compressor at the driving end. The actual values (flowrates) appear to be following predicted values initially but then starts to deviate from predictions over time. Initially the flowrates appear to be following predictions @ 3.25 Nm^3/hr. After a brief shutdown, when compressor was restarted the flowrates appear to deviate progressing upwards, breaching predictive high limits set at @ 3.7 Nm^3/hr. This could probably be due to increase in clearances in dry gas seals or due to malfunction of a pressure control valve in primary gas supply line to dry gas seal at the driving end. Average residuals % change shown in **Figure. 8** is @ 5.36%, with maximum residual values touching @ 15%. The predictive high alert for residuals is configured at @ 10%.

B. Equipment: Vapor recovery gas compressor

Parameter monitored: HSS Radial bearing vibration-Driving end X

Trends in **Figure. 9** show a deviation in HSS radial bearing vibration of a vapour recovery compressor at the driving end. The values appearing to be closely following predictions @ 9 µm during running and later appears to deviate to @ 9.5 µm breaching predictive high limits rapidly. This could probably be due to any vibrations caused by sudden operating process changes in refineries like flowrates, resonance effects, misalignment of shafting, surging of compressor, casing vibrations etc. The root cause should be detected and resolved. Average residuals % change shown in **Figure. 10** is @ 0.61 % with maximum values touching @ 5%. Predictive high alert for residuals is configured at @ 2%.

C. Equipment: Booster Compressor

Parameter monitored: Thrust Bearing Axial displacement Z1

Another example shown in **Figure. 11** is of a Thrust bearing axial displacement anomaly for a Booster gas compressor. During operation, the thrust bearing axial displacement position appears to steadily increase and deviate significantly from its predicted values breaching the configured predictive upper threshold limit. The values appear to be operating normally at @ 0.15 mm before it deviates resulting in an abnormal condition. Predictive high alert is set at @ 0.18 mm and maker's alert at @ 0.22

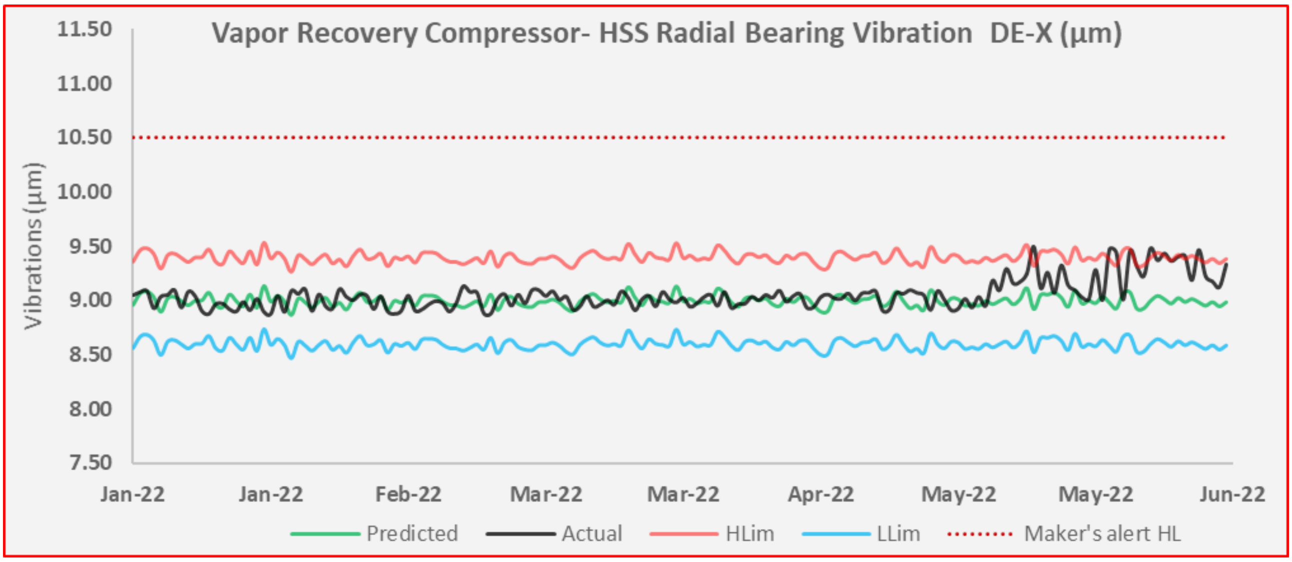


Figure 9. HSS Radial bearing vibration DE-X deviation from predicted values

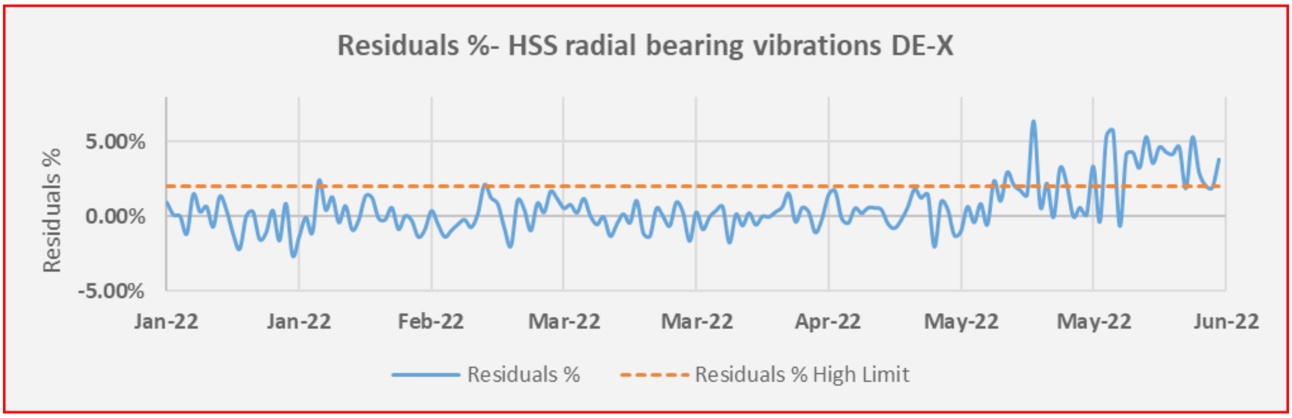


Figure 10. Residuals % change between predicted and expected values (Radial bearing)

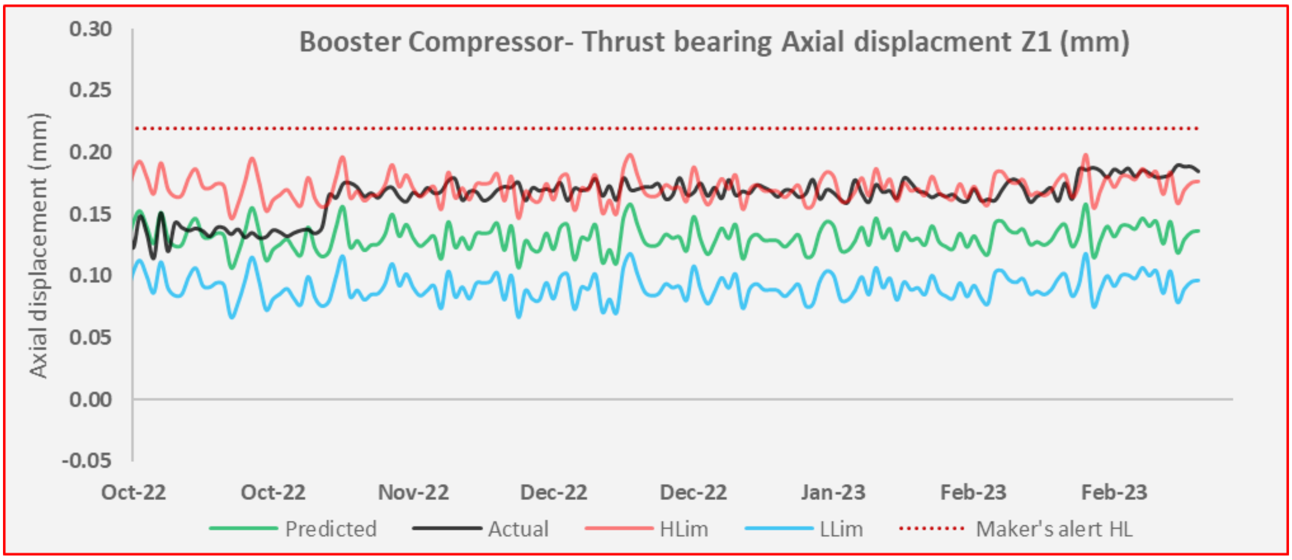


Figure 11. Thrust bearing axial displacement deviation from predicted values

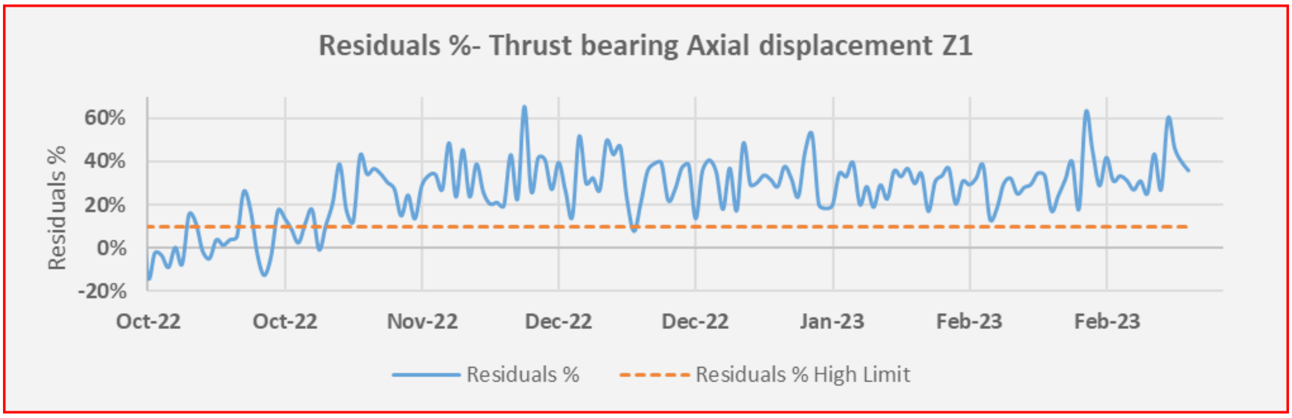


Figure 12. Residuals % change between predicted and expected values (Thrust bearing)

mm in this case. There is also a maker's low limit alert for axial displacement as Z1 can be more or less, both can be harmful, but it is not shown in trends here for the sake of simplicity.

Possible cause could be anomalies in (pressure) balance line system or rapid changes in flowrates causing changes in axial thrust resulting in axial displacement of thrust bearings. Average residuals % change shown in **Figure. 12** is @ 25 % with maximum values touching @ 60% at times. Predictive high alert for residuals is configured at @ 10%.

D. Equipment: Lean Gas Compressor

Parameter monitored: Lub. Oil system pressure

An example for system Lubricating oil pressure of a Lean gas compressor is shown in **Figure. 13.**

The lub. Oil pressure appears to drop suddenly and then steadily during operation, probably due to a leakage in system or other reasons.

The normal operating pressure during operation is @ 3.0 bar as per trends. Predictive limits (high and low) have been configured based on operator's confidence levels. Maker's limit for low level is configured @ 2.1 bar, below predictive low limit alert.

As seen the lub oil pressure drops during operation. It breaches the set predictive low limit, continuing to fall further below it. Once the predictive low limit is breached an early warning is provided to operator. This helps taking early corrective action and mitigating the anomaly.

Average % deviation change over time shown in **Figure. 14** is @ 12.5 % in this case. The predictive low alert for residuals is configured at @ -5%.

In a conventional conditional monitoring method, due to absence of expected values for current condition,

> *In a conventional conditional monitoring method, due to absence of expected values for current condition, an operator is unable to compare the actual values to assess the veracity of the ongoing process*

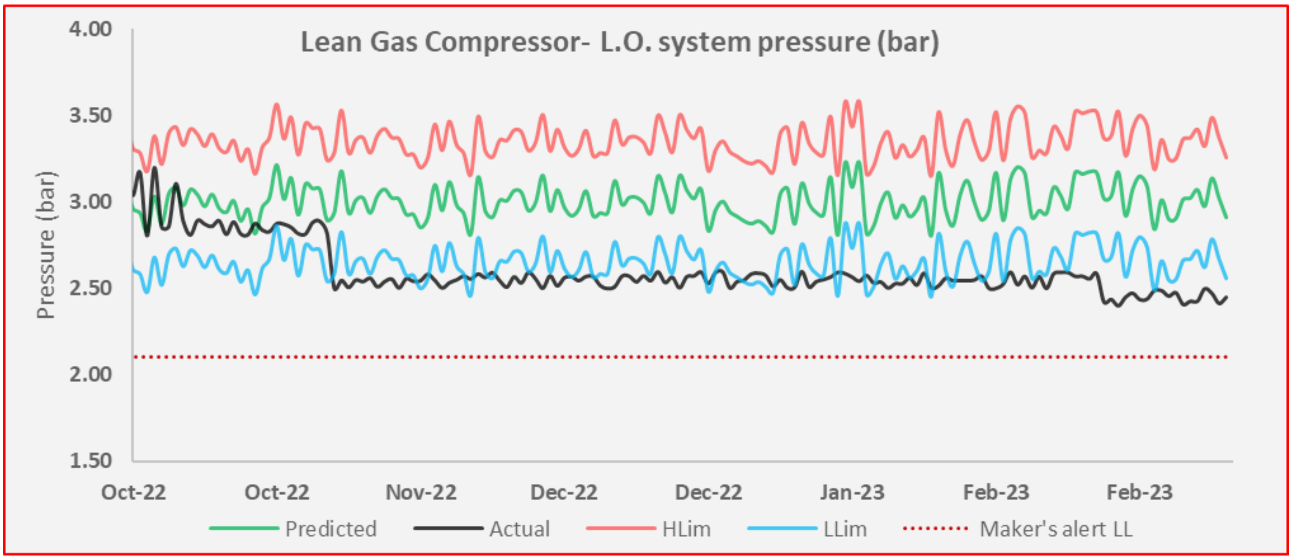


Figure. 13. L.O. system pressure deviation from predicted values

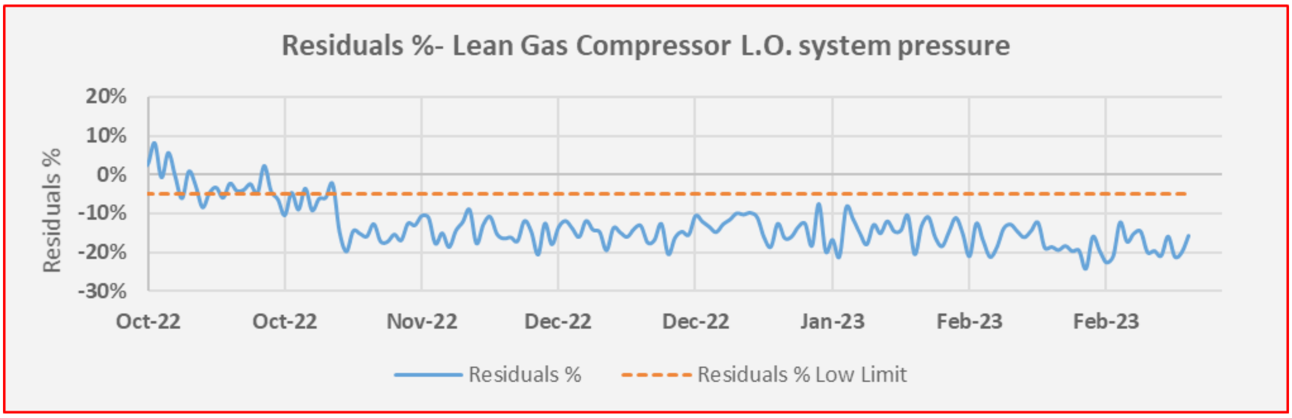


Figure 14. Residuals % change between predicted and expected values (L.O. pressure)

an operator is unable to compare the actual values to assess the veracity of the ongoing process. As long as it is within traditional fixed limit it is deemed to be operating normally.

The advantage of a predictive ML model is that it identifies deviations within a normally appearing condition, in comparison with ML generated expected values. It gives the operator a significant advantage over conventional monitoring methods. Thus, processes can be optimized to mitigate abnormalities, improvise processes, increase machinery life and efficiencies.

Figure. 15 and 16 show a scenario where an operator after identifying the deviations takes corrective action to restore the L.O. system pressure of the compressor back to normal conditions.

An operator should investigate the cause of such deviations as soon as it starts to appear, to capitalize the maximum advantage of condition monitoring derived through ML. Benefits of pattern recognition can be fully harnessed only if actions are taken as soon as a subtle deviation from expected values are identified and acted upon.

Retuning models

Sometimes there could be deviations between expected and predicted values when operating processes have changed and model has not been trained for under those conditions. These can be identified by the operators when deviations appear to be large but the operating patterns seem to be acceptable under current process conditions. For example, let's say that general operating trend of a machinery load condition is in the range 30 to 60 %. Based on it a model is trained and expected values or baselines are generated. After few months or years, the operating process changes due to industrial demands requiring the same machinery to run between 30 to 80% load. These are termed 'new normal' operating conditions. Since our model earlier was only trained between 30 to 60% it will not be able to predict values over 60% load correctly. The model therefore requires to be re-tuned to learn new patterns and generate modified expected values as per new normal conditions.

Thus, a continuous condition monitoring is achieved by creating ML models, by understanding processes, its

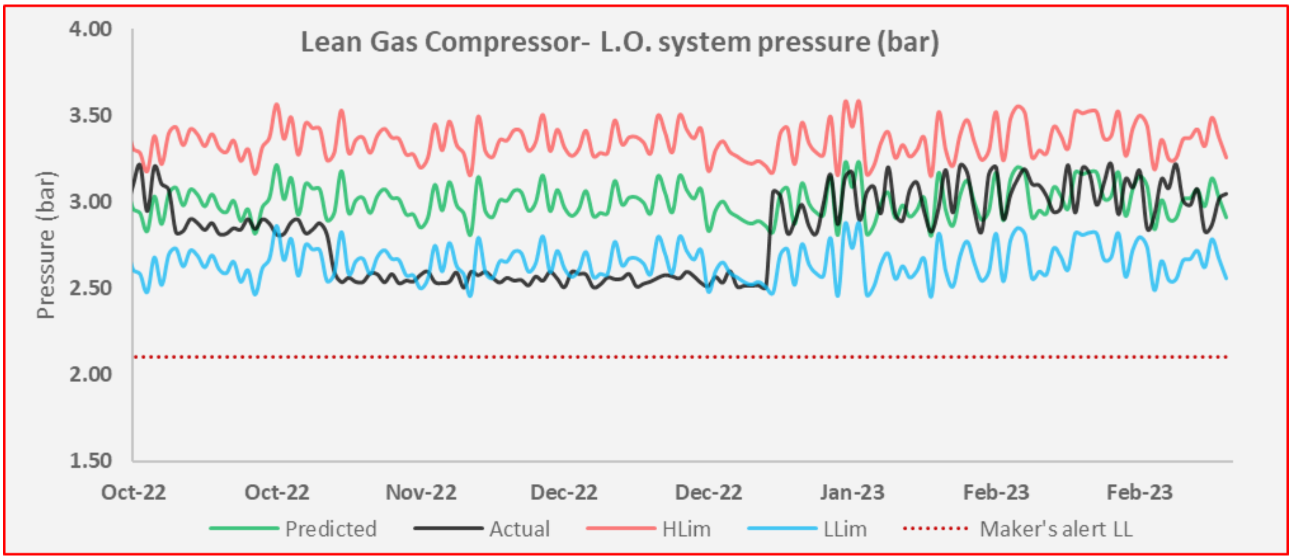


Figure 15. L.O. system pressure deviation corrected

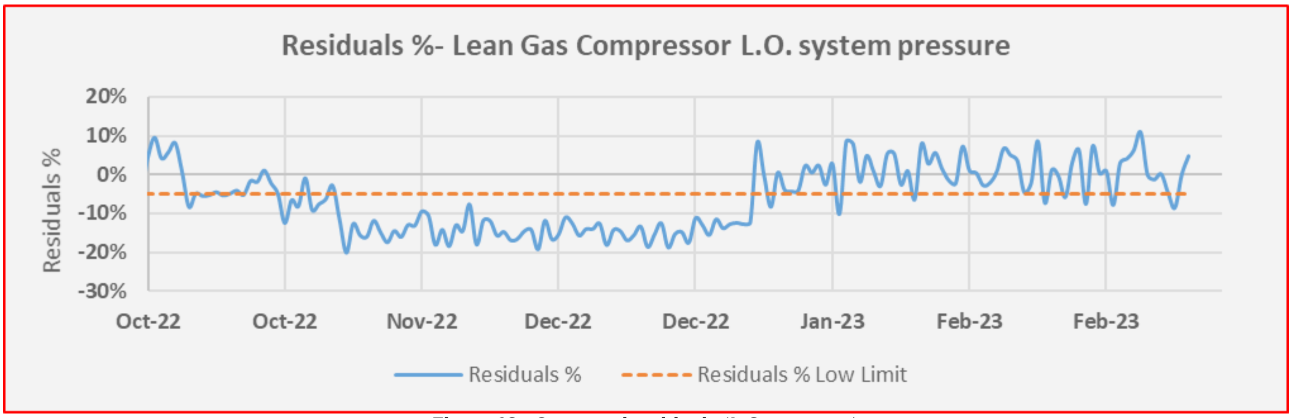


Figure 16. Corrected residuals (L.O. pressure)

variations over time, retuning models to modify expected values and thus optimize running of machineries.

One should take advantage of such predictive ML methodologies to optimize processes and safeguard machineries before it can lead to irreversible situations that could degrade or cause catastrophic damages to both machinery and operating personnel.

Monitoring Summary

A summary report for all machineries monitored can be generated monthly, quarterly, six monthly and annually to populate and analyze to formulate some valuable KPIs:

a. Number of alerts generated per day

b. Cases reported

c. Cases closed

d. Catch percentage

e. Cases under observation

f. Cases open and closed

g. False positives

h. System reliability

i. Health score (machinery /systems)

j. Value capture

Many such KPIs can be generated using suggested condition monitoring methods and assets can be closely monitored with such techniques.

It however requires a good coordination between the site team, managers, monitoring team, data analysts, system developers and others involved in it to continuously improve the system, implement and maintain it successfully.

A ‘Catch’ is an alert that refers to an anomaly detected by using predictive diagnostics, resolving it effectively and thereby translating it into commercial savings. Usually, industry standard is achieving 95% catches out of total number of events captured.

Annual categorisation of alerts and catch % can be visualized as shown in **Figure. 17.**

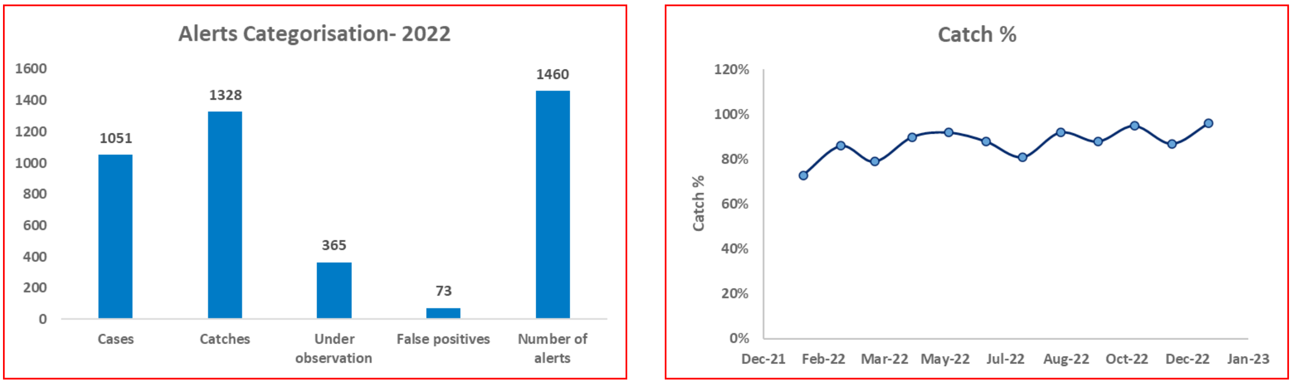


Figure 17. Alerts visualization and catch %

Similar such KPIs can be visualized that can drive decision making processes like future scope, budgets, planning and other key improvements.

Value capture

'Value capture' is a process of assessing usefulness of such condition monitoring methods that can help understand and estimate the commercial savings gained by using predictive diagnostics, taking necessary steps in preventing failures/breakdowns and saving thousands of dollars as a result.

If an anomaly was not predicted (for example, using conventional condition monitoring method), missed or not attended by site, it would have caused machinery failure and breakdown. The plant will shut down resulting in multiple consequences and mounting losses. Cost arising from such losses can be listed using an example of Value capture methodology shown in **Table 1.**

Thus, Value capture for this example based on predictive diagnostics is $ 413,144 along with 157 hours of saving production or equivalent losses. There could be other costs involved that could also be included in above calculations depending on the asset and conditions. A general calculation methodology for Value capture is shown in **Table 1.** It is evident how valuable condition monitoring based on predictive ML can translate into huge commercial savings.

4. Conclusions

Pattern Recognition and machine learning methods are able to provide valuable insights in the realm of predictive diagnostic and Condition monitoring. The models generated using past historic data can be easily retuned to adapt to the change in operating conditions of machinery either due to energy efficient modifications or any process changes that industry has adopted either due to modernisation or increased demands.

Normally, operating data for past one year would be required for tuning models and generating baselines or reference patterns. Getting more data points that significantly capture all operating conditions is the key to a credible model creation. The model will then get to learn and predict better.

Needless to say, the accuracy and efficacy of the models depend largely on data acquired through sensors at site measuring the parameters and data acquisition. The accuracy of measurements, maintaining and regular calibration of sensors is imperative for deriving credible data points for creating models.

Table 1. Value Capture

<table>
<tr><td colspan="3"></td><td colspan="3">Total Maintainenance Cost saved</td><td colspan="4">$ 413,144</td><td rowspan="2"></td></tr>
<tr><td></td><td colspan="3">Total Value Generated</td><td colspan="4">Avoided 157 Hours of Production loss + USD 413K (A+B+C+D)</td><td colspan="2"></td></tr>
<tr><td>Case ID</td><td>Terminal</td><td>Site</td><td>Asset</td><td>Production Loss (A) (Hrs)</td><td>Maintenance Duration (Hrs)</td><td>No. of personnel involved in maintenance</td><td>Man Hours (B) (USD)</td><td>Spares (C) (USD)</td><td>Secondary Damages (D)(USD)</td><td>Potential savings Maintenance Cost (B+C+D) (USD)</td></tr>
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<tr><td colspan="4"></td><td>157</td><td colspan="5"></td><td>$413,144</td></tr>
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With the advent of new technologies and rapid digitalization and remote monitoring, pattern recognition becomes a handy tool to capture real time events and mitigate failures or recognizing patterns tending towards failures much earlier.

The five key elements of condition monitoring are data collection, data analysis, alert generation, maintenance planning, and continuous improvement.

It can play a significant part in improving the energy efficiency of the machineries, save the environment by reducing carbon footprints while providing abundant commercial savings.

Cases showcased in the paper were typically for compressors employed for different kinds of processes in Oil and gas industry. The applications of pattern recognition can be broadly applied to any kind of machinery like engines, turbines, pumps, motors, heat exchangers to name a few. Such methods could be employed in various industrial sectors similar to Oil and gas. Marine industry could benefit immensely from such methodologies and can be relied upon.

5. Acknowledgements

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4. https://powerplantperformance.com/
5. Trends, table, visualizations and ML algorithms have been conceptualized using synthetic data self-generated by the author to explain use cases in this paper.
6. https://nptel.ac.in/courses/106107220 (Data analytics with python)

About the author

Mr. S. Venkat Krishna is a Chief Engineer with 15 years of experience on tankers and over 27 years of seafaring experience on different types of vessels and had been a Visiting Faculty. . Currently he is an Independent consultant, a knowledge transfer practitioner, supporting startup digital companies and reputed MNC service providers. His areas of interest are in applying statistical and data science methodologies in condition monitoring, predictive diagnostics, vessel performance optimizations, advising technical and product development solutions for Marine and Oil and gas sectors. He is a Fellow of Institute of Marine Engineers (India).

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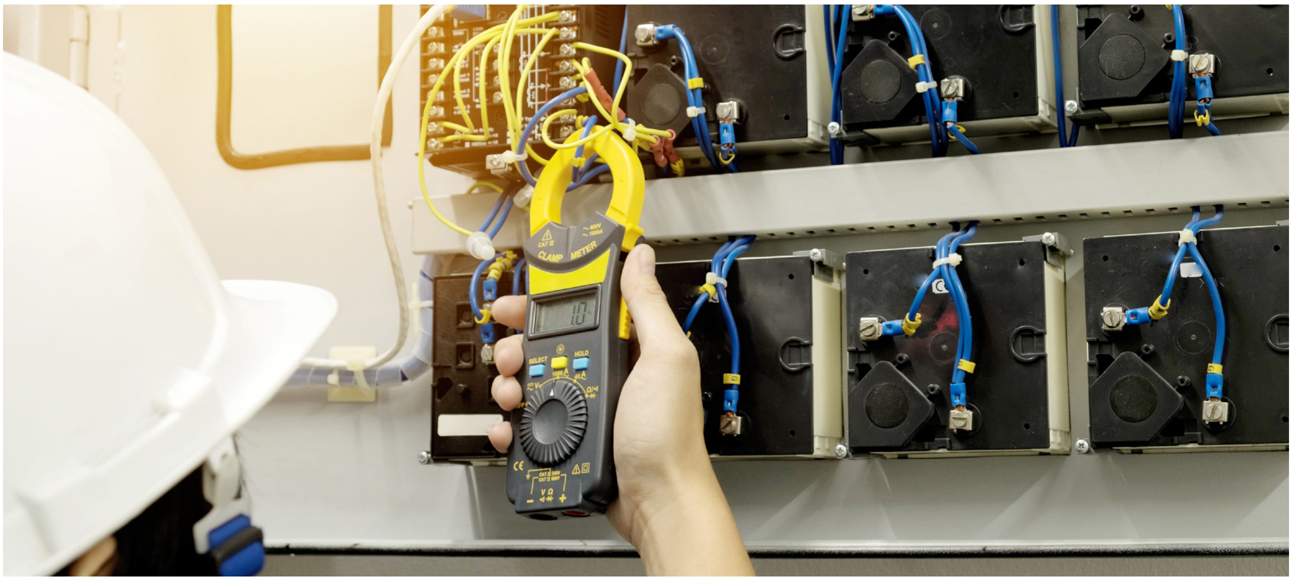
Marine Electrical Maintenance and Troubleshooting



Elstan A. Fernandez

Low, High and Unstable Output on No Load and While the Generator is On Load		
Symptoms	**Probable Causes**	**Remedy**
	Failure of the printed circuit board or disconnection of the thyristor's gate circuit	Replace the AVR.
	Disconnection of the detecting transformer	Repair or replace it.
	Disconnection of the AVR circuit.	Repair or replace it.
	Disconnection or incomplete contact of manual voltage rheostat	Replace the rheostat.
	Rotation speed abnormally high	Adjust the rotation of the prime mover.
Unstable Voltage (on No Load)	The engine governor is unstable (hunting).	Check for speed instability with a frequency meter, or tachometer. Sometimes this problem will clear when a load is applied to the engine.
	AVR Stability settings need adjustment.	Check the AVR stability links, adjust the stability potentiometer.
	Loose or corroded connections	Intermittent voltage fluctuations can be created by poor connections. Check the auxiliary and AVR terminals.
	Intermittent earth (low insulation resistance).	Megger test all windings including the exciter stator, as low insulation resistance can affect the AVR.
	Faulty AVR.	Check the AVR for corrosion or broken components. Replace the AVR and re-test it.

Continued...

Low, High and Unstable Output on No Load and While the Generator is On Load		
Symptoms	**Probable Causes**	**Remedy**
	Voltmeter faulty / unstable.	Panel mounted voltmeters are sensitive to vibration. Check and verify the readings.
	Faulty diodes (may be short circuited)	Check and replace any damaged diodes if necessary
Unbalanced Voltage (on No Load).	Fault on main stator windings	Disconnect all external leads to the generator and re-test it. Separately excite it. A winding that os short circuited will get hot, and the engine will sound slightly loaded. Shut down the set and check by hand for hot spots.
	Single-phase loads (phase - neutral) are unevenly distributed over the three phases.	Check the current in each phase with a clip-on ammeter. The full-load rated current must not be exceeded on any individual phase.
Unstable Voltage (while On Load).	The engine governor is unstable (hunting)	The engine governor is unstable (hunting)
	Check the currents in each phase with a clip-on ammeter. The full load rated current must not be exceeded on any individual phase. Re-distribute the load if necessary.	Check the currents in each phase with a clip-on ammeter. The full load rated current must not be exceeded on any individual phase. Re-distribute the load if necessary.
	A Leading Power Factor load is created by power factor correction capacitors.	A Leading Power Factor load is created by power factor correction capacitors.
	Check with a frequency meter or tachometer, for speed variations due to governor 'hunting', or cyclic irregularities in the engine.	Check with a frequency meter or tachometer, for speed variations due to governor 'hunting', or cyclic irregularities in the engine.
	Fluctuations in the load current, (motor starting, or reciprocating loads).	Fluctuations in the load current, (motor starting, or reciprocating loads).
	Imperfect contact of the manual voltage rheostat	Adjust or replace the rheostat.
	Failure of the AVR's damping circuit	Replace the AVR.

Fault Symptoms and Remedies When on Load		
Symptoms	**Probable Causes**	**Remedy**
High Voltage (while On Load)	Unbalanced load.	Check voltages on all phases. If they are unbalanced, re-distribute the loading over three phases.
	Leading Power Factor load (capacitor banks).	Check the excitation voltage across X+, (F1) and XX-(F2). A leading power factor will give an abnormally LOW DC excitation. Remove the power factor correction equipment at low loads.
	Parallel droop current transformers reversed.	Check for droop reversal.
	Burden resistor incorrectly set across improved regulation transformer. (Pre 1989 machines only).	Reduce the amount of resistance across the improved regulation transformer until on-load voltage is correct.

Continued...

Fault Symptoms and Remedies When on Load		
Symptoms	**Probable Causes**	**Remedy**
Poor Voltage Regulation (while On Load)	Large speed droop on the engine. The AVR's UFRO protection has activated.	Check that the speed droop from no load to full load is no greater than 4%. Check AVR LED, if LIT, increase engine speed.
	Unbalanced load.	Check voltage and load current on all phases. If unbalanced, redistribute the load more evenly across the phases. This could be the case with shore-based alternators as a ship's loads are normally balanced by design.
	Parallel droop circuit incorrectly adjusted, or requires shorting switch for single running.	The droop circuit will give additional voltage drop of -2½ % at full load 0.8 pf. For single running machines this can be improved by fitting a shorting switch across the droop CT input, (S1 – S2), on the AVR. (Pre 1989 machines, short across the burden resistor in the terminal box).
	There is a voltage drop between the machine and the load, due to I2R losses in the supply cable. (This will be made worse by motor starting current surges, etc).	Check the voltage at both ends of the cable run while the generator is at full load. The differences in voltage indicate a voltage drop along the cable. In severe cases, a larger diameter cable is required; this will normally not happen in a generator that is already installed, commissioned, tested and running.
Poor Voltage Regulation (while On Load)	Improved regulation equipment is reversed. (Pre 1989 machines only).	Reverse the secondary leads on the transformer, and re-test it on load.
	Fault on the main rectifier or excitation windings.	Check if the no-load excitation voltage across the AVR X+ (F1) and XX- (F2) is as per the manufacturer's specifications.
Poor voltage response to load surges or motor Starting	AVR Under frequency protection circuit, (UFRO) has activated.	Check AVR LED, If it is lit, the UFRO has activated, (engine speed is low). Check engine speed and adjust to correct the nominal speed, (or frequency).
	The engine is faulty or the engine governor is unable to respond, (speed drop too low).	Check the performance of the engine during the application of load. Check if the AVR LED is lit during motor starting. Check if the AVR 'DIP' or 'DWELL' engine relief circuits are activated. Adjust them as necessary.
	The parallel droop circuit is incorrectly set	Too much droop will increase voltage dips when motors are starting. Fit a shorting switch for a single running Generator
	Load surges exceed 2.5 times the full load current.	Check load surges with a clip-on ammeter. The voltage dip may be excessive if the current exceeds 2.5 times the full load. Refer to the manufacturer for motor starting calculations.
	Voltage drops between the generator and the load, due to I2R losses in the cable. This will be worse during current surges (motor starting etc).	Check the voltage at both ends of the cable run while the generator is at full load. The differences in voltage indicates a voltage drop along the cable. In severe cases, a larger diameter cable is required.
	Motor contactors are dropping out during starting, (due to large current surges, Voltage dips greater than 30%).	All the symptoms and remedies in this section may apply to this problem.
	The AVR "Stability" control is incorrectly adjusted.	Adjust the AVR 'Stability' control potentiometer anticlockwise until the voltage is unstable, then turn it slightly clockwise until it is stable.

Continued...

Fault Symptoms and Remedies When on Load		
Symptoms	**Probable Causes**	**Remedy**
Poor voltage response to load surges or motor Starting	Fault on windings or rotating rectifier.	Any fault in this area will appear as high excitation voltage across X+ (F1) and XX- (F2), higher than figures the recommended values in the manual. Check the Rotating Rectifier Assembly and Voltage as advised earlier.
	The AVR UFRO and / or engine relief circuit is activated during motor starting.	Check the performance of the engine during the application of load. Check if the AVR LED is lit during motor starting. Check if the AVR 'DIP' or 'DWELL' engine relief circuits are activated. Adjust them as necessary. See the AVR instructions for details.
	Faulty AVR.	Replace it and re-test it on load.
Low voltage (while on load)	The engine speed droop is greater than 4%.	Check if the AVR LED is lit, i.e., the UFRO is activated, (a low-speed indication). Check that engine speed at no load and full load. The engine's governing should be within + 4% and –1% of nominal speed. Reset it as necessary.
	The Under-frequency protection circuit has operated (UFRO).	Check the AVR LED. If it is lit, the UFRO is activated, increase the engine speed to correct levels.
	Fault in AVR's power supply from the main stator.	Separately excite the machine as mentioned in this chapter. Check voltage across the AVR's terminals P2, P3, P4, or 7 and 8. Normal AVR power supply should be between 190 to 240 V AC.
	The AVR is faulty.	Replace the AVR and re-test it.
	Fault on the winding or with the rotating diodes.	Any fault in this area will appear as a high excitation voltage across X+ (F1) and XX- (F2), higher than figures listed in article 8.1.10
	There is a voltage drop between the Generator and the load, due to I2R losses in the cable. This will be worse during current surges (motor starting etc).	Check the voltage at both ends of the cable run while the generator is at full load. The differences in voltage indicates a voltage drop along the cable. In severe cases, a larger diameter cable is required – not usually the case with alternators that are already in operation for some time.

Acknowledgements and References

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

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Elstan A. Fernandez has 43 years of experience in the Maritime and Energy Indutries; Author / Co-author of 80 Books; Chartered Eng., FIE, MIET (UK), MLE℠ Harvard Square (USA); Joint Inventor with a Patent for Supervised BNWAS; Promising Indian of the Year in 2017.

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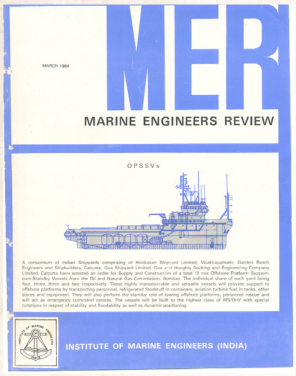
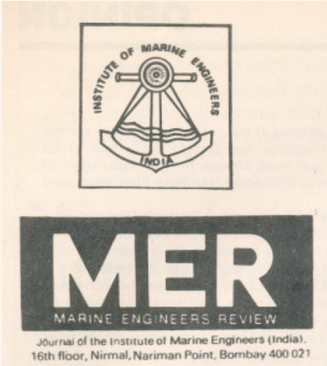
Going Astern into MER Archives...





The March 1984 issue sports the OSV (Offshore Platform Support and Standby vessels, as truly mentioned). The Editorial hails the Consortium that had made this happen and pitches for more of such enterprises, quality upkeep of Indian shipyards and also fostering ancillary units.

This is followed by a call for marine engineers to take up management studies to become better managers. The second 'Opinion' talks turn technical on ceramics. The merits of using ceramics vis-à-vis nimonic application in combustion chamber components are briefly highlighted. Engineers with experience on these, particularly exhaust valves of 2S engines may share their views.

We move on to an informative version of a paper by McGregor AB on cargo gear (hatch covers, arrangements for containers, securing contraption for the covers etc. This period could be the turning point when cargo hatch strengths and facilitation for container stacking etc., were gaining attention. This will be of interest to engineers who would have witnessed the transition in cargo gear technologies.

This is followed by an interesting maintenance article on fuel injection equipment. The repair/reconditioning of fuel injectors etc., are discussed, explaining the methods of testing etc. This will certainly add value to engineers preparing for CoC examinations. The paragraphs on locating dowels is a good takeaway.

The next one will be of food for thought for all... a paper presented in an IMarE Conference. Incidentally, the Conference itself was on Maritime Education & Training with the focus on training for the nineties (the decade to follow). Apart from earnest suggestions to tackle the manpower issues and quality, an interesting proposition is the training mechanism for the Ratings to progress towards Officer verticals. An onboard cum shore based training, spread over 4 years developed by Cunard Line-Merchant Navy College, Greenhithe, is proposed. A table shows the progression of this Open Learning Course. This could be of interest to the maritime educators. Two inserts are given for immediate reference.

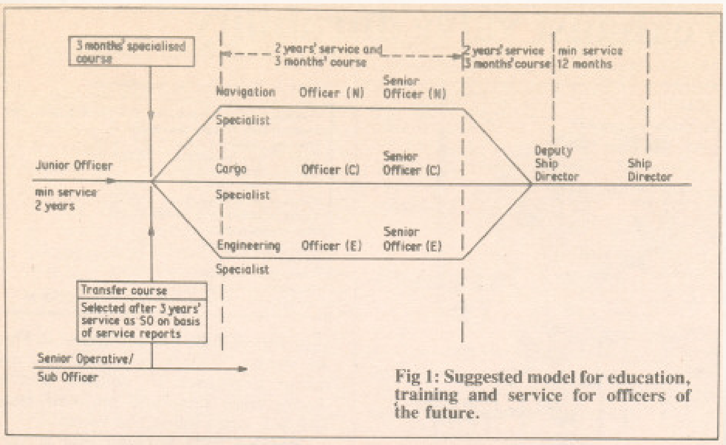


Fig 1: Suggested model for education, training and service for officers of the future.

Table 1: A Technician Education Council Open-Learning Course.

	11 weeks	conventional pre-sea course at the National Sea Training College, Gravesend, with additional studies in the evenings, prior to employment by the Company.
FIRST YEAR		
	2 weeks	Induction Course
at sea	32 weeks	Open-learning in Mathematics, Applied Heat, Applied Mechanics, Engineering Drawing and Marine Engineering Practice
at sea	10 days	Attendance at College between voyages as Junior Motorman
	2 weeks	Laboratory and classroom work
	2 weeks	Classroom and End-Tests
SECOND YEAR		
	6 weeks	At College for practical work (minimum 210 h)
at sea	32 weeks	Open-learning in Electrical Principles, Workshop Processes, General & Communication Studies, Mathematics, Applied Heat
at sea	10 days	At College between voyages during year. Service at sea: 2 mths as Junior Motorman, 3 mths as Motorman II, 2½ mths as Motorman I Completion during first 5 mths of Motorman II Training Record
	2 weeks	Laboratory and classroom work
	2 weeks	Classroom and End-Tests
THIRD YEAR		
	6 weeks	College for practical work (min 210 h)
at sea	32 weeks	Open-learning in Applied Mechanics, Electrical Principles, Workshop Processes, Electronics, General and Communication Studies
at sea	10 days	At College between voyages as Motorman I
	2 weeks	Laboratory and classroom work
	2 weeks	Classroom and End-Tests
FOURTH YEAR		
	6 weeks	At College for practical work (min 210 h)
at sea	12 weeks	Open-learning in Engineering Drawing and Marine Engineering Practice
at sea	5 days	At College between voyages as Motorman I
	3 weeks	Laboratory and classroom work; End of Course assessment.

The next one turns technical and is on testing of exhaust valves for durability. Inserts from this article also are given, which are quite self-explanatory.

Fig 1: Exhaust valve durability test rig.

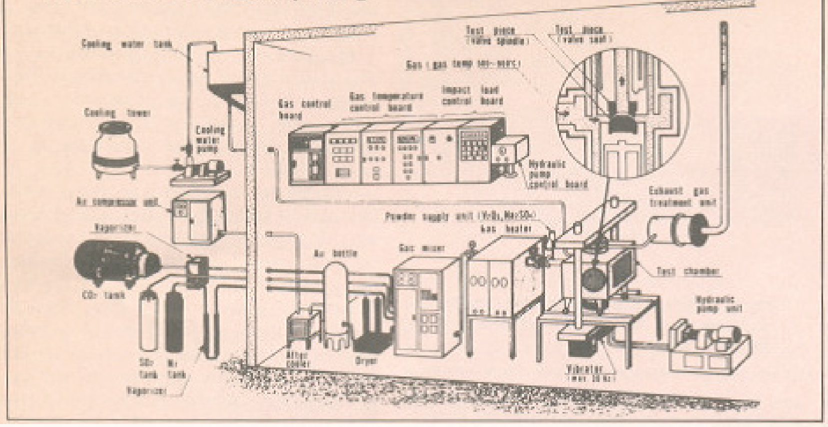


Fig 2: Volume decrease of tested valves.

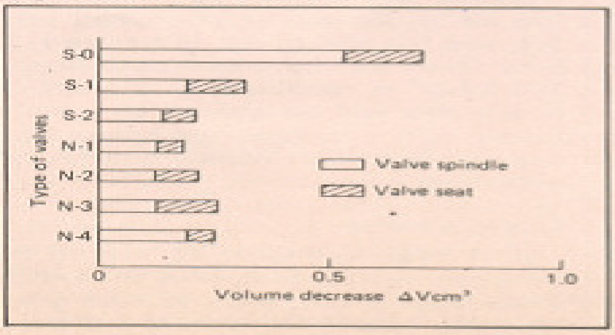


Fig 3: Volume decrease of ceramic valves.

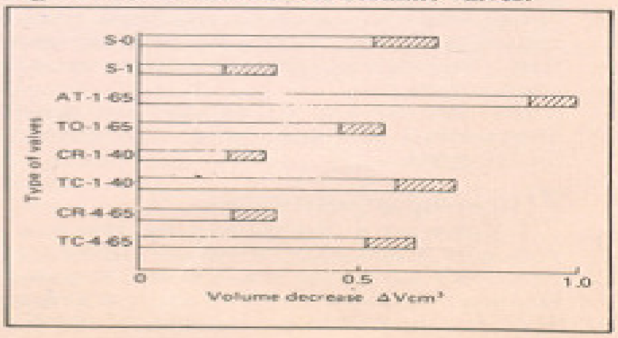


Table 1: Valve testing conditions.

Testing gas composition	16% O_2, 6% CO_2, Bal N_2
Testing gas temperature	750°C
Testing gas flow rate	57 m^3/h
Testing gas pressure	3 kgf/cm^2
Adding rate of V_2O_5 – 15% Na_2SO_4 powder	0·1 g/h
Valve seat temperature	720°C
Valve spindle face temp	710°C
Maximum repeated compressive load	5 t
Stroke	1·7 ~ 1·9 mm
Frequency of repetition	10 Hz
Number of repetitions of testing process	10^4 cycles (27·8 h)

Table 2: Valves with different coatings.

Type	Base material	Deposit material	Depositing process
S–0	SUH3	Stellite 20	—
S–1	Nimonic 80A	Colmonoy 6	—
S–2	Nimonic 80A	1st layer Colmonoy 6, 2nd layer Höganäs 1–60	—
N–1	Nimonic 80A	NHX 4	TIG welding
N–2	Nimonic 80A	1st layer NHX 4, 2nd layer NHX 4	1st layer TIG welding, 2nd layer padding
N–3	Nimonic 80A	Höganäs 1–60	Flame spraying
N–4	SUH31	1st layer Colmonoy 6, 2nd layer Höganäs 1–60	1st layer TIG welding, 2nd layer Flame spraying

Table 3: Specifications of ceramic coated layer.

Type	*Specification of layer(s)*	
AT-1–40	$Al_2O_3 \cdot TiO_2$–NiCr	1 layer
TO-1–40	TiO_2–NiCr	1 layer
CR-1–40	Cr_3C_2-NiCr	1 layer
TC-1–40	TiC–NiCr	1 layer
CR-4–65	Cr_3C_2–NiCr	4 layers
TC-4–65	TiC–NiCr	4 layers

MAN's new 4S engine series, gas carrier build completion, drill platform riser tensioning systems (a long technical paper) are few more finding place in the Issue. The MER has published the section with queries and responses on the paper. We may fashion such discussions in MER. Interested engineers may mail us.

We come to the POSTBAG section. The first letter continues from an earlier one on hydrogen fires caused by dry running. This is topical with hydrogen getting some attention in recent times. The next letter highlights the cost of spares between UK and non-UK suppliers (UK is much costlier; didn't we know?). The PRODUCTS section has a few worth mentioning: flexible fenders, tube cleaners, hose clamps, anti-rust fluid.

POSTBAG

Hydrogen production

Sir,
The important and rarely discussed issue of hydrogen burning arose briefly in the correspondence by S Das Sarma and John McKillup in the January Postbag.

Mr Das Sarma recalled the school text book formula of steam on heated iron production of hydrogen (slight misprint on the part of MER, 3Fe, not 2Fe), which allows me to emphasise the warning italicised in the school chemistry text book 'be very careful whenever hydrogen is prepared. It forms very dangerous explosive mixtures with air . . .'.

I would like to elaborate on this aspect, which might assist John McKillup in his search for historic evidence of the reaction causing hydrogen under conditions of dry running.

An extract from an article on boiler failures, published in 'The Steam and Heating Engineer' (Nov 1971), refers to failure of a water-tube boiler through gross overheating. The cause was related to hydrogen production when feed water was introduced into a boiler overheated because of continuous firing after loss of water. Gaps in the tube ends, due to loosening by overheating, allowed the hydrogen to escape into the now-unfired furnace to burn in air, intensifying the heat of the tubes, and thereby increasing the rate of hydrogen production. Fused iron debris, examined from the remains, indicated that a temperature of at least 1500°C had been reached.

I am investigating an explosion that occurred in the water space of a small, welded steel, hot-water boiler, fired by solid fuel. Lack of circulation caused gross overheating which was sufficient to exhaust all the water through an open vent and gravity-run cold-feed pipework, to the extent that the boiler-furnace side-plate became red hot at the time that the cold feed was finding its way into the dry boiler.

At the same time as the trickle of water was entering, air was induced down the separate vent pipe. The hydrogen reaction ensued in the presence of air until the proportions reached those of a critical explosive mixture. The resultant blast blew the 5 mm thick steel plate off its welded seam; the remainder of the boiler reversing its curvature.

Steam pressure had been eliminated as the cause because, under the circumstances of open exhaust paths for steam by way of the open vent and cold feed separate pipes, negligible pressure would be generated—sufficient only, it was deduced, to prevent the cold feed from gravitating down to the boiler from a feed tank a few metres above.

The very force of the explosion, and the circumstances prevailing, pinpointed a hydrogen-based explosion.

It is surprising how many people think that cold water hitting a hot boiler will cause an explosion merely due to steam. The type of event described, might sway boiler dry runners into thinking a little differently.

Peter Kennedy
Harlow, Essex

Pricey UK spares

Sir,
With reference to your October 83 'Opinion', where it is pointed out that British marine equipment may be more expensive to buy in the UK than overseas: if this is the case then the equipment in the UK must be very expensive indeed.

We operate, among others, two ships, where some of the auxiliary equipment, such as diesel generators, pumps, etc, are British made. Our experience is that the price of spares or complete replacement units are normally 50 to 200% higher than comparable goods from non-UK manufacturers.

Recently, we needed a compressor crankshaft with bearings from the UK. The price quoted was £2700. However, as the compressor was fairly old, we then asked the price of a complete compressor to fit the existing skid and motor: £6100. The price from a non-UK firm was £3545 which included making necessary modifications and also included a new flywheel. Delivery from the UK-firm would have been 8 weeks and, from the other firm, 10 days.

Furthermore, some firms charge a minimum fee on spare parts orders. At one time we were charged £80 while the cost of the part itself was £4·90, another time £50 was charged for spares costing £22.

UK prices for piston rings for auxiliary diesels are £24 each, although the same from European makers was £6·80 to £8. Pricewise, we have not yet come across any UK spare parts or units that are even close to non-UK made equipment.

Our policy is now, instead of buying major spares for UK-produced equipment, to replace the complete unit with a non-UK one.

Tore Gjerulfsen
Ugland Shipping

Tanker safety

Sir,
Messrs Mills and Oldham (Jan 84 Postbag) take issue with me over the text of the International Safety Guide for Oil Tankers and Terminals (ISGOTT), saying that it was drafted by a committee of experts from all parts of both industries and that the precautions therein, if properly and conscientiously carried out, will minimise the hazard—presumably from fire and explosion! Companies which demand 'more stringent operational precautions' are said to be taking a 'more conservative approach'.

ISGOTT still persists in saying that it is safe to use either the 'too lean' or 'too rich' systems for tank washing without any reference to the size of the tank concerned. Are they implying that *Mactra* and *Marpessa*, two Shell VLCCs, had not properly and conscientiously used the 'too lean' system when they suffered an 'in tank' explosion with disasterous effects, or that crews of all large tankers which have exploded subsequently whilst tank cleaning were merely being careless?

Will ISGOTT and the industry admit what some independent experts at IMO have decided—that a VLCC washing tanks in any but the inerted condition cannot be guaranteed to be safe from fire and explosion if the usual fixed washing guns of high-pressure and high discharge-rate are used? Perhaps those companies which require more stringent operational procedures are, in fact, more safety conscious.

IMO require all such vessels over 20 000 dwt to be fitted with an effective IG system—or cease trading. Therefore, ISGOTT will finally have to come into line, after 15 years of fighting to preserve an outmoded and potentially hazardous system of operation, merely because the earlier VLCCs were not fitted with an IG system and economics required that some method should be found to allow them to operate.

The industry might finally get into step and require that tanks of large crude oil carriers should be fully inerted at all times, except when required to be gas-free, especially when washing with high power fixed machines; and lay down very tight requirements, in accordance with IMO guidelines, on the use of inert gas, for those occasions when, for some reason or another, the proper inerting of the tank cannot be guaranteed.

G Victory
Wallington, Surrey

Cumbersome

Sir,
I am glad to have been of some small service to Mr Church (Postbag Nov 83). I quite agree with him about the Doxford lever-driven pump system. Apart from this, the Doxford engine did not lend itself to the fitting of engine driven pumps as well as the B&W, and it was the arrangements of Stothert & Pitt pumps with the Doxford engine that I meant as cumbersome and not Mr Church's proposal, which appears very sensible.

C M Hall
Newbridge, Cornwall

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

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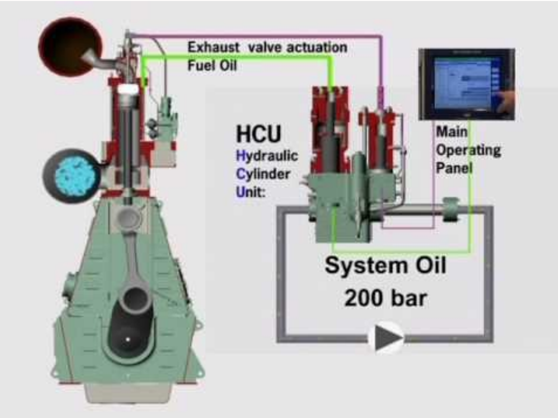
Electronic Engine Familiarisation Course (ME-Type Engine) Delivered online with Cloud access to ME Engine Simulator



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

Course Aims and Objectives:

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

Coverage / Program Focus:

This course deals with the following training areas:

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

Entry Requirement / Target Group:

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

DATE & TIMING : **26th – 28th Mar 2024/ 23rd – 25th Apr 2024/ 28th – 30th May 2024/ 25th – 27th June 2024/ 29th – 31st July 2024/ 27th – 29th Aug 2024/ 24th – 26th Sep 2024/ 28th – 30th Oct 2024/ 26th – 28th Nov 2024/ 17th – 19th Dec 2024**
8:00 am - 4:00 pm IST

VENUE : Web Platform / Zoom. **APPLICATION LINK:** https://imeimum.marineims.com/course/register

REGISTRATION & PAYMENT : Rs. 15,000/- /- per participant – inclusive of taxes.
For IME(I) Members 13,500/- per participant - inclusive of taxes.
Payment to be made to: https://imeimum.marineims.com/course/registe
(Under Category - Value added Courses) *10% discount available for IME(I) members*

FOR MORE INFORMATION : **@IME(I)** - **email:** training@imare.in, Ms. Anukampa
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@ MASSA Maritime Academy Chennai - **email:** mmachennai@massa.in.net
Ms. Saraswathi, **(T)** 8807025336 / 7200055336 .

After registration and payment, please email the details of the receipt to: ***training@imare.in***

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

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