Automated process of surveillance on Board marine vessels- A Review

Manasseh Karnan. C[1*], T. Subhashini [2]

[1]Senior Lecturer/Chief Engineer, Department of Marine Engineering, Vels Institute of Science, Technology & Advanced Studies (VISTAS) School of Maritime, Chennai, India.

[2]Lecturer, Department of Marine Engineering, Vels Institute of Science, Technology & Advanced Studies (VISTAS) School of Maritime, Chennai, India.

Abstract

A sea-going vessel has many different systems that operate to fulfil the objective. To ensure un-hindered function and best performance, many types of surveillance technologies are being used with different new advanced data processing techniques. The purpose of surveillance on-board Marine Vessels is to detect deterioration, especially wear and tear, of Machinery /hull components or parts of them. To achieve that, significant parameters are to be collected with the aid of adequate measurement instruments. The collected parameters shall be able to indicate the trend of the monitored deterioration over certain time. The purpose of this paper is to conduct an up-to-date review of the surveillance technologies used on board vessels and establish the fault detection and diagnostic methods used in this context. In this respect, this paper also presents the surveillance Capabilities for Enhanced Ship Safety which aims to bring an innovative solution to the ship inspection regime through the introduction of enhanced inspection of ship structures, by integrating robotic-automated platforms for on-line or on-demand ship inspection activities and selecting the software and hardware tools that can implement or facilitating specific inspection tasks, to provide input to the Decision Support System (DSS).

Keywords: Infrared Thermography (IRT); Condition Monitoring (CM); Vibration; Remotely Operated Vehicles (ROV); Hull Condition Assessment (HCA).

1. Introduction

Failures of machinery in the day-to-day ship operations lead to major accidents, endangering crew and passengers on board, posing a threat to the environment, damaging the ship itself and having a great impact in terms of business losses. For eliminating the hazards posed by high-risk and sub-standard ships and to obtain the optimum inspection results, for a large number of new ships the monitoring and inspection from both regulatory bodies and Classification Societies have become more and more difficult. So the budget gain perspective is switched over to investment for continuous, safe and reliable asset service. This is seen as the transition of maintenance through time from a reactive manner to a more proactive approach.

Generally, inspection and maintenance departments in shipping companies are the largest in work force and expense [23].

The principle of Condition Based Maintenance and various ways of monitoring. Apart from the environmental and economical point of views, the use of computer offers a number of interesting benefits to ship-owners and operators such as the ease of monitoring of the diesel engines and comparing between different working conditions.

The scope of Condition Based Maintenance and fault diagnosis is to detect the upcoming failure before even beginning to happen or develop, increasing machinery's availability, reliability, efficiency and safety, by reducing maintenance costs through controlled spare part inventories [39]. So, implementation of Condition Based Maintenance should lead to reliability and cost reduction by integrating information and management of critical components for time reduction of expensive and challenging maintenance phases such as dry-docking and overhauling [24]. Condition Monitoring technology is applied to various tools, recording and evaluating measurable parameters such as Pressure, Temperature, wear, vibration signal analysis, thermography, lube oil analysis …etc [37]. Vibration monitoring is mostly applied on rotating machinery as it can detect unbalanced rotating machinery parts, excess sleeve or bearing wear, misalignments, damaged gear teeth and damaged bearings [33]. The data record involves measurement of physical magnitudes such as displacement, velocity or acceleration. This measurement is converted into a proportional electrical signal that can be examined into fundamental frequencies. On the other hand, thermography is Condition Monitoring tool applicable to both electrical and mechanical equipment, and is deployed to identify hot and cold spots providing early signs of equipment failure. Infrared Thermography (IRT) is one of the most accepted Condition Monitoring tools [20]. This non-contact function is suitable for detecting structural, machinery, electrical and material malfunctions. Recording handheld devices are used such as thermal cameras and thermometers. The third under assessment Condition Monitoring technology is lubrication oil analysis. Oil analysis is achieved through laboratory concentration analysis in lubricant, which deals with shape, size, the composition of wear particles and lubricant degradation analysis for physical and chemical characteristics. Lube oil analysis is time consuming as it requires transportation of oil samples from the ship to onshore. However, it seems to be the most efficient diagnostic tool as from a small number of fluids the condition of the entire lubricant in each machinery can be determined.

The surveillance Systems shall be capable of producing relevant data trends from the values collected and compare them with pre-defined acceptance criteria (e.g. limit curves) [10].

Enhanced inspection of ships will also include ship structures and machinery monitoring with real time information using 'intelligent' sensors and incorporating structural and machinery risk analysis, using in-house structural/hydrodynamics and machinery computational tools [28]. Moreover, condition based inspection tools and methodologies, reliability and criticality based maintenance is introduced. An enhanced central database handles ship structures and machinery data. The data is available to ship operators and are utilized by the DSS for ship structures and machinery for continuous monitoring and risk analysis of ship operations [32].

Various techniques used are as follows

1. Measurement data are taken from all machinery for Vibration and shock pulse and spot analysis and interpretation of results.
2. Inspection of all electrical and mechanical systems Thermo graphically.
3. Passive ultrasonic frequency methods for Pressure and vacuum leak.
4. Measurement of machinery systems including thickness measurement.
5. Performance test and power balance analysis for Main and auxiliary engines.
6. Machinery health assessment report [34].

Acoustic emission

Structures release high frequency stress waves when damaged. Due to their frequency limitation, these waves cannot be measure by the vibration technologies and so they require the acoustic emission technologies for analysis. Acoustic emission technologies foretell faults at a stage earlier than that of the vibration condition monitoring. Cracks, fibre breakage and delamination faults can be detected through Acoustic emission technology [1].

Vibration

For mechanical fault diagnosis, the parameters of displacement, velocity and acceleration are used [41]. The vibration technologies are used on board for the mechanical and Electrical machinery applications. Shock Pulse Monitoring is a technique of predictive maintenance by measuring vibration and shock pulses of bearing in motors and to identify their condition and operating life before the next overhaul procedure [3]. The amplitude of the shock is a function of the rolling element and the instrument measures the absolute value and subtracts from it the expected shock value from a good bearing at a similar speed. This gives us an indication of the bearing operating condition.

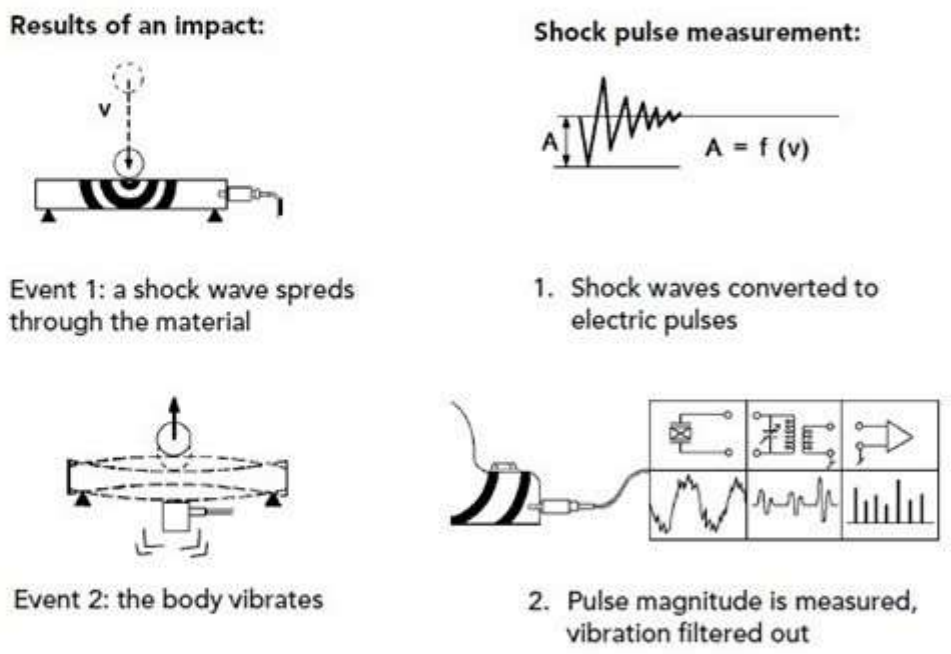


Figure: 1 Shock Pulse Monitoring

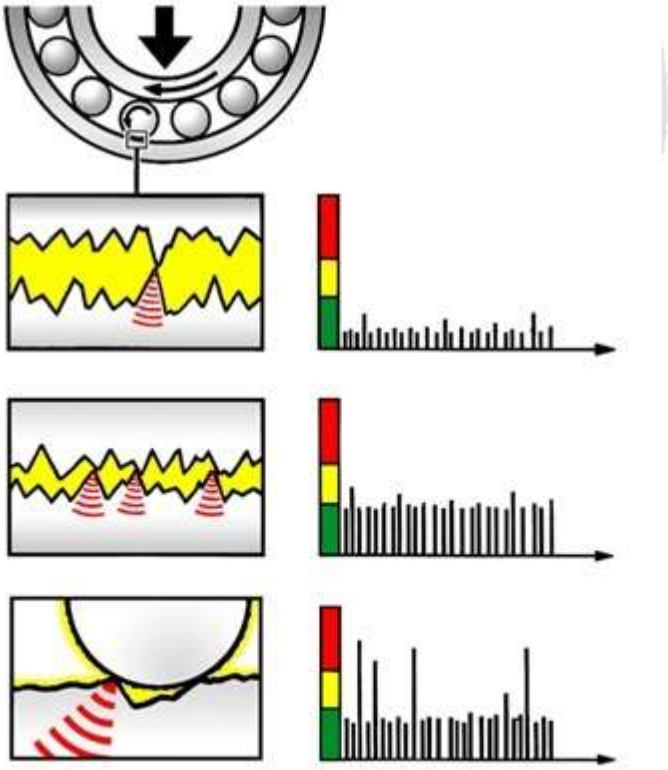
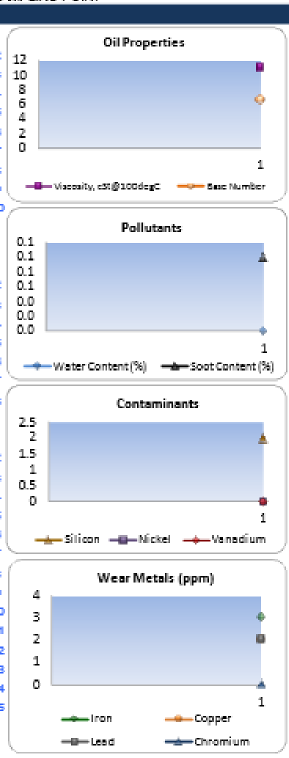


Figure: 2 Vibration Measurement

Oil and fuel analyses

It includes measured parameter like viscosity, acid and base number, water contamination, random substances contamination and others which are used to determine the chemical state of the fluid in the applications of fuel and lubrications [25]. Some worth mentioning key technologies classified under the lubricating oil analyses are shown below:

	Sample Information					1
1	Sample No					G035264
2	Bottle No					06499331
3	Date Received (dd/mm/yy)					22-Jul-15
4	Sampling Date (dd/mm/yy)					18-Jul-15
5	Country of Origin					Singapore
6	Oil on Label					GS 3006
7	Fuel In Use (Sulphur)					2.51%
8	Total Machine Hours					209
9	Lubricant Hours					209
10	Lubricant Condition					Normal
	Results					1
	Oil Analysis					
1	Viscosity, cSt@40degC					95.37
2	Viscosity, cSt@100degC					11.07
3	Viscosity Index					101
4	Soot Content (%)					0.1
5	Flash Point					Pass
6	Water Content (wt%)					<0.05
7	Nature of Water					-
8	Base Number (mg/KOH/g)					6.56
	Element Analysis, ppm					
1	Aluminium					<1
2	Barium					<1
3	Boron					7
4	Chromium					<1
5	Copper					2
6	Iron					3
7	Lead					2
8	Molybdenum					<1
9	Nickel					<1
10	Silicon					2
11	Silver					<1
12	Sodium					1
13	Tin					1
14	Vanadium					<1
15	Lithium					<1
	Additional Analysis					
1	Particle Quantifier Index					7



Recommendations

All the analysis results are well within the acceptable limits. There is no abnormal physical properties/ wear/ contamination noticed. The oil is fit for further use. Please submit sample as per regular schedule. Limits and analysis above is based on engine maker's specification.

Figure: 3 Sample Marine Engine Lubricating Oil Analysis Report

Particle counters Particle counter technologies are used to detect and classify particles each to its prospective range of size for diagnoses of the mechanical state. It is used mainly for oil lubrication to monitor the state of the oil and is used also for exhaust monitoring [2]. Knowledge about the size of particles that exist in the machinery air or fluid gives an indication of its health state. X-Ray Fluorescence (XRF) Analyser is a portable testing device which, among other parameters, provides an accurate indication of sulphur content through the analysis of a small fuel sample in less than three minutes [8]. The XRF Analyser can be used to test the fuel and verify the sulphur content against what's stated on the BDN, eliminating the risk of accidental non-compliance of the 2020 global sulphur cap. Cylinder Oil Drain Analysis [27] gives information on: combustion conditions in the cylinder, wear rate of the rubbing parts of the cylinder liner and piston ring, adequacy of cylinder lubrication and the risks / danger of contamination of cylinder oil drain with crankcase oil and potential for major problems as a result of serious blow back in the engines.

Ferrography

The monitoring of the metallic particles existent in the oil gives an indication about the friction and wearing state of the machinery, and also gives an earlier warning of the machinery failure than that of the vibration. This technology usually adopts magnetic techniques to detect metallic particles. On the other hand, the most used operational parameters in the literature of internal combustion engines multi-sensor diagnosis [40] were:

Rotation monitoring

As internal combustion engine application is all about rotation, the parameter of rotation is critical to measure. Rotation monitoring technologies account for highest utilization in the internal combustion systems, where they are mainly used for shafts monitoring. Rotation sensing technologies monitor the rotating parts like crankshaft, camshaft [13].

Oxygen measurement

Oxygen parameter measurement is a critical aspect of the internal combustion engine applications, especially for the fuel, air and exhaust systems [36]. Some of the inferences that can be found from such measurements are the injection mass and cylinder selective injection mass [29].

Air flow measurement: Mounted on air flow channels, the air flow sensors monitor the true mass of the flow of air flowing into the engine [30]. The benefit of this parameter is that it allows making sure that the right amount of air that is mixed with fuel is which is critical for the operation of the engine.

Bearing temperature and wear monitoring

An important sign of an abnormality in the engine bearings is the rise in temperature [15]. Major breakdown of the engine crankshaft and bearing arrangement can be prevented if the temperature of the bearing can be monitored and taken into account before it rises to a dangerous level.

The measurement of bearing temperature can be done by Direct Measurement (Using temperature sensors normally fitted at the rear side of the bearing shell) or Indirectly (Detecting the temperature of return oil from each bearing in the crankcase) [6].

Main Bearing Temperature sensors mounted on the bearing girders with the tip in direct contact with the bearing shell continuously monitors the temperature of the bearings and an alarm is initiated when the temperature reaches the alarm point. For crankpin and crosshead bearing temperature monitoring, the wireless bearing temperature monitoring system is capable of continuously measuring the temperature of bearings during engine operation [22]. The wireless sensors use a multiplexed Signal Processing Unit which uses a high frequency and low energy radar pulse. Through a coaxial cable the radar pulse is transmitted to the wireless sensor from the stationary antenna positioned inside the crank case [14]. Stationary antenna responds to the radar pulse by reflecting a pulse pattern back to the Signal Processing Unit, the characteristics of which are defined by the temperature.

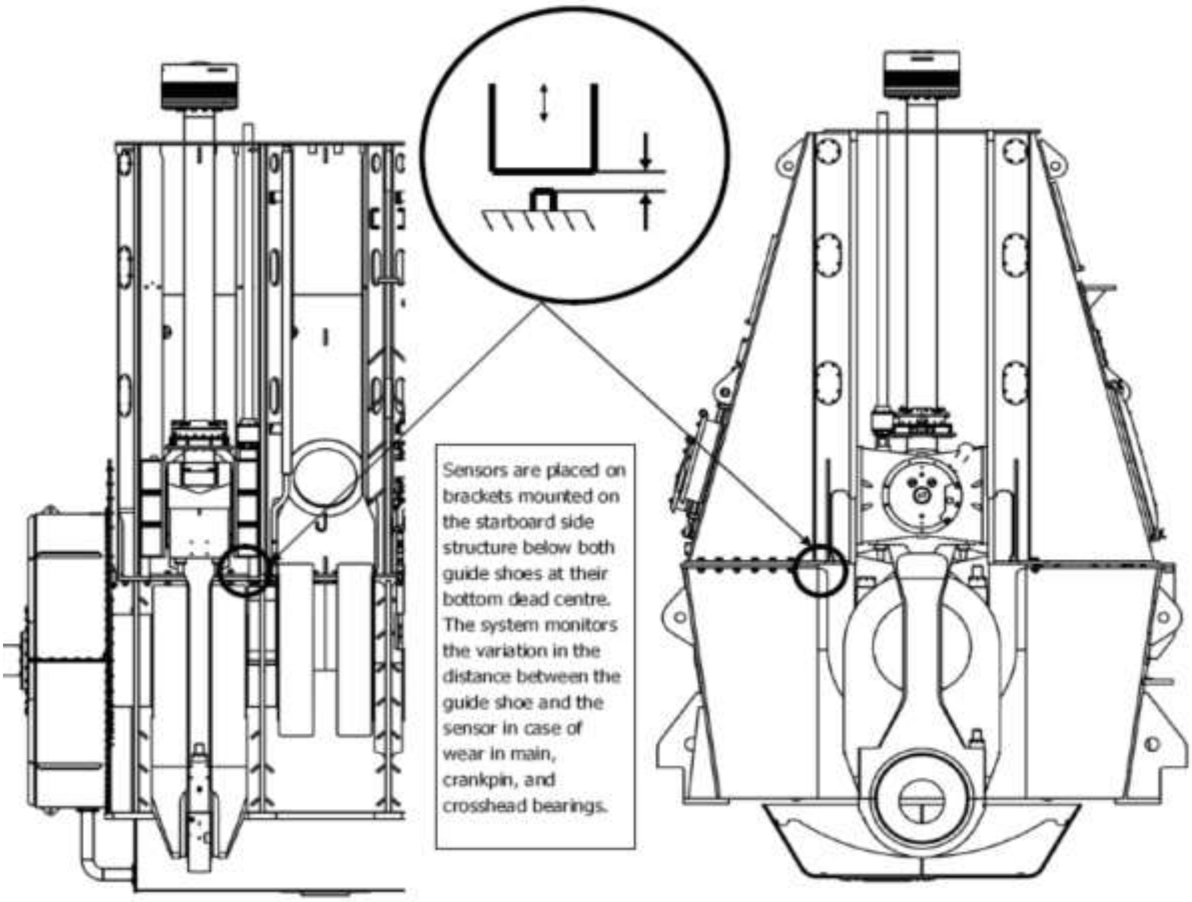


Figure: 4 Large Marine Two Stroke Engine Bearing Condition Measuring Sensor

Monitoring of bearing wear

The Bearing Wear Monitoring system predicts bearing wear in large two-stroke diesel engines, before it becomes critical [18]. During ship operation the system will provide a nearly warning if any of the three crank-train bearings (crosshead, crank and mean bearing) experience unexpected wears. The Bearing Wear sensor works on the eddy current principle and is used for measurements against electrically conductive, ferromagnetic materials. Every time the cross head passes Bottom Dead Centre (BDC), the measurements take place. After compensating for various engine loads and speeds, when there is a notable wear in the main, crankpin or in crosshead bearing, this monitored vertical position will shift and the same will be reflected in the monitoring system of the ship. If this shift reaches the set alarm values for one or more unit, the alarm will be raised. This monitoring system is connected to the safety system of the engine which might slow down the engine when the Bearing wear alarm occurs.

Water in oil monitoring

For maintaining a good bearing condition in the main engine, the Water content in the lubricating oil is an important factor. Engine bearings get damaged when the water content increases above 0.2% by Vol in the lubricating oil. The increase in water content will cause the lead overlay, which acts as a running layer, in crosshead bearings (Tin-Aluminium lined) to corrode away and Main and crankpin bearings lined with Babbitt or Tin- Aluminium may also suffer irreparable damage from water contamination. *Automatic:* By continuously measuring the relative humidity in the system oil using a probe in the oil piping system, the signal can be transmitted to a unit intended to calculate the humidity as Water Activity [5]. The major advantage of such system is the continuity in monitoring the water content in oil for early troubleshooting. The system is connected to the alarm system which will activate an alarm if the water content reaches the set value.

Torque and power monitoring

By measuring the twist of a rotating shaft using two slotted wheels, torque can be calculated when the light transmitted by LEDs through slots in each wheel is converted to a digital electronic signal and sent back to the processing unit for calculation of the corresponding torque [4]. In this way torque on the engine is continuously monitored and a set torque limit will not allow overloading of the engine [35].

Monitoring cylinder liner temperature

By measuring the temperature of the upper part of the cylinder liners, the cylinder liner monitoring system monitors the piston running performance [7]. Increased friction between the piston rings and the cylinder liner creates an elevated temperature level leading to abnormal liner wear and potential piston ring breakage. Temperature alarm limits can be individually set on the computer work station to give early warning about high thermal load and potential cylinder liner scuffing, or inadequate ring sealing and individual relay output alarms are provided directly to the cylinder lubrication units in order to temporarily increase the cylinder lubrication.

Hull Condition Assessment (HCA)

Using hull condition assessment the structural condition of the ship can be monitored. This will ensure the vessel's ability to sail safely. Since the ship's hull and the structural members have a significant monetary value for ship operators, Hull condition assessment performs a key role in inspection and maintenance A well-designed Hull condition assessment programme conducts the maintenance activities in a better way and reduces the failure propagation effects by using real-time information and integrating it with the influence of the hydrodynamic performance of the ship [38]. The analysis identifies the critical ship structural areas and consequently ship [9].

Vessel's defect detection utilizing image processing

The inspection of the external part of the hull by means of Remotely Operated Vehicles (ROV) or unmanned vehicles:

By utilizing autonomous vehicles such as quad copters and magnetic crawlers for image recording and automated processing, we can detect the loss of the external coating, accelerating corrosion, detection of artificial objects attached to the hull, and weld inspection [12].

Surveillance capabilities

Surveillance can be carried out in two areas, the on board environment (local) for technical decision-making and the onshore (global) for economic and maintenance planning. It includes ship structure and machinery related data gathering, assessment and risk and reliability evaluation. The program used within the surveillance capabilities are the Structural and Machinery Risk Analysis and the central database for data processing.

Each program is integrated with a maintenance schedule. The software program combines traditional structural load assessment techniques with real-time monitoring and conducts automated risk and reliability analysis methodologies using various types of data gathered. The output of this program is led into on board data for structures and machinery aspects, helping to take decisions for maintenance actions. Finally, the processes involve the transfer of outcomes to the central database. These results contain inspection reports and predictive maintenance tasks, which are in place onshore updated with maritime stakeholders' responses. The central database contains information for ships' structures and machinery, their expected and actual performance, survival and failure data as well as potential failure consequences. This in turn enables the central database being updated including the latest information.

Risk analysis for structure and machinery

Input data from the various source are fed into the program which includes previous ship inspections history (digitalized and hard copy records, surveys, annual reviews and incident and accident reports), Maker input, judgement, suggestions and current sensor data for machinery control and reliability predictions [17]. Shore databases offer Offshore Reliability Database (OREDA), which includes failure rates for components and maintenance intervals. All the input data from these sources are fed into the software program. Quick decision making will be possible with the program giving warnings of impending high risk and eventually providing decision support following a shipping incident. Planned maintenance system is employed for the long term decision support, so as to detect the required maintenance activities, arrange for the approval of maintenance and repair jobs to be performed on-board as well as enable the provision for spare parts and logistics requirements.

Pressure monitoring instrument system

The Pressure Monitoring Instrument System is a computerised tool designed for pressure measurements and analysis on two-stroke diesel engines. This system measures cylinder pressure online from permanently mounted sensors on the engine cylinder head and gives a graphic display of various parameters (PT, PV and Balance Diagrams) including Mean Indicated Pressure and Max. Pressure deviation limits at the engine control room [19]. It also calculates values of Effective Power, Mean Indicated Pressure Pi, Compression Pressure Pcomp, Max. Pressure Pmax, and Scavenge Pressure Pscav, including proposed values for index adjustments, etc.

The engine control system constantly monitors and compares the measured combustion pressures to a reference value and automatically adjusts the fuel injection and valve timing to reduce the deviation between measured and reference values [21]. Thus, the system ensures that the engine is running at the desired maximum pressure, p (max) [11]. Pressure measurements are presented in real time in measurement curves on a computer, Key performance values are continuously calculated and displayed in tabular form and stored for future reference.

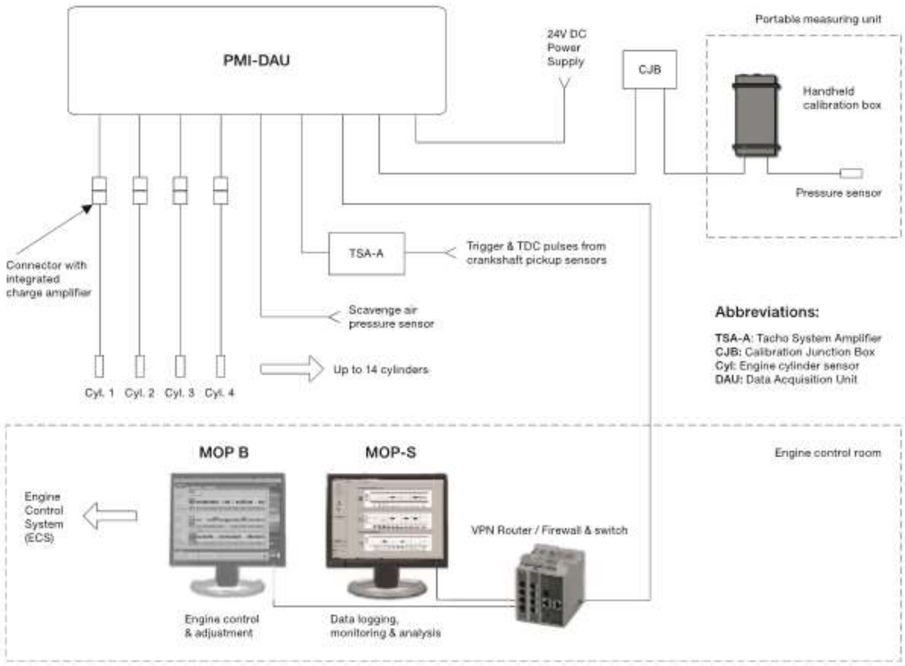


Figure: 5 Combustion Pressure Monitoring System

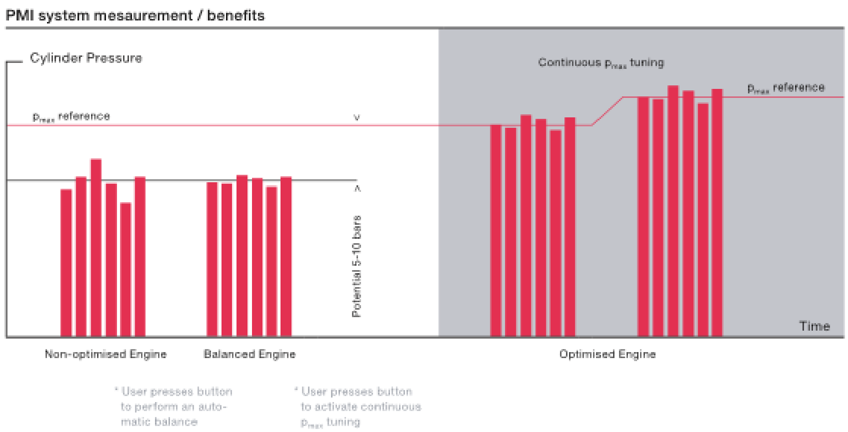


Figure: 6 Graphic Display of PMI on Monitor

Diagnostic Tool to Prevent Machinery Failure

Diagnostic tool records, visualizes, and analyses the operational sounds of a vessel's engine plant. This tool has equipment for recording and visualizing sounds around the ship's engine room and software that scans the sounds and detects abnormalities [16]. It uses electrical listening devices to record, accumulate, and share sounds that can then be view as data on a computer. The software then diagnoses the engine condition using logic based on vessel operation experience.

The important factor used to diagnose the condition of the machinery in Engine Room is the sound they produce while in operation. Crew members can determine the normality of operational sounds depending on their experience and judgment. Using this concept, an application is developed that diagnoses and detects abnormal conditions and breakdowns of machinery at an early stage and so we can shift from conventional time-based maintenance to condition-based maintenance [26]. This tool can be used for all kinds of machinery and equipment that produce operational sounds.

Piston-ring wear online monitoring

The piston-ring wear can be monitored online by placing a sensor in each cylinder liner just above the scavenge airport to measure the width of a triangularly shaped brass which is inserted in one of the piston rings. The wear of the piston ring corresponds to the reduction in the width of the triangular section [31]. Data can be monitored for piston ring wear over certain running hours, Average piston-ring wear, Piston-ring segment wear, Piston-ring wear distribution, Piston-ring rotation and online monitoring of the piston-running reliability

2. Conclusion

This paper conducted a comprehensive and an up-to-date literature review of the Automated Process of surveillance on board Marine Vessels and identified the fault detection and diagnostic methods used in this context. Using the computer in the marine field and the integration between the electronics and surveillance result in many benefits including lower fuel consumption and better performance parameters thanks to the variable electronically controlled timing of fuel injection and exhaust valves. Modernised control system with more precise timing, giving better engine balance with an equalized thermal load in and between cylinders. Adequate monitoring and diagnostics of machinery reduce maintenance requirements including longer time between overhauls.

References

[1] Albarbar, F. Gu, and A. D. Ball, “Diesel engine fuel injection monitoring using acoustic measurements and independent component analysis,” Meas. J. Int. Meas. Confed., vol. 43, no. 10, pp. 1376–1386, 2010.

[2] Andersson P and L. Eriksson, “Detection of Exhaust Manifold Leaks on a Turbocharged SI-Engine with Wastegate,” in SAE 2002 World Congress & Exhibition, 2002.

[3] Basir O and X. Yuan, “Engine fault diagnosis based on multi-sensor information fusion using Dempster-Shafer evidence theory,” Inf. Fusion, vol. 8, no. 4, pp. 379–386, 2007.

[4] Bernard Challen, Rodica Baranescu, in: Diesel Engine Reference Book, Second ed., Reed Educational and Professional Publishing Ltd., Butterworth-Heinemann, 2005.

[5] Bogue R, "Sensors for condition monitoring: a review of technologies and applications," Sens. Rev., vol. 33, no. 4, pp. 295–299, 2013.

[6] Cao W, G. Dong, W. Chen, J. Wu, and Y. B. Xie, "Multisensor information integration for online wear condition monitoring of diesel engines," Tribol. Int., vol. 82, no.PA, pp. 68–77, 2015.

[7] Çelik M.B and R. Bayir, "Fault detection in internal combustion engines using fuzzy logic," Proc. Inst. Mech. Eng. Part D J. Automob.Eng., vol. 221, no. 5, pp. 579–587, 2007.

[8] Chiao S, P. Xufeng, and L. Xiaolei, "The application of multisensor fusion technology in diesel engine oil analysis," International Conference on Signal Processing, 1996., 3rd, vol. 2. pp. 1695--1698 vol.2, 1996.

[9] Dai X and Z. Gao, "From model, signal to knowledge: A data-driven perspective of fault detection and diagnosis," IEEE Trans. Ind. Informatics, vol. 9, no. 4, pp. 2226–2238, 2013.

[10] De Kleer J and J. Kurien, "Fundamentals of model-based diagnosis," IFAC Proc. Vol., vol. 36, no. 5, pp. 25–36, 2003.

[11] Domkundwar V.M, A course in internal combustion engines, DhanpatRai, India, 1994.

[12] Erjavec J, Automotive Technology: A Systems Approach, 5th ed. Cengage Learning, 2010.

[13] Fleming W.J, "Overview of Automotive Sensors," IEEE Sens. J., vol. 1, no. 4, pp. 296–308, 2001.

[14] Fleming W.J, "New automotive sensors - A review," IEEE Sens. J., vol. 8, no. 11, pp. 1900–1921, 2008.

[15] Griffiths D, Marine low speed diesel engines, IMarEST (2003).

[16] Goh K.B, S. K. Spurgeon, and N. B. Jones, "Fault diagnostics using sliding mode techniques," Control Eng. Pract., vol. 10, no. 2, pp. 207– 217, 2002.

[17] Guo H, P. Xingiong, Z. Chaojie, M. Tingfeng, and Q. Jiufeng, "Multisensor Information Fusion Method and Its Applications on Fault Detection of Diesel Engine," in Interational Conference on Computer Science ad Network Technology, 2011, pp. 2551–2555.

[18] Harrington R.L, Marine engineering, SNAME (1992).

[19] Ibrahim A, Combustion Engines, Dar El-Ma'aref, Egypt, 1995.

[20] Jones N.B and L. Yii-hua, "A Review of Condition Monitoring and Fault Diagnosis for Diesel Engines," Tribotest, vol. 6, pp. 267–291, 2000.

[21] Khaleghi B, A. Khamis, F. O. Karray, and S. N. Razavi, "Multisensor data fusion: A review of the state-of-the-art," Information Fusion, vol. 14, no. 1. pp. 28–44, 2013.

[22] Kimmich F, A. Schwarte, and R. Isermann, "Fault detection for modern Diesel engines using signal- and process model-based methods," Control Eng. Pract., vol. 13, no. 2, pp. 189–203, 2005.

[23] Roemer M.J, G. J. Kacprzynski, and M. H. Schoeller, "Improved diagnostic and prognostic assessments using health and management information fusion," AUTOTESTCON Proceedings, 2001.IEEE Syst. Readiness Technol. Conf., vol. 7 16, pp. 365–377, 2001.

[24] Li Y, M. J. Pont, and N. Barrie Jones, "Improving the performance of radial basis function classifiers in condition monitoring and fault diagnosis applications where 'unknown' faults may occur," Pattern Recognit. Lett., vol. 23, no. 5, pp. 569–577, 2002.

[25] Macian V, B. Tormos, A. Sala, and J. Ramirez, "Fuzzy logic-based expert system for diesel engine oil analysis diagnosis," Insight Non-Destructive Test. Cond. Monit., vol. 48, no. 8, pp. 462–469, 2006.

[26] Manders E.J, G. Biswas, P. J. Mosterman, L. A. Barford, and R. J. Barnett, "Signal interpretation for monitoring and diagnosis, a cooling system testbed," IEEE Trans. Instrum. Meas., vol. 49, no. 3, pp. 503–508, 2000.

[27] Morsy El Gohary. M, Finite element analysis of marine diesel engine components, Alexandria Eng. J. 47 (4) (2008) 307–316.

[28] Morsy El-Gohary M, Energy conservation: passenger and container ships case studies, Alexandria Eng. J. 48 (2) (2009) 151–159.

[29] Nyberg M and T. Stutte, "Model based diagnosis of the air path of an automotive diesel engine," Control Eng. Pract., vol. 12, no. 5, pp. 513– 525, 2004.

[30] Parikh C.R, M. J. Pont, N. B. Jones, and F. S. Schlindwein, "Improving the performance of CMFD applications using multiple classifiers and a fusion framework," Trans. Inst. Meas. Control, vol. 25, no. 2, pp. 123– 144, 2003.

[31] Porteiro J, J. Collazo, D. Patiño, and J. L. Míguez, "Diesel engine condition monitoring using a multi-net neural network system with nonintrusive sensors," in Applied Thermal Engineering, 2011, vol. 31, no. 17–18, pp. 4097–4105.

[32] Salehi R, A. Alasty, M. Shahbakhti, and G. Vossoughi, "Detection and isolation of faults in the exhaust path of turbocharged automotive engines," Int. J. Automot. Technol., vol. 16, no. 1, pp. 127–138, 2015.

[33] Twiddle J.A and N. B. Jones, "Fuzzy model-based condition monitoring and fault diagnosis of a diesel engine cooling system," Proc. Inst. Mech. Eng. Part I-Journal Syst. Control Eng., vol. 216, no. I3, pp. 215–224, 2002.

[34] Tidriri K, N. Chatti, S. Verron, and T. Tiplica, "Bridging data-driven and model-based approaches for process fault diagnosis and health monitoring: A review of researches and future challenges," Annu. Rev. Control, vol. 42. pp. 63–81, 2016.

[35] Venkatasubramanian V, R. Rengaswamy, S. N. Kavuri, and K. Yin, "A review of process fault detection and diagnosis part III: Process history based methods," Computers and Chemical Engineering, vol. 27, no. 3. pp. 327–346, 2003.

[36] Wang and S. Z. Xu, "Research on Engine Fault Detection System Based on Exhaust Emission," Adv. Mater. Res., vol. 590, pp. 516–520, 2012.

[37] Wilbur C.T, D.A. Wight, in: Pounder's Marine Diesel Engines, 9th ed., Elsevier Ltd, 2009.

[38] Woud H.K, D. Stapersma, Design of Propulsion and Electric Power Generation Systems, IMarEST, ISBN: 1-902536-47-9, 2003.

[39] Wu J.D and J.-C. Chen, "Continuous wavelet transform technique for fault signal diagnosis of internal combustion engines," NDT E Int., vol. 39, no. 4, pp. 304–311, 2006.

[40] Yunsong W, C. Fulei, H. Yongyong, and G. Dan, "Multisensor data fusion for automotive engine fault diagnosis," Tsinghua Sci. Technol., vol. 9, no. 3, pp. 262–265, 2004.

[41] Zhang Y and J. Jiang, "Bibliographical review on reconfigurable fault tolerant control systems," Annu. Rev. Control, vol. 32, no. 2, pp. 229– 252, 2008.