Identification of Diesel Engine Defects of Corvette Type Naval Ships

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ABSTRACT
One of the main machineries of a ship is the high-speed diesel engine, which is used for main and auxiliary propulsion systems. Due to the high cost of these assets, their operational reliability needs to be optimally ensured for efficient and effective exploitation of these machineries. The current existing flow chart of registering diesel engine defects has been reviewed and a new methodology, which is more systematic and reliable has been proposed. From this study, the most prominent type of defect and its component and subsystems together with their running hours have been identified by using the information extracted from the Job Card (JC) and Return of Vessels' Availability (ROVA) documentation. In future, this methodology could be potentially utilized for other services and applications areas of the diesel engine.

Keywords: auxiliary, defect, high speed diesel engine, machineries, propulsion

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INTRODUCTION

Diesel engine is defined as an internal combustion engine (I.C.E) in which ignition of the fuel injected into the combustion chamber is initiated by the high temperature which a gas achieves when greatly compressed [1]. These days, diesel engine is widely used in many industrial sectors compared to other types of engines such as gas turbine and steam engines. Diesel engine is playing an important part in major sectors such as land and sea transportation, power generation, agriculture, mining and others as well [2]. One industrial sector, which successfully utilises the diesel engine is the shipping sector. This is due to the diesel engine's heavy-duty capability and proven reliability especially in different weather conditions. However, when exposed to harsh and extreme conditions, the marine diesel engine is prone to breaking down, leading possible marine related accidents. Therefore, it is imperative to monitor the conditions of marine diesel engines and hence, predict impending failures. By doing so, the scheduled completion and efficiency of a voyage can be ensured [3–6].

There are many advantages of condition monitoring over the other maintenance strategies. The main advantage is improved plant availability and reduced breakdown costs. Additionally, the diesel engine availability can be improved through maximizing the time between overhauls since maintenance will be carried out only when needed. Secondary damage is also reduced because the onset of failure can be predicted and hence fewer spares will be needed for any planned maintenance. Since failure can be predicted, spares will only be purchased when required. Another advantage of condition monitoring is improved safety and planning [7].

A diesel engine is a complex machine, consisting of many components where its complicated design is exposed to very high temperatures and pressure. In comparison with other types of rotating machinery, performing condition monitoring programmes on diesel engine is more challenging comparatively. This is due to the fact that vibration and sound signal of diesel engines are typically unsteady [8]. Also, diesel engine has several vibration sources, such as from combustion, fuel injection, piston slap and valve operation [9].

As part of the research on high speed radial diesel engines, an analysis had been carried out on the use of the operating systems of the missile boats and comparison of the results with the manufacturer's recommendations [5]. A graphic model had been set up (block – diagram) on high-speed radial ship diesel engine. On the basis of research and empirical data collected on defects which causes the inability to use the engine, the total exploitation reliability of complex technical system and the statistical characteristics of the life of the system had been defined, starting from the assumption that the life of the technical system tested belongs to the Weibull distribution [5].

The diesel engine can be divided into two distinct types i.e. two-stroke and four-stroke engine types. In marine and stationary engines, a two-stroke turbocharged configuration is most frequently used, while in smaller size of engines, a four-stroke cycle is more common. The numbers two and four refer to the number of piston strokes occurring during any one cycle of events [10]. Figure 1 shows the cross section view of a diesel engine and their critical components.

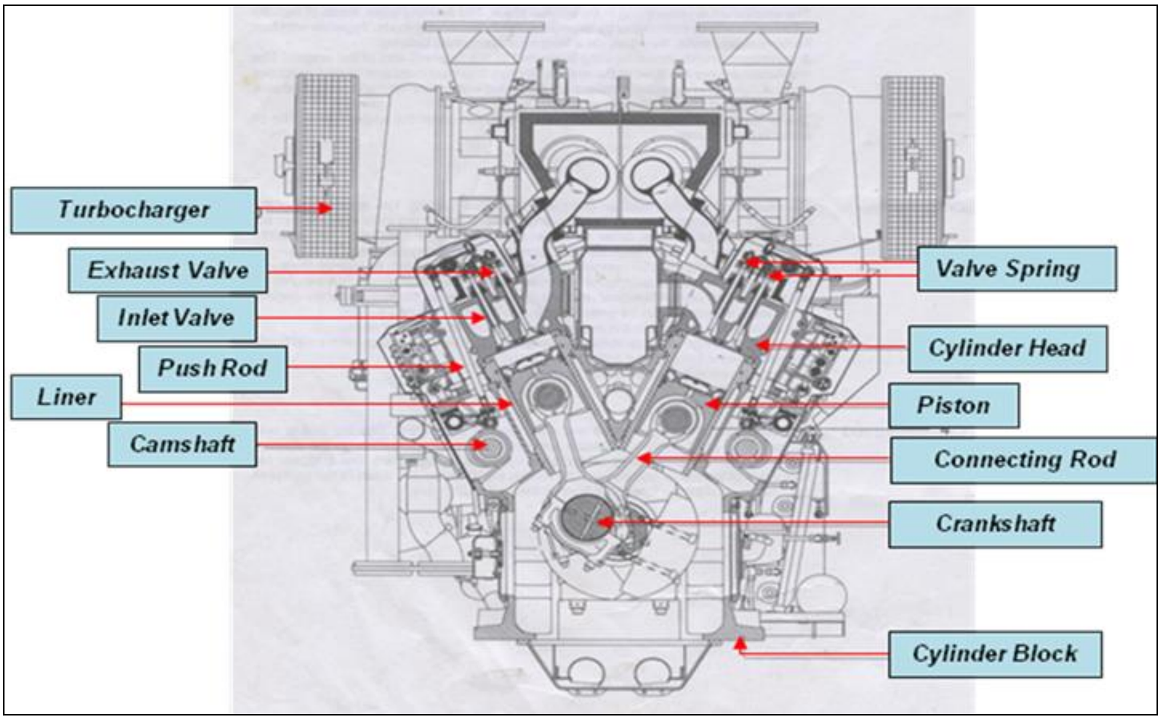


Fig. 1. *Main components of diesel engine [11].*

Diesel engine is one of the most important machineries of a ship's propulsion system. There are many types of defects, which could affect the performance of the engine and potentially causing losses to users.

Therefore, the reliability of these high cost assets is essential for their optimum use on line and minimum detention in a maintenance facility. The unavoidable, unnecessary and idle movements need to be minimized for their optimum utilization to run the ship services.

Unfortunately, due to huge size of the system, the reliability of marine diesel engine is badly affected due to out of course repairs, insufficient research initiatives, inefficiencies in procurement of material and recruitment of staff, and so many other untouched reasons.

Diesel engine is a critical and essential piece of equipment because its potential failure has high consequences on cost. Therefore, it is very essential that developing a sensitive condition monitoring system that is capable of detecting a fault in its early stages before a break-down happens [7].

Table 1 shows the general specifications of a diesel engine of corvette class of naval ships. Each ship has four main diesel engines. This engine is a Vee-type engine and consists of 20 cylinders with two rows of bank; identified as bank-A and bank-B. This engine is four-stroke type and is categorized as a high-speed engine. The model number of this type of engine is MTU 20V 956 TB92 and capable of producing 14.8 MW output at maximum engine revolution.

Table 1. *General specification of corvette type diesel engine.*

Operating method	Four-stroke cycle, single-acting	**Bore**	230 mm
Combustion method	Direct injection	**Stroke**	230 mm
Mode of supercharging	Exhaust turbo-charging	**Displacement, cylinder**	9.56 litres
Cooling method	Water cooling	**Number of cylinders**	20
Cylinder arrangement	60° VEE	**Compression ratio**	12:1

By using condition monitoring, it is possible to provide adequate warning of imminent failure such as leaking. Additionally, it is also possible to schedule future preventive maintenance and repair work for these engines.

This can result in minimum down time and optimum maintenance schedules so that the machine operator will have the necessary spare parts before the machine is stripped down, thereby reducing outage time.

Hence, effective condition monitoring of diesel engine and coupling is critical in improving the reliability, safety and productivity of diesel engine.

OBJECTIVE

In this study, all the defect reports under main propulsion and transmission systems that is related to the diesel engine, gear box and others thoroughly checked individually and separated as per the equipment or machinery involved.

Then, each defect report for diesel engine of corvette type ships will be further studied.

The aim of this study is to identify the main type of critical component and the most critical components of corvette type ships. The study will be carried out based on engine defect reports and running hours from the year 2010 to 2015.

METHODOLOGY

The methodology is divided into two stages; the extraction of information related on defect report of high speed diesel engine based on running hours based on defect description for each as per stated on Job Card (JC) and monthly ships' availabilities from Return of Vessels' Availability (ROVA) statements. Both documents have been studied and all related information gathered according to the type of defects and components. The second stage is carried out by combining both sets of information to form more accurate and reliable data management system.

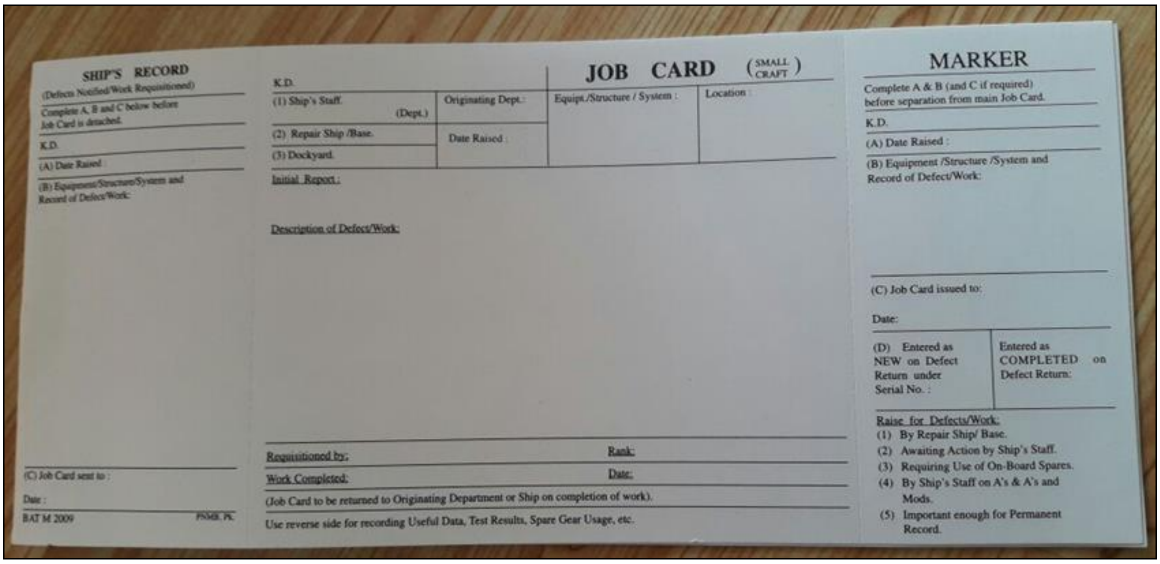
The JC is an official document used by the ship to request for repair, maintenance, testing and calibration. Figure 2 shows an example of a JC. Meanwhile, Figure 3 shows the flow chart of the receiving and registering job card and the combination of the ROVA information into this chart. A formal recording of the information on the JC is processed in Microsoft Excel [12–14].

In this study, all JCs for diesel engines of corvette class ships have been segregated from other classes as per the type of defects and components. Then, each JC was counter-checked with the repair log book which is under the custodianship of the respective ship.

Also, interviews were conducted among maintenance crews of the ship to further gauge information such as root cause, the severity of the defect, impact on engine operation and, etc.

The ROVA is a monthly statement sent by the ship to the Fleet Operation Centre (FOC), which governs the movement and operation of the ships. ROVA contains information such as the running hours for all the individual engines. Based on the ROVA, the FOC will be able to set up operational and maintenance plan for the ships with the assistance from the Naval Engineering Headquarters (NE HQ).

Subsequently, the information of each defect in terms of defect description and the associated component or system analysed utilizing SPSS software. From the analysis, the most prominent type of defect, component and their running hours will be identified.



SHIP'S RECORD
(Defects Notified/Work Requisitioned)
Complete A, B and C below before Job Card is detached.
K.D.
(A) Date Raised :
(B) Equipment/Structure/System and Record of Defect/Work:
(C) Job Card sent to :
Date :
BAT M 2009 PNMB. PK.

JOB CARD (SMALL CRAFT)
K.D.
(1) Ship's Staff. (Dept.)
Originating Dept.:
Equipt./Structure / System :
Location :
(2) Repair Ship /Base.
Date Raised :
(3) Dockyard.
Initial Report :
Description of Defect/Work:
Requisitioned by: Rank:
Work Completed: Date:
(Job Card to be returned to Originating Department or Ship on completion of work).
Use reverse side for recording Useful Data, Test Results, Spare Gear Usage, etc.

MARKER
Complete A & B (and C if required) before separation from main Job Card.
K.D.
(A) Date Raised :
(B) Equipment /Structure /System and Record of Defect/Work:
(C) Job Card issued to:
Date:
(D) Entered as NEW on Defect Return under Serial No. :
Entered as COMPLETED on Defect Return:
Raise for Defects/Work:
(1) By Repair Ship/ Base.
(2) Awaiting Action by Ship's Staff.
(3) Requiring Use of On-Board Spares.
(4) By Ship's Staff on A's & A's and Mods.
(5) Important enough for Permanent Record.

Fig. 2. *An example of Job Card (JC).*

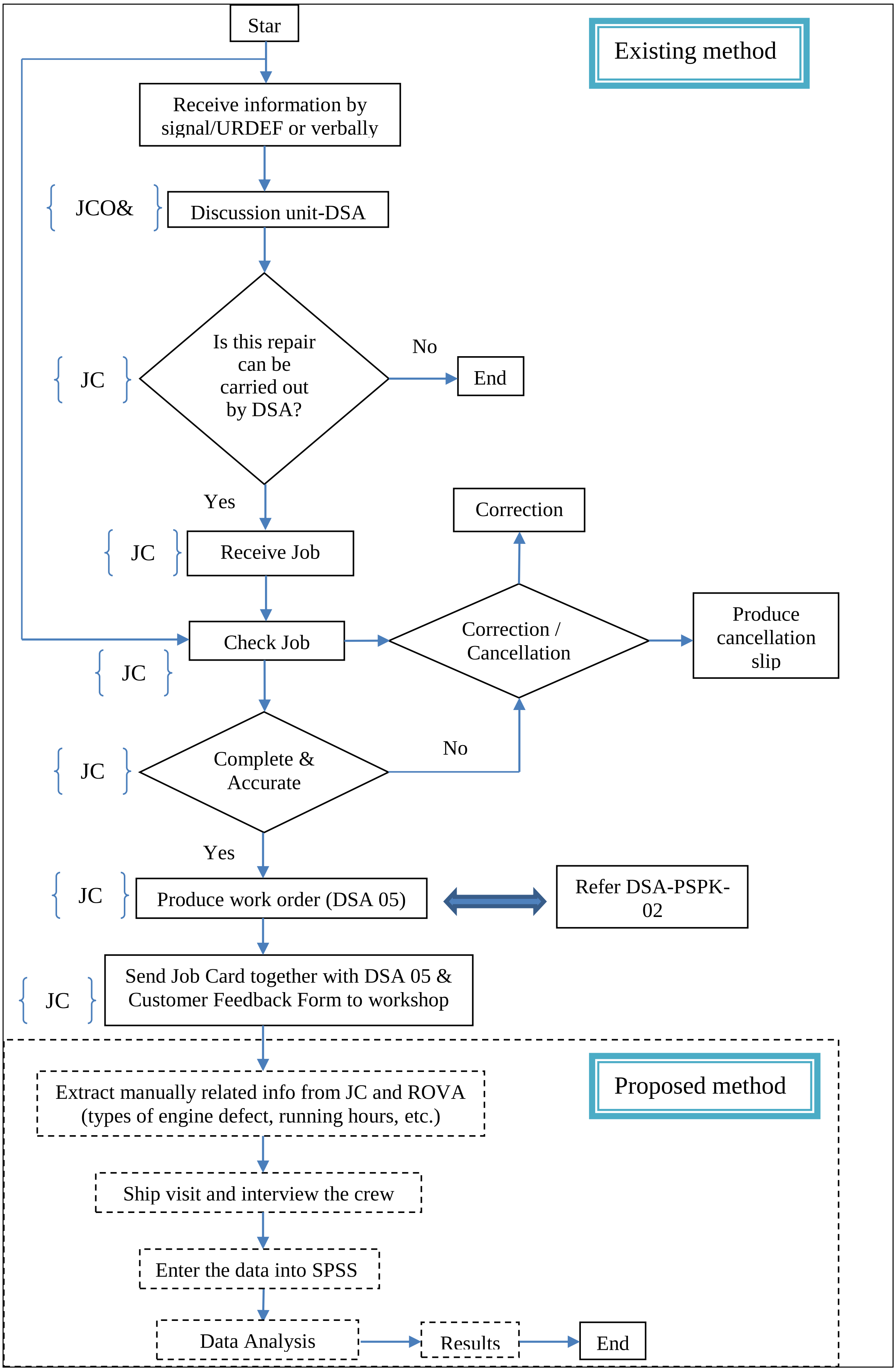


Fig. 3. *Flow chart of job card receiving and registration.*

RESULTS AND DISCUSSION

Data Preparation

Table 2 shows the segregation of the mechanical and electrical/electronic types of diesel engine components. In our study, only 10 of the mechanical type components as per highlighted below have been selected for further analysis based on the frequency of failure recorded, types of defect and also on the importance of the respective component for the whole operation of the engine, especially for high speed operational requirement. Most the components of diesel engine belong to mechanical and related type systems such as combustion, cooling, coupling and others as well.

Table 2. *Components of diesel engine divided into mechanical and electrical/electronic groups.*

Mechanical	**Electrical/electronic**	
Exhaust trunking	Water pipe sleeve	Preheater controller
Exhaust lagging	Exhaust portage of generator funnel	Shaft speed indicator
Flexible coupling	Fuel return pump of generator	Electronic card
Fuel injector	Water flap exhaust	Air regulator throttle
Sea water cooling pipe	Exhaust valve	MCS panel
Fresh water cooling pipe	*Cylinder liner*	MCS switch
Exhaust cooling pipe	Pneumatic air control pipe	Monitoring gauge
Suction valve	Sea water mechanical seal	Preheater transformer
Water bracket	Lubricant oil pipe	Pneumatic control
Flat tube core	Air control system	Local operating panel
Coolant pump	*Connecting rod*	Exhaust fan motor
Exhaust valve	Water pipe plug	
Globe valve	Starting air distributor	
Fuel line return pipe	Fuel line pipe	
Engine resilient mounting	Air starter pipe	
Stop pin	Coolant delivery valve	
Exhaust caging	Fuel rack angle pick	
Valve seat of generator	Coolant draining system	
Governor	Underwater flap exhaust	
Air control valve	*Piston*	
Emergency cooling pipe	Cut-less bearing of shafting line	
Heat exchanger housing	2/3 Way solenoid valve	
Prefilter casing	Electro extractor canvas	
Sea water suction	Intercooler	
Underwater flap exhaust	*Turbocharger*	
3-Way valve	Intercooler	
Preheater motor	Exhaust bellow	
Exhaust cooling pipe	Water exhaust	
Butterfly valve	*Heat exchanger*	
Exhaust flap	Valve head of generator	
Sea water pump	Lubricant oil priming motor	
Fuel oil transfer pump	Cooling water pump	

Data Analysis

Figures 4–9 show the diesel engine components and types of defect between the years 2010 and 2015.

In this analysis, seven types of defects have been taken into consideration such as leaked, misalignment, cracked, deteriorated, corroded, vibration and knocking sound, and wobbling.

Meanwhile, among the 10 components of diesel engine, four of the components are directly related to the combustion process such as the piston, cylinder liner, fuel injector and connecting rod.

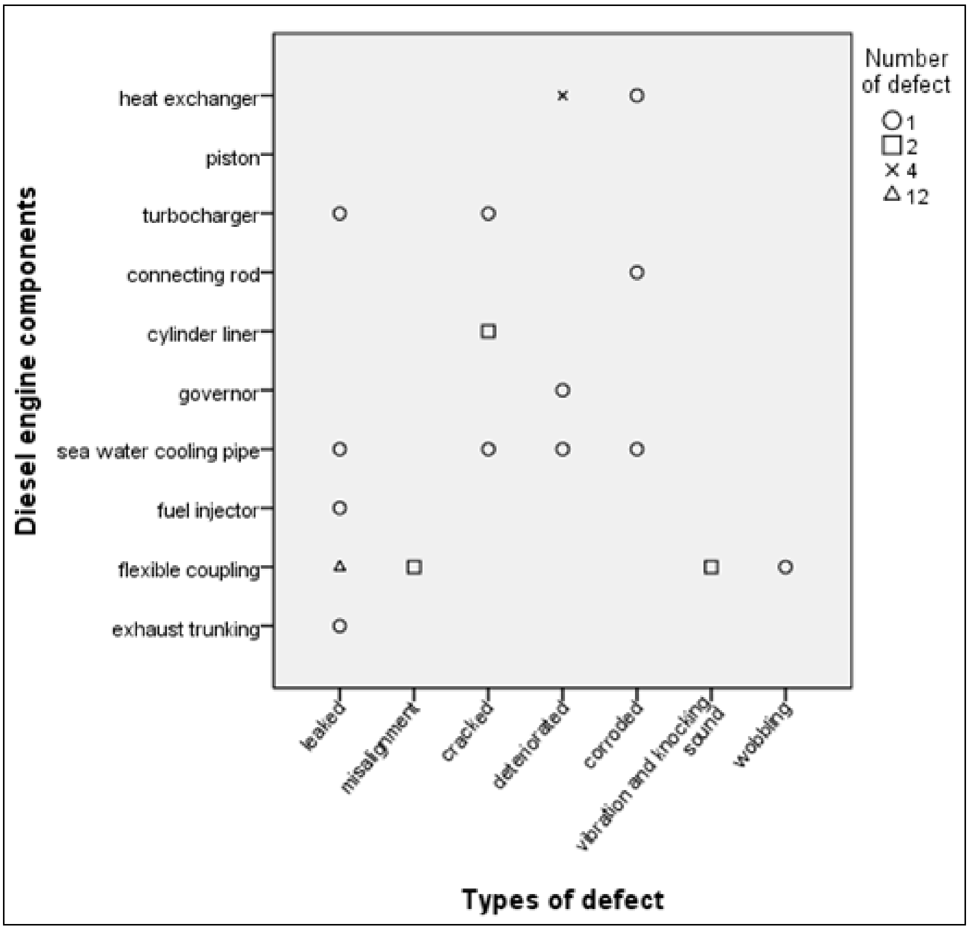


Fig. 4. *Diesel engine components versus types of defect in the year 2010.*

Based on Figure 4, it was found that the flexible coupling recorded the highest number of defects in year 2010.

There were four types of defects recorded by flexible coupling such as leaked, misalignment, vibration and knocking sound and wobbling. It was also found that the most common type of defect recorded among these components was *leaked.* All the components recorded at least one or more types of defects except for the piston.

In comparison with the other years in terms of number of defect, year 2010 recorded the highest number of defects

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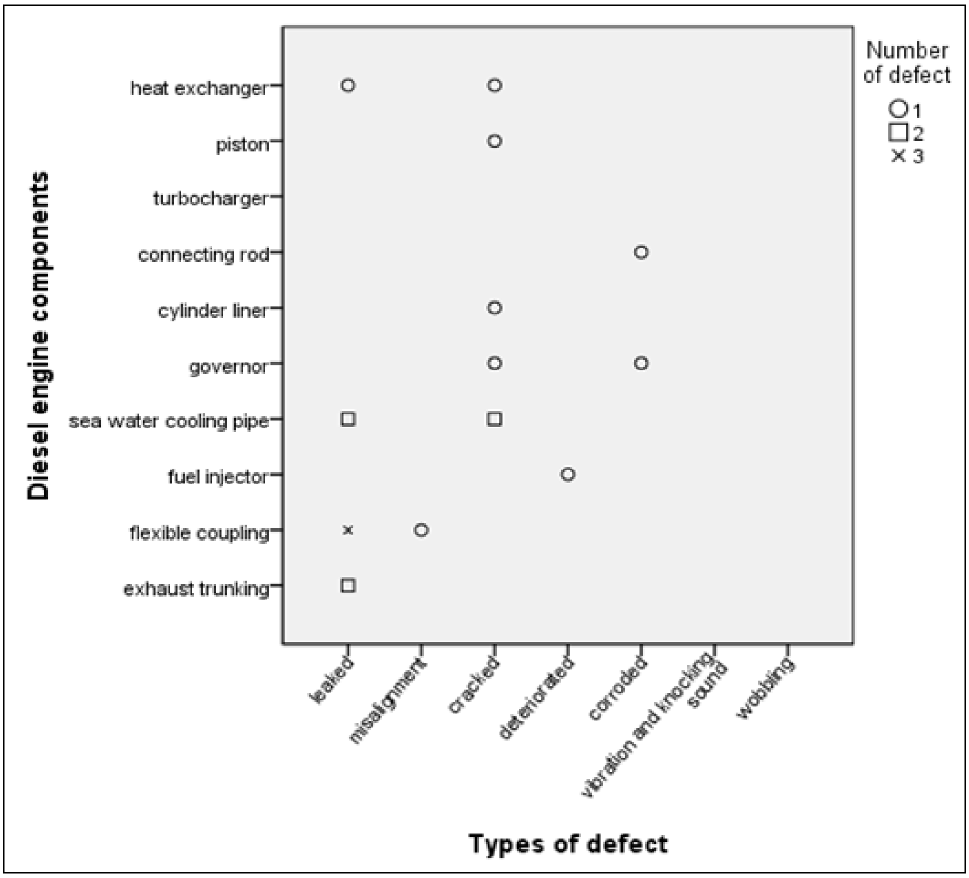

Fig. 5. *Diesel engine components versus types of defect in the year 2011.*

As shown in Figure 5, in year 2011, the flexible coupling recorded the highest number of defects, which was followed by the sea water cooling pipe. Nevertheless, all of the components recorded at least one or more types of defect except for the turbocharger. Out of the ten components in this study, all of the components recorded at least one or more defects except for the turbocharger. The piston, connecting rod, cylinder liner and fuel injector recorded different defects, which were cracked, deteriorated, and corroded, respectively.

It has also been found that the most prominent type of defect was leaked. Besides leaked, another type of defect, which recorded higher number of defects was cracked. Some of the defects such as vibration and knocking sound, and wobbling were not recorded by any of the other components. In comparison with the year 2010, the number of defects in the year 2011 was found to be lower and only the flexible coupling and sea water cooling pipe were the most defective components.

As shown in Figure 6, it was found that the flexible coupling and exhaust trunking recorded highest number of defects in year 2012. Also, it was found that out of the ten components, only five components recorded defects. The flexible coupling was found with two types of defects; leaked, and vibration and knocking sound. The others just recorded one type of defect only.

Some other components such as turbocharger, piston and cylinder liner recorded defects such as leaked, cracked and deteriorated, respectively. Meanwhile, the exhaust trunking recorded just one type of defect; leaked, which was the most prominent type of defect recorded in year 2012. Also, it has been found that defects such as misalignment and wobbling were not found on any of the components.

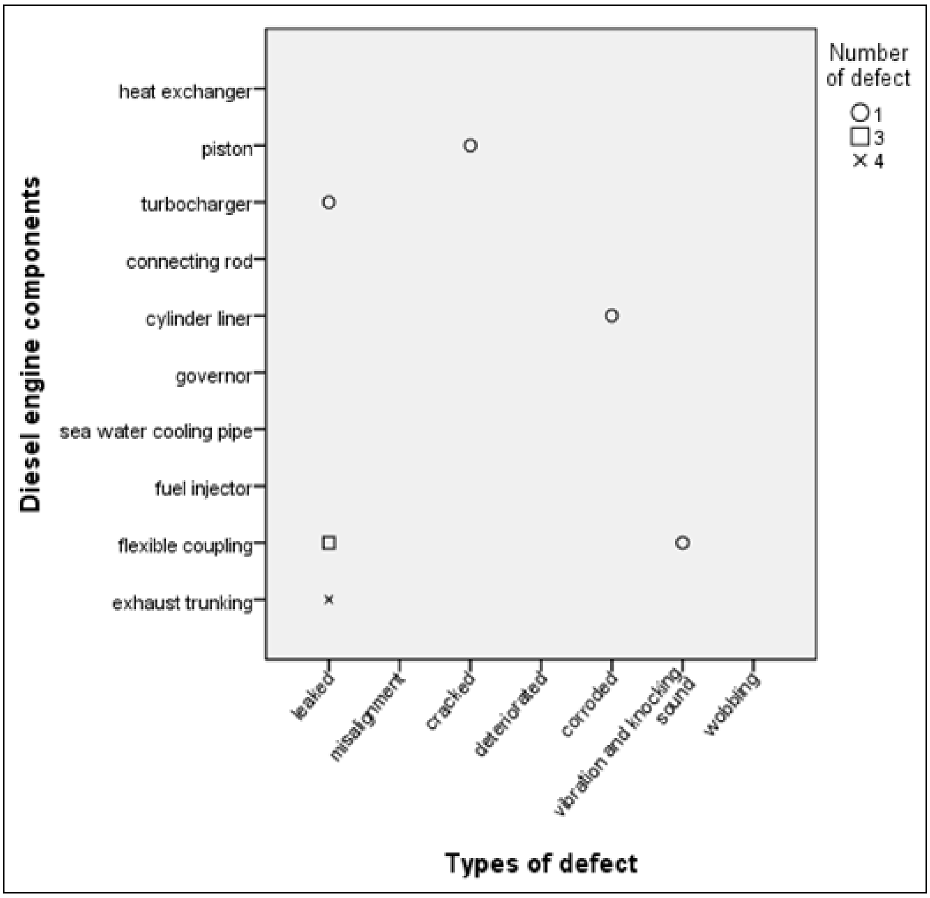

Fig. 6. *Diesel engine components versus types of defect in the year 2012.*

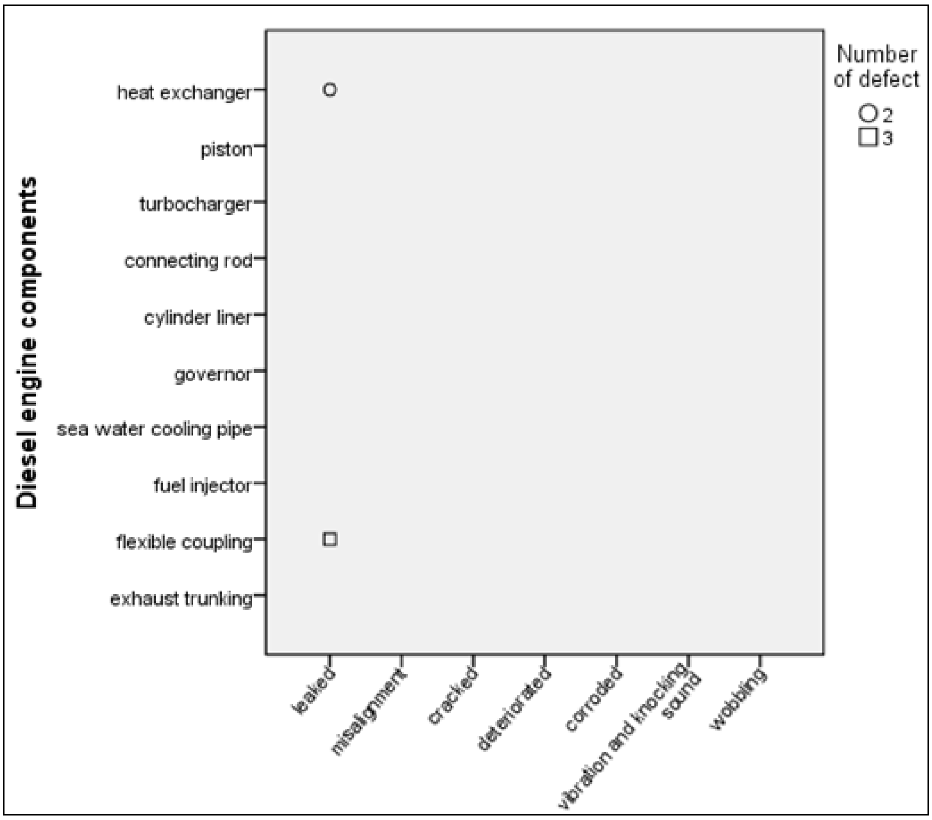

Fig. 7. *Diesel engine components versus types of defect in the year 2013.*

As shown in Figure 7, it was found that only the flexible coupling and heat exchanger recorded defects in year 2013. In comparison with the other years in terms of number of defects, the year 2013 recorded the lowest number of defects. Only one type of defect was recorded in this year, which was leaked. Flexible coupling and heat exchanger recorded two cases and one case of leaked respectively. Also, it has been found that in the year 2013, flexible coupling recorded the lowest number of leaked cases. In the year 2010, flexible coupling recorded the highest number of leaked cases. Flexible coupling is situated between the diesel engine and the gear box of the ship propulsion system. The main function of this coupling is to dampen the torsional vibrations and to adjust the critical speeds of the engine away from the application operating range.

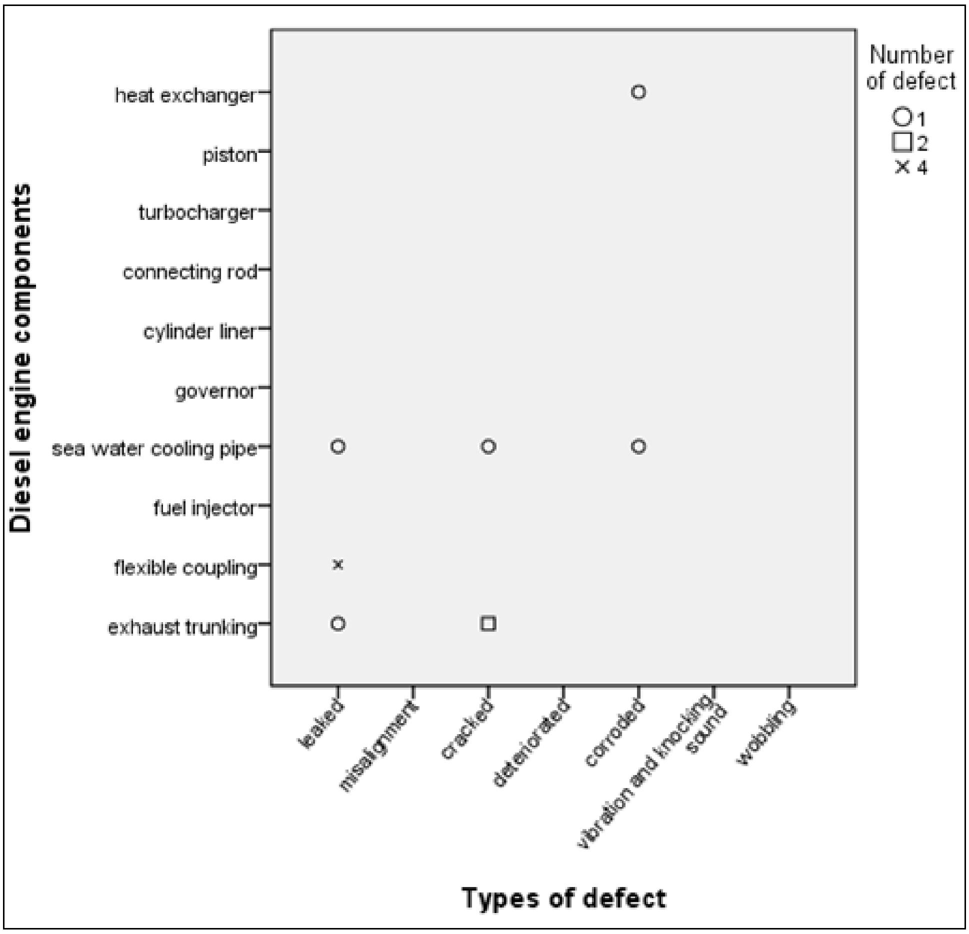

Fig. 8. *Diesel engine components versus types of defect in 2014.*

As shown in Figure 8, it was found that the flexible coupling recorded the highest number of defects in year 2014. Besides the flexible coupling, the sea water cooling pipe, heat exchanger and exhaust trunking also recorded defect cases. Out of the ten components, only four components were found to be recorded with defects. Also, it was found that the sea water cooling pipe recorded three different types of defect and the exhaust trunking with two different types of defects. Meanwhile, the flexible coupling and piston recorded one type of defect only. In total, the leaked cases were the most prominent type of defect in the year 2014 with six cases and followed by cracked with 3 cases.

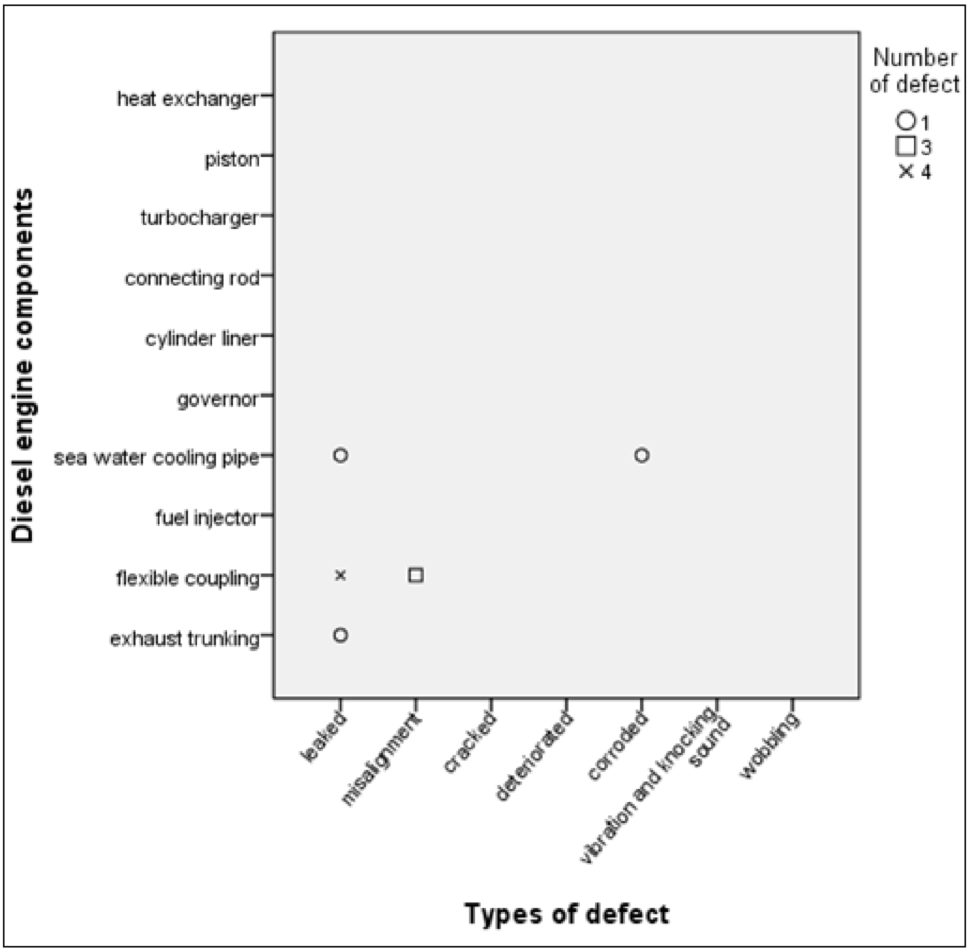

Fig. 9. *Diesel engine components versus types of defect in the year 2015.*

As shown in Figure 9, in year 2015, it was found that flexible coupling recorded the highest number of defects where it was leaked cases and misalignment, followed by sea water cooling pipe and exhaust trunking. Some other components such as the heat exchanger, piston, turbocharger, connecting rod, cylinder liner, governor and fuel injector did not record any defect. As shown in Figure 9, out of the ten components, only three components were found to have with defects.

Also, it was found that the sea water cooling pipe and flexible coupling recorded two different types of defects and the exhaust trunking with one type of defect. In comparison with the other years in terms of number of defects, the year 2013 recorded among the lowest number of defects.

Figure 10 shows the running hours for each type of defect on flexible coupling between the year 2010 and 2015. There were four types of defects related to the flexible coupling which are leaked or leaked oil seal, misalignment, vibration and knocking, and wobbling. This graph is divided into five sections, which is based on the maintenance schedule-running hours provided by the engine manufacturer. Meanwhile, the information on the engines' running hours has been gathered from the ROVA, a monthly statement from each ship. These sections are from 0 to 3000, 3001 to 6000, 6001 to 9000, and 9001 to 12000 and above 12000. From this graph, it has been found that the most prominent type of defect was leaked cases. Also, it has been found that the frequency of defects recorded were almost similar for each section except for between

6000 and 9000. Also, there were no defects that were recorded in the section between 6000 and 9000 running hours, which is after the 2nd overhaul. Meanwhile, there was only one defect that was recorded after 12000 running hours in the year 2012. The running hours of some of the defects could not be traced due to lack of information such as engine serial number in the JC.

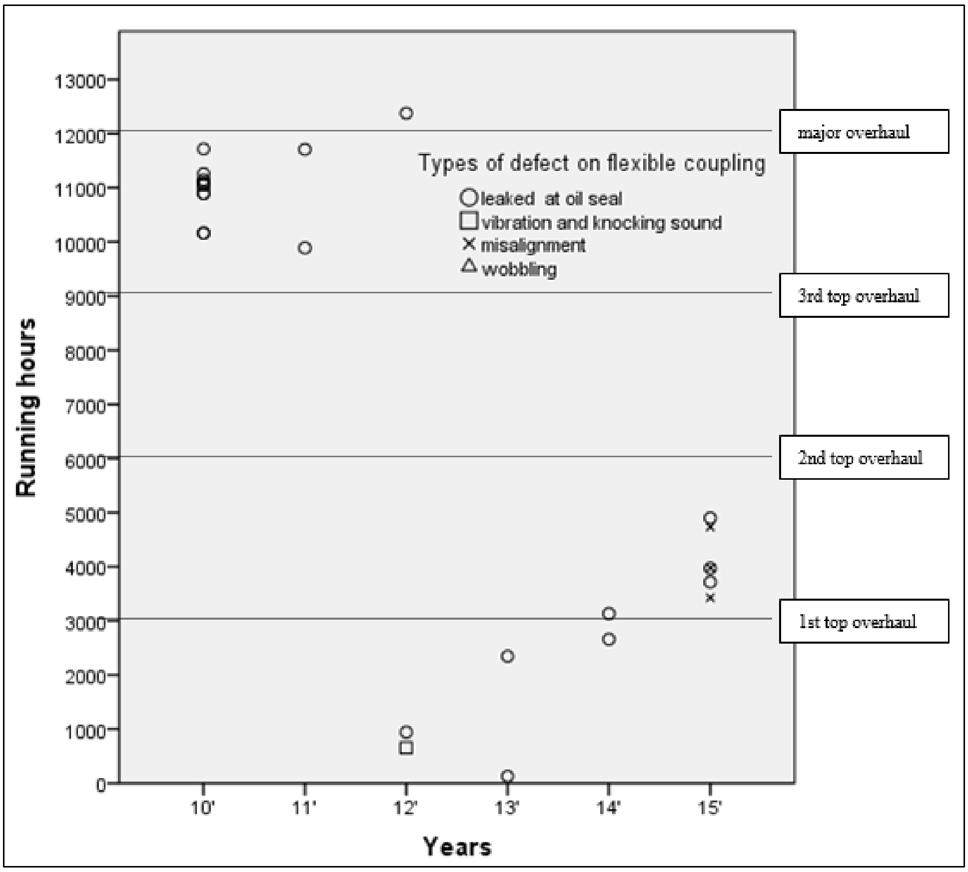

Fig. 10. *Number of defect cases on flexible coupling between 2010 and 2015 based on running hours.*

CONCLUSION

In this study, an improved method involving JC and ROVA has been proposed based on the existing system to smoothen the process of identifying the most prominent defects of components of diesel engine. This is shown in Figure 3. The effectiveness of the combination of the information from the JC and ROVA between years 2010 and 2015 has been verified using the SPSS analysis software. Based on the analysis carried out, the flexible coupling has been identified as the most prominent defective component and leaked as the most prominent type of defect. Hence, this methodology could be used as a template for other applications, including land, sea and air vehicles for future projects.

Also, this study could be used as a platform to highlight the importance of implementing condition monitoring. The existing monitoring system, which involves cylinder temperature and in-cylinder pressure has been found not able to detect problems such as the leakage on flexible coupling. Condition monitoring could be used to detect any abnormalities at an early stage and subsequently could be utilized to prevent catastrophic failure of diesel engines in order to prevent the whole operation of the system from being jeopardized.

ACKNOWLEDGEMENT

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REFERENCES

[1] A.K. Antonopoulos, D.T. Hountalas. Effect of instantaneous rotational speed on the analysis of measured diesel engine cylinder pressure data, *Energy Convers Manage.* 2012; 60: 87–95p. doi: 10.1016/j.enconman.2012.01.020.
[2] J. Arroyo, M. Muñoz, F. Moreno, N. Bernal, C. Monné. Diagnostic method based on the analysis of the vibration and acoustic emission energy for emergency diesel generators in nuclear plants, *Appl Acoust.* 2013; 74(4): 502–8p. doi: 10.1016/j.apacoust.2012.09.010.
[3] V.T. Lamaris, D.T. Hountalas. A general purpose diagnostic technique for marine diesel engines – application on the main propulsion and auxiliary diesel units of a marine vessel, *Energy Convers Manage.* 2010; 51(4): 740–53p. doi: 10.1016/j.enconman.2009.10.031.
[4] Z. Li, X. Yan, Z. Guo, Y. Zhang, C. Yuan, Z. Peng. Condition monitoring and fault diagnosis for marine diesel engines using information fusion techniques, *Electron Electr Eng.* 2012; 123(7). doi: 10.5755/j01.eee.123.7.2387.
[5] L. Mihanović, I. Komar, M. Gržan. Methodology Analysis using exploitation reliability with the use of the RTOP main diesel engine, *Int J Martime Sci Technol*. 2015. doi: 10.17818/NM/2016/2.2.
[6] P. Kakade, M.D. Pasarkar. Analyzing and identifying various approaches for crankshaft failures, *J Multidiscipl Eng Sci Technol*. 2015; 2(2).
[7] Y. Alhouli, A. Alkhaledi, A. Alzayedi, M. Alardhi, A.I. Abed. Study of diesel engine vibration condition monitoring, *Global J Res Eng.* 2015; 15(6).
[8] G.-X. Jing, Z.-Y. Hao. A new technique based on traditional wavelet transform used in NVH application of internal combustion engine, *Mech Syst Signal Process.* 2009; 23(3): 979–85p. doi: 10.1016/j.ymssp.2008.08.009.
[9] X. Liu, R.B. Randall. Blind source separation of internal combustion engine piston slap from other measured vibration signals, *Mech Syst Signal Process.* 2005; 19(6): 1196–208p. doi: 10.1016/j.ymssp.2005.08.004.'
[10] F. Elamin. *Fault Detection and Diagnosis in Heavy Duty Diesel Engines Using Acoustic Emission.* 2014. Retrieved from Retrieved from http://eprints.hud.ac.uk/19324/.
[11] K.D. Hang Tuah, Wartsila. *Diesel Engine Maintenance Manual*. 1980.
[12] M. Fonte, V. Infante, M. Freitas, L. Reis. Failure mode analysis of two diesel engine crankshafts, *Proc Struct Integr.* 2016; 1: 313–8p. doi: 10.1016/j.prostr.2016.02.042.
[13] X. Liu, R.B. Randall. Blind source separation of internal combustion engine piston slap from other measured vibration signals, *Mech Syst Signal Process*. 2005; 19(6): 1196–208p. doi:10.1016/j.ymssp.2005.08.004.
[14] Z. Li, X. Yan, Z. Guo, Y. Zhang, C. Yuan, Z. Peng. Condition monitoring and fault diagnosis for marine diesel engines using information fusion techniques, *Electr Electr Eng*. 2012; 123(7). doi:10.5755/j01.eee.123.7.2387.