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LOW SPEED MARINE DIESEL ENGINE DIAGNOSIS BASED ON PASSIVE EXPERIMENT

Stanisław Polanowski, Rafał Pawletko

Gdynia Maritime Univeristy
ul. Morska 81-87, 81-226 Gdynia, Poland
tel.: +48 586901319
e-mail: stpolanowski@gmail.com, pawletko@am.gdynia.pl,

Abstract

Analysis of the indicator diagram is the basis of technical state evaluation of marine diesel engines. The indicator diagram contains a large amount of diagnostic information. In most cases, analysis of the graph is reduced to determination only the maximum pressure or mean indicated pressure. It seems appropriate to determine the possibility of use heat release characteristics for the diagnostic purpose. The paper presents results of studies related to the use of indicator diagrams for the diagnosis of high power marine diesel engine. The results include a comprehensive approach to problems of use of the cylinder pressure curves for the evaluation of the technical condition of the engine. The problem of dynamic adjustment of the GMP position, smoothing distortions due to the impact of the channel and indicator valve were considered. Diagnostic analysis includes also the designation of the heat release characteristics on the basis of the curves pressure in the engine cylinder. The algorithms allow to determine both the curves of heat release rate q and the heat released Q. The curve of heat release rate q is a full equivalent to fuel injection pressure curve in the fuel pipes. It allows identification of the failure of the injection system. The curve of Q allows such determination and additional assessment of internal efficiency of the cylinder. The analyzed indicator diagrams were obtained during the sea voyage with the use of the stationary electronic indicator PREMET. The pressure sensor were placed on the indicator valves.

Keywords: *marine combustion engines, heat release characteristics, indicator diagram analysis*

1. Introduction

Modern cargo ships are distinguished by considerable tonnage freight, requiring considerable power propulsion systems, which is associated with significant fuel consumption and generation of combustion products by a single object.

The cargo ship propulsion systems are primarily used the slow and medium speed diesel engines with power exceeding 80 MW. If we use the example of the marine engine MAN 9K90MC (41162 kW/94 rpm), improving its efficiency by 1%, at 75% load would reduce fuel consumption by 0.05 t/h. At a year scale, such improvements, would save about 250 t, assuming a specific fuel consumption of at SFOC = 169 g/kWh. Getting savings is possible with a good engine technical condition and with optimal settings and regulation of fuel and propulsion system.

For this reason, there is a need in shipping, to use diagnostic systems to monitor the working process in the cylinders and diagnostic reasoning based on indicator diagrams. In general, the greatest expectations in relation to diagnostic systems are associated with failure detection and forecasting of the technical condition. This follows from the need to maintain sailing safety and environmental protection. In shipbuilding there are still widely used indicators of both mechanical and automatic measurement and the on-line diagnostic systems.

The indicator diagrams of marine engines are considered to be one of the major sources of diagnostic information about the work and condition of engine cylinder sections. There are still widely used on ships mechanical and electronic maximum pressure meters, mechanical and electronic indicators for measurements in the time domain, and the more complex indicators in the field of the crank angle. Pressure measurement in the crank angle domain is the one of the condition of the automation of data processing.

The still actual problem is a selection of diagnostic information contained in the indicator diagrams and evaluation of the reliability of obtained information. Despite the rapid development of measuring techniques, in the field of methods and scope of obtaining diagnostic information from the indicator diagram there is a stagnant.

Diagnosis, in these types of systems, is based on comparing the values of the maximum compression pressure, the maximum combustion pressure and the mean indicated pressure (MIP). Pressure curves and parameters listed above or their deviation from the mean value are compared between the engine cylinders at a given load. In more advanced systems, trends of observed diagnostic parameters are created, which allows obtaining additional diagnostic information. In order to obtain the trends of diagnostic parameters, it is necessary to use pressure sensors that maintain long-term measurement characteristics. An additional condition is the creation of diagnostic parameters independent of the load.

It seems that a significant increase in diagnostic capacity of indicator diagrams, can be obtained by heat release characteristics. These characteristics, despite the high diagnostic potential, are still not used to assess the condition of marine engines.

2. The experiment methodology

The paper analyzed the diagnostic information obtained on the one type of container vessel with a capacity of 67 682 DWT (4612 TEU). Measurement information are related to main engine MAN B&W 9K90MC, which uses on-line diagnostic system of known company widely used in the ships. The study cover six test sessions, which are performed by the crew within three months of sea voyage. Test results includes information about detected malfunctions and maintenance activities performed during this period (Table 1).

Tab. 1. Measurement sessions (indications), detected failures and maintenance operations on main engine MAN B&W 9K90MC

Measurement session (date)	Detected failures, symtpoms	Maintenance operations
A (12.07.2011)		
B (23.08.2011)		
C (30.08.2011)		
	Cyl. 9 - exhaust valve leakage (high temperature of exhaust gas, a large amount of fuel)	Cyl. 9 – exhaust valve replacement
	Cyl. 2 - blocked two upper piston rings (detected by performing other procedures)	Cyl. 2 – piston rings launched
	Cyl. 7 – fuel pump damage (VIT setting 8,1; should be about 6,7)	
D (23.09.2011)		
E (07.10.2011)		
		Cyl. 7 – fuel pump replacement

		(VIT in operation)
		Cyl. 1;3;5 – eliminated leaks inAIR SPRING (large pressure drops indrop test)
F (20.10.2011)		

It should be noted that most of the diagnostic observations were not based on indicator diagrams and the results of the test reports of indication, but on different diagnostic parameters and symptoms. In this paper an analysis of whether any malfunction can be detected using the previously used indicator diagram processing methods, and using the heat release characteristics.

3. Assessment of the diagnostic usefulness of pressure curves and MIP values

Direct comparative analysis of the indicator diagram, as well as the MIP values allows diagnostic inference only in case of significant deviations from the mean values. Even in such cases there are diagnostic interpretation difficulties. The example is illustrated in Figure 1, where in session C, in the case of cylinder 2 there was a significant deviation of the MIP about 15 %.

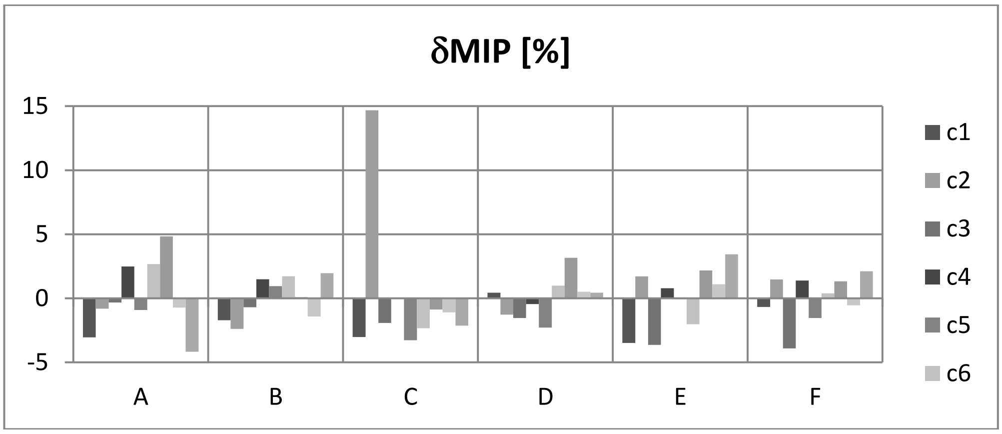

Fig. 1. Percentage deviations from mean δMIP for the cylinder for all test sessions A ÷ F

A significant deviation of the cylinder 2 with respect to the course of an average is seen on the imposed pressure curves (Figure 1).

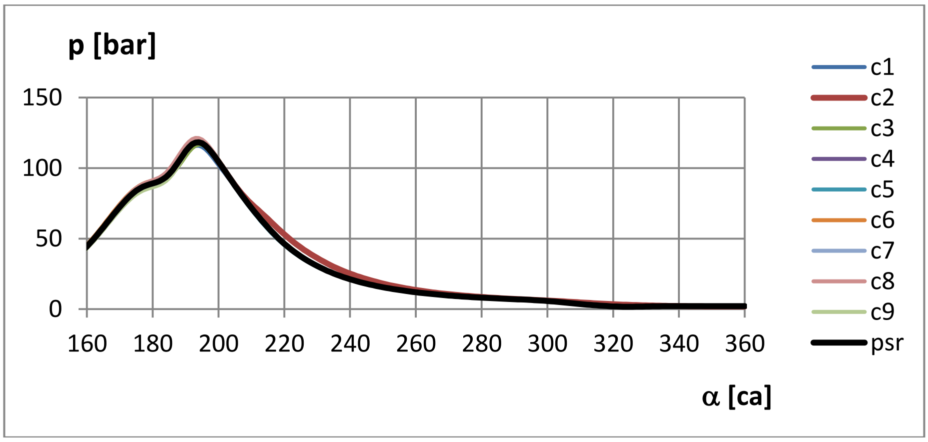

Fig. 2. Comparison of the pressures in the cylinders and their averaged in the session C

The identification of reasons of deviation of cylinder nr 2 is very difficult. Is known only that the amount of fuel is higher.

4. Assessment of the diagnostic utility of the maximum combustion pressure

The maximum combustion pressure p_m is the parameters which can be measured even by the simplest maxi meters or mechanical indicators. This parameter is usually used in the operation for the overall evaluation of the technical condition of cylinders and fuel injection systems regulation. It is believed that the maximum combustion pressure can be used to assess on the engine load balance between the cylinders in place of the mean indicated pressure (MIP).

Analysis of measurement data obtained during the operation (Table 1) showed that the use of the maximum combustion pressure for the loads regulation assessment of marine engines, in this case, is not eligible. The indicator diagrams were smoothing before analysis to reduce the impact of large measurement noise. The values of correlation coefficients between the values of the maximum combustion pressure p_m and p_{wm}, and the values of p_i, for each measuring session (Table 2) indicate no significant relationship at the level of variation at a given level of loads.

Tab. 2. The values of correlation coefficients between the mean indicated pressure pi, and maximum combustion pressures: p_{max} – designated from original pressure curve, p_{wmax} - designated from pressure curve after smoothing

Correlation coefficients	Measurement session					
	A	B	C	D	E	F
$K(p_{max};p_i)$	0,23	0,21	0,24	0,00	0,10	-0,09
$K(p_{wmax};p_i)$	0,24	0,18	0,16	0,06	0,02	0,07

As can be seen (Table 2) smoothing slightly affected the values of correlation coefficients. The results obtained in both cases indicate a lack of correlation between p_m, p_{wm}, and p_i. Thus, for a given load level for the maximum pressure deviations below 5% should not be guided by the value of the maximum combustion pressure for the assessment of the cylinder load. The reasons may be different.

5. The heat release characteristics and their possible diagnostic use

Determination of the heat release dynamics is a complex mathematical and measuring problem [3, 4]. For diagnostic purposes it is advisable to use a simplified model of the net heat release rate q_n for an ideal gas [3].

This formula can be written as follows:

$$q_n = \frac{dQ_n}{d\propto} = (\kappa - 1)^{-1}\left[\kappa p \frac{dV}{d\alpha} + V\frac{dp}{d\alpha}\right] \quad (1)$$

where:
Q_n – net heat release,
κ – isentropic exponent,
V – current volume of the cylinder,
α – crank angle.

Determination of released heat Q requires the integration of the value of q in the field crank angle, from the piston BDC.

In this work the net heat release rate and net heat released are related to a cylinder volume. In this case the unit of heat release is pressure.

In order to determine the heat release characteristic as well as MIP values thermodynamic TDC was used which was calculated with the original method based on polynomial model of compression curve exponent [1, 2].

Figure 3 shows an example of a significant deviation of heat release Q is easy to see that in the case of cylinder 2 appeared much higher Q value than for the other cylinders.

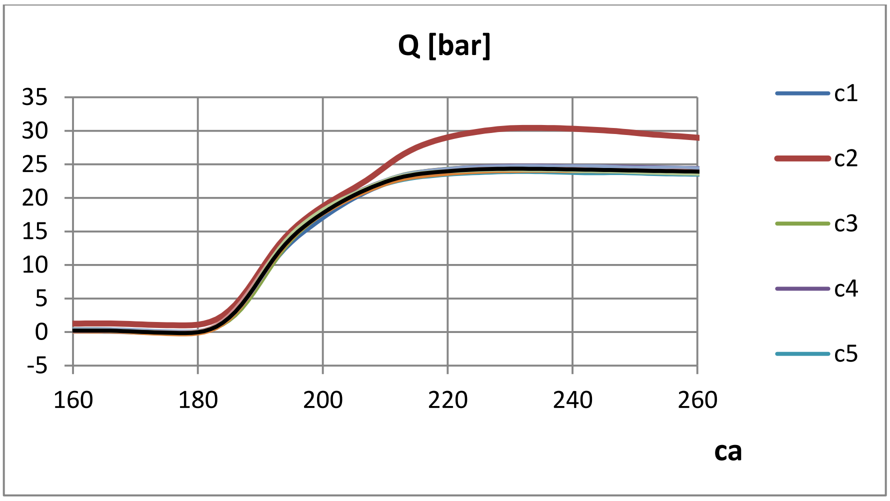

Fig. 3. Curves of net heat released in the cylinder Q for the measurement session C

The fault symptoms visible on cylinder nr 2 are results of faulty operation of the fuel injection system. The identification of fault can greatly facilitate with the analysis of the curve the heat release rate (Fig. 4), which is correlated with the process of fuel injection into the cylinder and the injection pump operation.

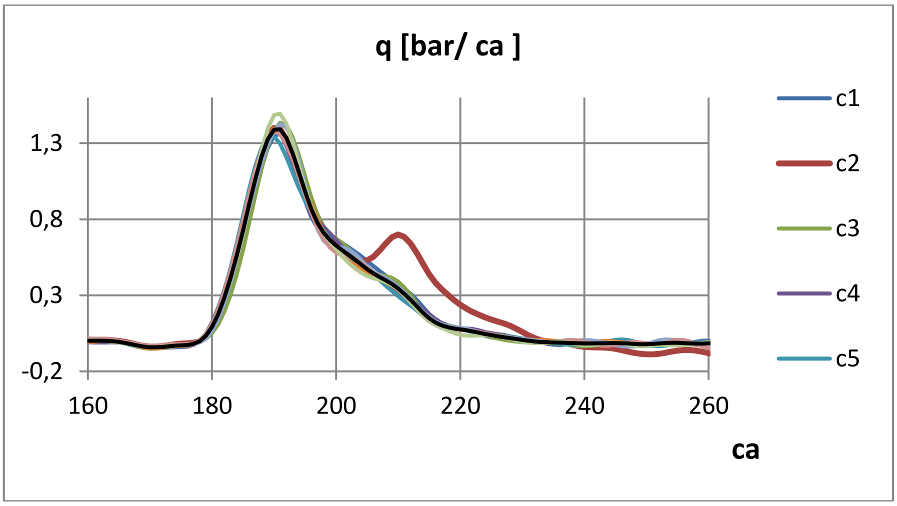

Fig. 4. The curve of heat release rate in the cylinders for the session C

By analyzing the observed curve of q in the cylinder 2, in conjunction with the principle of operation of the injection system, it's easy to perform diagnostic reasoning. In total, the analyzed test sets identified several cylinders for which there were various derogations from the normal curve of q. It is appropriate to create a catalog for the failure of symptom-injection systems. For this purpose, it's plans to establish wider cooperation with the crews machine, which will enable the development of diagnostic methods of injection systems based on the heat release characteristics.

Summary

Diagnostic reasoning based on a comparison of indicator diagrams and the variation of maximum combustion pressure within the 5% and even 10% is very difficult. The diagnosis in this case is limited to an occurrence of significant deviations without specifying of its reasons. This conclusion is confirmed by the results of analyzes of indicator diagrams taken for other engines, ships and pressure analyzers.

Similar problems have occurred with regard to the use of the MIP for diagnostic purposes, which further requires a sufficiently precise determination of TDC position of the piston, and in particular the thermodynamic TDC determination. Most electronic indicators used on ships, are characterized by inadequate methodology and poor accuracy of determination of TDC. The absolute values of TDC position errors sometimes exceed 1 ° OWK, apart from systematic errors. Designation error of MIP values, which results from the accuracy of the determination of TDC at the nominal engine load can exceed 8%.

Improvement of diagnostic inference based on indicator diagrams, can be obtained by analyzing the characteristics of the net heat release rate, determined on the basis of indicator diagrams. Heat release characteristics allows the observation of the angular amplitude variation associated with the operation of the injection systems and cylinder loads. Since there is no possibility of carrying out active research on this type of object, methods of diagnosis based on heat release characteristics will be written in the passive mode experiment based on measurement data provided by the crews of merchant ships.

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