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The Increase of Operational Safety of Ships by Improving Diagnostic Methods for Marine Diesel Engine

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ABSTRACT: This article shows the importance of the diagnostic improvement methods of marine engines to boost the economy and safety of operation of marine cargo ships.
The need to implement effective diagnostic methods is justified by presenting statistical data of marine diesel engines failure and the cost of their operation.
Based on the own research has been proven, for the chosen example, that indicator diagrams and analysis of indicated parameters have limited utility in the diagnosis of damages of marine engine, although this is a method commonly used in operational practice. To achieve greater diagnostic effectiveness, when, based on indicator diagrams, are calculated and then the characteristics of heat release is analyzed - net of heat release characteristics and the intensity of the heat release, it was demonstrated. This procedure is particularly effective in the diagnosis of damage of injection system components marine diesel engine.

1 INTRODUCTION

Main propulsion of ships as well as marine power station in the vast majority are the piston internal combustion diesel engine turbocharged. There is a direct relationship between reliability of engines for main propulsion and power station, and marine navigation safety and operating costs.

The operating costs of marine diesel engines are very high, primarily because of the relatively high prices of fuels and lubricating oils. Hence, the cost of exploiting them are even over 70% of the operating costs of the entire engine room and has a significant influence on the costs of operation of the vessel. The increase in these costs may affect the current technical condition of the ship's engine. The decline in its efficiency will cause an increase in fuel consumption.

Marine engines very complex technical objects, having many important functional systems, which include, inter alia, injection system, characterized by high unreliability. In this system, there may be different types of defects (damage) that affect the engine parameters, including specific fuel consumption, as well as failures endanger the safety of the ship.

From the statistical data (Piaseczny. 1992) concerning the most common damage to the ships follows that, they are related to low-speed engines - 38.0% damage, medium speed engines - 15.7% and other damage to the concern of other machinery and marine equipment. Looking specifically on their failure it has been shown that the most unreliable engine fuel system (injection system). Statistics show that is nearly 50% of all damage to marine engines are the fault of this system. In the injection system the most common damage occur in relation to the injectors - 41% and injection pumps - 38% and the fuel pipes - 12% (Fig.1.).

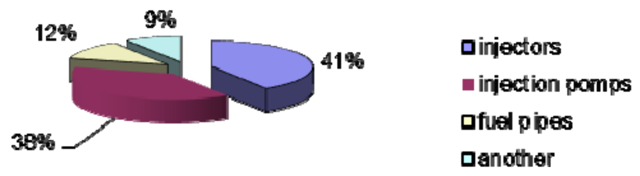

Figure 1. Statistics damage of the injection system components of marine engines

Regard to the damage caused by, the most injectors are:

1 wear cone of the needle - 73%
2 wear hole and in the loss of patency nozzle holes injector - 12%
3 loss of pressure spring stiffness(pressure drop injector opening) - 4%
4 the other causes - 11%

and damage to the injection pumps are associated most often with:

1 leak delivery valves - 42%
2 leak in pair of precise - 24%
3 blurring of piston in injection pumps - 18%
4 the other causes - 16%.

The development of diagnostic methods is the basis for the ability to detect defects at an early stage of their formation, thus improving the operational safety by preventing failures.

2 POSSIBILITIES OF DIAGNOSIS SYSTEMS INJECTION

The improvement of the methods of diagnosis of marine diesel engines is a very important task to monitor engine operation, fault detection at an early stage of combustion engines are applied in the vast majority their formation, which contributes to improve the economics and safety of the ship. Ships reciprocating internal of the main propulsion of cargo vessels (over 80%), as well as drive marine generators set. When one talks about the need to equip with modern marine power systems and diagnostic equipment, it refers primarily to the diagnosis of marine engines.

On ships with conventional equipment, ie. without specialized diagnostic equipment, the current engine condition monitoring is based on the measured values of the parameters controlled. Diagnostic evaluation mainly includes processes: injection, combustion, cooling and lubrication of the engine.

Many marine power plant are equipped with portable diagnostic test for periodic diagnostic testing of engines. The measurements of the maximum cylinder pressure, compression pressure, medium pressure and indicated power are carried out.

On some ships, with high power plants stationary monitoring and diagnostics systems are installed, operating on-line. Some stationary systems are equipped with systems to measure the pressure in the fuel injection systems.

Evaluation of technical condition and state of the motor load is thus carried out in an indirect way, based on the known relationship between the parameters of the working processes, and states of the structure and the load test piece.

The reliability of the diagnosis, its uniqueness, the ability to determine the location of faults and their causes with this study depends largely on the knowledge and experience engineer officer, and has a very subjective nature. It should be noted that the conventional set of parameters controlled ships currently available are not sufficient for making a reliable diagnosis, especially in relation to fault location.

Practical implementation of diagnostic functions for machine crew (engineer officers) is not conducive to the frequent rotation of crews between ships. The efficiency of the diagnostic process is particularly unsatisfactory on modern building ships, with a complex structure and a highly automated design, on which also applies additional principle of limiting the number of members of the crew in engine-room.

A large amount of current duties performed by the engineer officers on the one hand, and the lack of appropriate diagnostic measures, on the other, do not facilitate the implementation of diagnostic tasks. Marine engines are technical objects with a high level of complexity (several tens of thousands of elements).

Each of these elements can characterize in technical terms even several parameters of the structure. Controlling the technical condition in this situation is very difficult. As a result, the functions of the machine crew vessels are often limited to removal during the voyage of the marine failure, to maintain the energetic autonomy of the vessel. These situations are often the result of not detected in time damage. The number of failures could by significantly reduced by adequately devices and diagnostic methods.

Functional system of marine engine, which has basic influence on the quality of the work process, the economics of operation of the engine and its reliability is the injection system.

During running the marine engine, operational supervision the engine fuel supply system is reduced to operating current control operating parameters of as well as for periodic cleaning of fuel filters and centrifuges as well as tightness control the entire system. The main parameters on the basis of which engineer oversees the work of the engine fuel supply system are: pressure and temperature (viscosity) of fuel.

Regarding to the injection system condition of the injectors is checked periodically.

To evaluate the operation of the injection system are mainly used the following parameters:

1 operational (routinely measured):
   – the exhaust gas temperature, T_g,
2 read with indicator diagrams:
   – maximum combustion pressure, p_{max},
   – mean indicated pressure, p_i,
   – the angle where p_{max} occurs, referred to TDC, αp_{max}.

In the diagnosis of defects in the injection system would be useful to measure the pressure in the system. The main parameters determined on the basis of this measurement are:

– the maximum injection pressure fuel injectors, $p_{max\ inj.}$,
– injector opening pressure, $p_{open\ injr.}$,
– the angle of injection period.

The parameters read on the basis of recorded pressure in injection system are indeed important diagnostic, but their measurement is difficult due to the limited sensors installation possibilities.

Injection system, for security reasons, must be leakproof. Injection piping commonly placed in special cases ("buffer zones"), which in the case of damage to the fuel pipe do not allow uncontrolled effluent of fuel to the engine room.

Therefore, it is advisable to search for such an effective method of diagnosing damages of the injection system, which does not require interference in the injection system. This is a condition correspond to methods based on the analysis of the information contained in the indicator diagrams. This will be the indirect method to evaluation of the technical condition of injection equipment, which will cancel costly and unreliable measuring systems the pressure in the injection systems.

In order to obtain an effective method for the identification of major damages components in the injection system in-depth analysis of indicator diagrams is needed. This refers to the designation on the basis of the indicator diagram heat release characteristics, obtained based on the measurement of cylinder pressure the electronic indicator. Cylinder pressure transducers are mounted on the indicator valves.

3 THE FUEL SUPPLY SYSTEMS MODERN MARINE ENGINES

Modern marine propulsion engines and generator sets are supplied mainly with heavy fuels (Heavy Fuel Oil, Residual Fuels), and the viscosity can be at a temperature of 100 ° C 1,4÷14 cSt for Marine Light Fuel Oil and 10÷55 cSt for Marine Fuel Oil. Lower viscosity fuels are used to for supplying the four-stroke medium speed engines, while the higher viscosity fuel - for supplying the low speed two-stroke engines.

Heavy fuel oil are contaminated with, inter alia, sulfur, water, compounds contained in seawater, bituminous materials (resins, hard asphalt) and solids. Such fuels require specific preparatory activities prior to injection into the engine.

The problems with using heavy residual fuels can be categorized as: storage and handling, combustion quality, contaminants - resulting in corrosion and damage to engine components. Fuel supply to the combustion chamber of a piston engine performs injection system, which feeds the fuel at a certain time, properly atomized, in an amount corresponding to the instantaneous power requirement.

In contemporary marine engines still dominated by traditional injection systems, are constructed with the following elements:
– injection pump driven by the camshaft,
– high pressure fuel pipes,
– fuel injectors.

Injection pumps are displacement pumps, piston type, and typically each cylinder has a separate injection pump or a separate operating unit consisting of a cylinder, piston, non-return valve and drive mechanism piston. Variable maximum pressure in injection pipes can obtain a value from 40 to 100 MPa.

Energetic and economic indicators (parameters) of the engine, and the reliability of its operation largely depends on the operation of the injection system. On the one side an important factor will be constructional, technological and manufacture perfection of system components, especially the injection pumps and injectors, on the other hand, the proper conduct static regulation and proper exploitation.

It is believed that the most important quality parameters of the regulation of the conventional injection system are the beginning, end, and duration of fuel delivery by the pump and the injector expressed in degrees of crankshaft rotation. From these parameters, under the constant engine load, combustion process depends on. To combustion process evaluate it uses dynamic parameters and economic indicators cycle.

In practice, sought the optimal injection advance angle, to achieve high diesel engine efficiency, for a given load.

On ships during sea voyages it takes place attempts to diagnose damage to the injection system by analyzing the changes in marine engine operating parameters, including, in particular indicated parameters. There are analyzed, among others, changes of the maximum cylinder pressure.

The significant impact on the value of the maximal cylinder pressure is the beginning of the injection, and more precisely - associated with injection, ignite the fuel-air mixture. Too the early injection (ignition) causes an increase in the maximum pressure, while the too late - maximum pressure drop. In most large marine engines change injection timing fuel of 1° changes maximal pressure from 0.1 to 0.4 MPa.

The maximum pressure (p_{max}) is a parameter, on which all components of the working process have an influence on , and in particular:
– injection timing and the fuel self-ignition (injection timing and fuel ignition angle expressed relative to the upper dead center of the piston in the cylinder - TDC),
– the size of the injected fuel delivery,
– fuel quality and the quality of the resultant fuel-air mixture,
– pressure and temperature charge air.
– the pressure and temperature at the end of the compression stroke.

This indicates that the analysis of the value of this parameter does not always lead to the detection of faults in the injection system. In many ships engine room, where it is possible to indicate individual engine cylinders, attempts are made to diagnose fuel injection systems by directly comparing the indicator diagrams. Proper diagnostic inference on the basis of the above procedure is difficult and uncertain. This is confirmed by the test results.

Figure 2 shows graphs indicator measured on a nine-cylinder marine engine SULZER 9RTA90 used to drive the main cargo ship. Although you can see the difference in the course of expansion pressure in the cylinder 2, but it is very difficult to say what is the cause. That is why nowadays should be used a deepened analysis of the indicator diagrams, which related to calculation on the basis of the graphs of heat release characteristics. This requires the development of an appropriate model for calculation and software used electronic indicators, but it can bring tangible benefits.

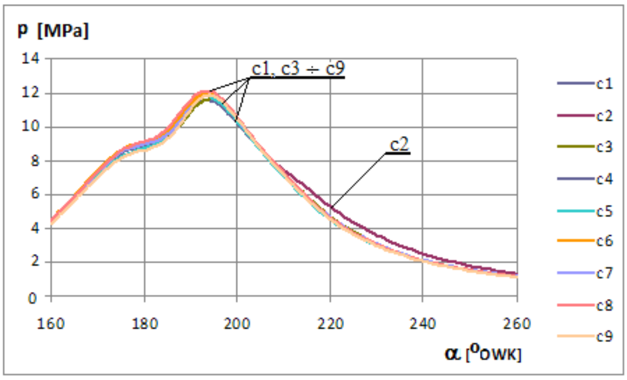

Figure 2. Indicator diagram engine SULZER 9RTA90: c1 ÷c9 - individual cylinder pressure (source: own research)

4 HEAT RELEASE MODEL FOR THE ENGINE WITH DIRECT INJECTION

Development of modeling heat release piston engines occurred at the end of the sixties and the seventies of the last century, which was largely associated with the development of computer capabilities calculations and simulation research and the emergence of diesel engine new research opportunities.

In the diagnosis of piston engines are of particular interest in single-zone models based on indicator diagrams as a source of information (Heywood.1988, Kriger et al. 1966, Schweitzer 1926, Wajand. 1966). Indicator diagrams are commonly used in research and diagnostics combustion piston engines conducted both in the laboratory and supplies. This also applies to tests carried out in the country (Ambrozik et al. 1983, Ambrozik et al. 2005, Lyn. 1960, Michalecki. 1973, Polanowski. 2007, Polanowski et al. 2011, Wajand. 1966).

Krieger and Borman model (Kriger et al. 1966) is commonly used for diesel engines with direct injection.

The starting point for each model of heat release is the principle of conservation of energy in the form of the first law of thermodynamics, which is for an open system can be written as follows:

$$\text{đ}Q_{sp} = dU + \text{đ}W + \text{đ}Q_{ch} + \sum \text{đ}m_i h_i \qquad (1)$$

or in the form of heat release dynamics equations in the time domain:

$$\frac{\text{đ}Q_{sp}}{d\tau} = \frac{dU}{d\tau} + \frac{\text{đ}W}{d\tau} + \frac{\text{đ}Q_{ch}}{d\tau} + \frac{d}{d\tau}\sum dm_i h_i \qquad (2)$$

were $\text{đ}Q_{sp}$ = the heat transported (by combustion of fuel),dU = change in internal energy of the mass in the system, đW = the work produced by the system, $\text{đ}Q_{ch}$ = the cooling heat loss, $\text{đ}m_i$ = flows in and out of crevice regions; piston ring blow-by and direct injection of fuel into the cylinder, h_i = the enthalpy flux across the system boundary and τ = time.

Due to difficulties in calculating the cooling heat and charge loss as a result of gas blow-by, for diagnostic purposes it is appropriate to use the net heat release characteristics, which is an sum of the internal energy and the work.

It is assumed that the cooling heat loss, will be the same for each cylinder, and will has little effect on the character of the course of heat release characteristics.

The formula for Q_n net heat evolution is obtained by transformation of equation (1) to the form:

$$\text{đ}Q_n = \text{đ}Q_{sp} - \text{đ}Q_{ch} - \sum \text{đ}m_i h_i = dU + \text{đ}W \qquad (3)$$

Assuming that the gas is ideal and neglecting the exhaust and crevice loss, equation (1) takes the form (Rychter et al. 1990):

$$\text{đ}Q = \frac{\kappa}{\kappa - 1} pdV + \frac{1}{\kappa - 1} Vdp \qquad (4)$$

were κ = const – isentropic exponent, V = volume of the cylinder, p = pressure of the cylinder.

The instantaneous volume V of gas in the cylinder can be expressed as the sum:

$$V = V_s - V_{sx} + V_c + V_z + V_{px} \qquad (5)$$

were V_s = displacement volume cylinder, V_{sx}= cylinder volume corresponding to the distance traveled by the piston from a BDC, V_c = clearance volume, V_z = change the volume of the cylinder due to wear and impact assembly, V_{px} = the apparent change in the volume of the cylinder due to gas blow-by (function road of the piston).

If it were accepted V_z = 0 and V_{px} = 0, the current volume of gas in the cylinder is given by:

$$V = V_s - V_{sx} + V_c \qquad (6)$$

After dividing the equation (6) by the stroke volume V_s we get volume in dimensionless form:

$$v = 1 - v_{sx} + v_c \qquad (7)$$

Dividing equation (4) by the displacement volume cylinder the intensity of the heat release q, written in the form:

$$q = \frac{\text{đ}Q_n}{V_s d\alpha} = (\kappa - 1)^{-1}\left[v\frac{dp}{d\alpha} + \kappa p\left(\frac{dv}{d\alpha}\right)\right] \qquad (8)$$

5 AN EXAMPLE OF PRACTICAL USE OF THE HEAT RELEASE CHARACTERISTICS IN THE DIAGNOSIS

On the basis of preliminary verification indicator diagrams shown in Figure 2, it may by noticed that further analysis is necessary, first of all, the graph obtained for the cylinder 2.

In deepened analysis of the characteristics of the designated heat release - net of heat release characteristics Q and the intensity of the heat release q. These characteristics are shown in Figure 3 and 4.Their waveforms indicate a faulty operation of the injection system the second cylinder. Especially a characteristic is the change q - instantaneous clear increase in the angle of about 210 degrees rotation of the crankshaft and a significant increase in the maximum value of Q for the cylinder on the angle of about 210 degrees rotation of the crankshaft, what probable cause is post-injection of fuel caused by faulty regulation of the overflow valve on the discharge side of the injection pump.

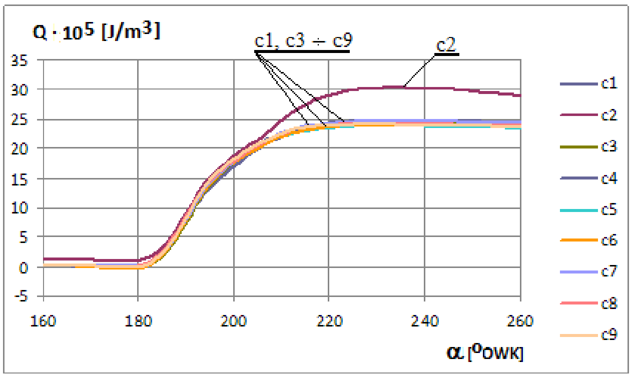

Figure 3. Characteristics of heat release Q determined on the basis of indicator diagrams shown in Figure 2: c1 ÷c9 - Q for each cylinder (Source: own research)

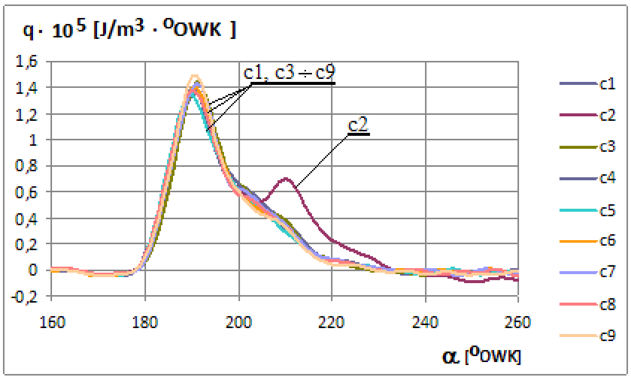

Figure 4. The characteristics of intensity of the heat release q determined on the basis of the indicator diagrams shown in Figure 2: c1 ÷c9 - q for each cylinder (Source: own research)

6 CONCLUSIONS

Operating experience shows that the interpretation of diagnostic indicator diagrams in the diagnosis of damage to the elements of injection system is often insufficient.

The research results confirm that, with heat release characteristics calculated on the basis of the indicator diagrams, can be more easily and with greater certainty to recognize the damage occurring in the injection systems of marine engines.

The characteristics of heat release net can be used in the diagnosis of injection systems of marine engines to detect such damages as loss of tightness precision pairs, the loss of patency nozzle holes injector, pressure drop injector opening and many others.

The improvement of diagnostic methods of injection systems can contribute to improving the reliability growth of marine engines, maintenance of their economic exploitation, and also has an impact on the safe operation of ships.

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