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THE POSSIBILITY OF FUEL INJECTION PUMP DIAGNOSIS ON THE BASIS OF INDICATOR DIAGRAM

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Abstract

The paper presents the results research related to the possibility of fuel injection pump diagnosis on the basis of indicator diagram. The study was conducted on a laboratory four-stroke marine engine, type Sulzer 3Al 25/30, with nominal power N_{en} = 408 kW at nominal rotational speed n = 750 rpm. The study was carried out according to active experiment plan, during which the engine failure of the injection system was simulated. Simulation of fuel pump leakage was completed by the opening of the adjusting screw on the pump discharge. Measurements were made at a constant engine speed of 750 rev/min for five loads: 50, 100, 150, 200, 250 kW. Measurements of pressure of combustion were performed by means of tensometric sensors of Spice Company. Based on measured pressure curves heat release characteristics were determined. The algorithm allows the determination of net heat release rate q and the net generated heat Q characteristics. Based on the obtained results it can be concluded that significant improvement in the diagnostic use of indicator diagrams can be obtained by using heat release characteristics. These characteristics are correlated with the process of fuel injection and the injection pump operation. As demonstrated in the work of analyzing the heat release rate q, it is possible to infer diagnosis on the technical condition of the fuel injection system.

Keywords: *indicator diagram, heat release characteristics, marine diesel engine diagnosis, fuel pump leakage*

1. Introduction

The increase of the environment protection requirements will force continuous optimization of the combustion process and the monitoring of marine piston engines. The quality of the combustion process is determined primarily by technical condition of injection equipment. Technical condition of injection system determines not only the performance and engine parameters such as torque and specific fuel consumption but also significantly affects vibration and noise. Impact of regulation of injection (injection timing) and its technical condition significantly affect the emission of toxic components of the exhaust [8, 9].

Very high accuracy of shape fuel pumps and injectors of up to several micrometres, the increasing use of residual fuels with a high amount of pollution and hard working conditions (pressure and temperature) are the cause of faults in the fuel injection system. The most unreliable elements in those system are injection pumps and injectors [10]. The reason of fuel pumps and injector wear are most often contaminants in the fuel [11, 10].

High faults susceptibility of the fuel injection system has led to the development of diagnostic methods of injection pumps and injection system. In the literature, the problem is often talk in general about the methods of evaluation of the technical condition of injection equipment, which methods include assessment of both pumping pumps sections and injectors.

In the case of fuel injection pump the most important invasive (requiring disassembly of the pump) are methods based on measurements of crowding geometrical elements and a method based on measurement of the pressure drop in the pumping section of the pump, treated as an indicator of the tightness of the system [11].

An important group of methods of diagnosis of the injection system are methods based on the analysis of the course of pressure in the high pressure pipe [10]. The major limitation of the practical applicability of this method is the need for intervention in the high-pressure part of the system. To this day, the problem of sealing the sensor in an effective way has not been solved. Such solutions are particularly difficult to implement in the case of marine engines for which have very stringent requirements relating to safety of injection equipment.

Recently, intensive research associated with the use of acoustic emission methods for injection equipment diagnose are conducted. There are attempts to use dedicated acoustic emission sensors as well classical acoustic microphones [12, 13]. The acoustic emission based methods are very promising primarily due to the minimally invasive nature and the potentially large amount of information contained in the signal broadcast. In addition, the possibility of very precise location of the signal source (injection pump, injector) is emphasized, and less prone to interference compared to traditional methods of vibration. The use of acoustic emission, however, requires the application of advanced signal processing methods, both in the preparation of the measured data (preprocessing) as well as to the selection of diagnostic symptoms. A significant disadvantage of the method is also impact of disturbances in the form of high-energy events related to the course of combustion and piston work on low-energy events relevant to the operation of injection equipment (opening and closing of the injector or valve operation) [13].

The presented methods of evaluation of the technical condition of injection were found very limited marine application. On the one hand, they require a significant interference with the structure of the high-pressure part of the fuel system, which is extremely difficult due to the security requirements, on the other hand (acoustic emission, vibration measurements) require the use of specialized measuring equipment and complex processing of the data.

Looks to have there is potential for greater use indicator diagrams for injection systems diagnosis. Due to the significant, in recent times, the fall in prices of electronic indicators, they are increasingly become a standard measuring equipment of marine engines. Despite the availability of, and significant progress in the field of equipment and measurement techniques of indicated pressure, there is no significant progress in the field of analysis and diagnostic use of the obtained pressure curves. Obtaining reliable diagnostic information based on the indicator diagram is an important research challenge [2, 3].

It seems that the significant improvement in the diagnostic use of the indicator diagram can be obtained by designating the heat release characteristics. The purpose of the article was to evaluate the potential for the use of heat release characteristics to evaluate the technical condition of the fuel pumps of marine diesel engines [4, 5].

2. Preparation and conduct simulation research

The tests were conducted on a four-stroke laboratory marine diesel engine, type Sulzer 3Al 25/30, with nominal power N_{en} = 408 kW at nominal speed n = 750 rpm.

Simulation of fuel injection pump leakage failure was carried out by an artificial fuel venting of high-pressure chamber of the pump. The consequence of the simulation was to reduce the amount of fuel supplied to the cylinder. It is believed that due to the increase of leakage the start of fuel injection is delayed and the average pressure in the fuel line is decreased.

A series of measurements for the nominal state (reference) and the state of the damage was done. Measurements were made at a constant engine speed of 750 rev/min for five loads: 50, 100, 150, 200, 250 kW.

The curves of indicator diagrams have been recorded with an electronic indicator Unitest 205 with angular resolution of 0.5^{o}CA. Tensometric pressure sensors from Spice Company were used for pressure measurement. The curves of pressure were averaged for 16 work cycles.

The article presents the measured values and curves only for two loads, due to the limited perception of a large number of curves on one figure.

3. Infuence of fuel pump leakage on the indicator diagram parameters

A visible symptom of the simulated injection pump leakage is the decline in mean indicated pressure and the accompanying decline in the value of the maximum combustion pressure (Fig. 1).

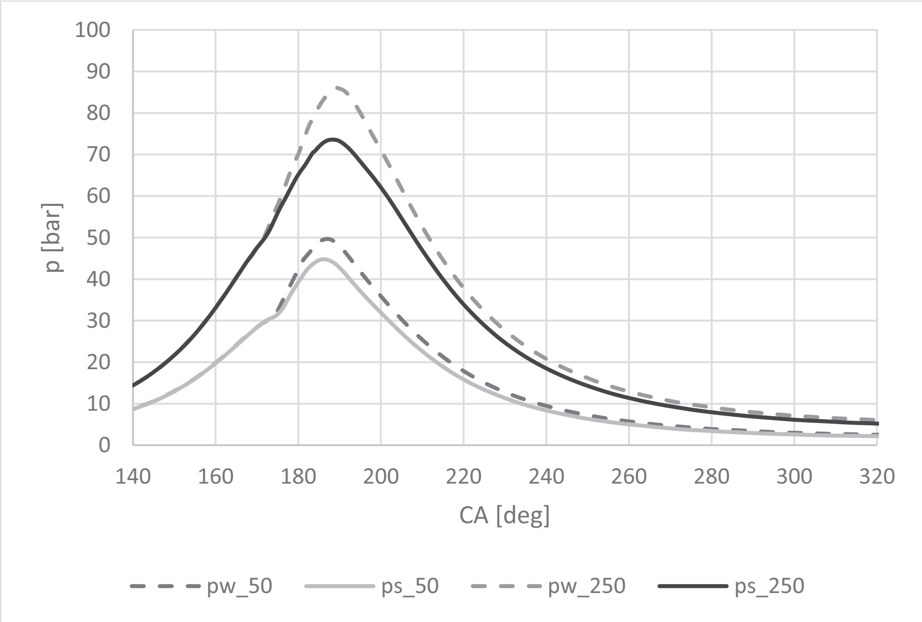

Fig. 1. Comparison of the indicator diagram for the reference state (pw50; pw250) and the simulation of fuel pump leakage (ps50; ps250) for engine power 50 kW and 250 kW

Table 1 compares the percentage maximum combustion pressure drop and mean indicated pressure caused by fuel pump leakage for different loads. The deviations were determined from the following formulas:

$$\delta p_{\max} = \frac{p_{\max w} - p_{\max s}}{p_{\max w}} \cdot 100[\%]; \delta p_i = \frac{p_{iw} - p_{is}}{p_{iw}} \cdot 100[\%], \tag{1}$$

where:
w – the index of the nominal state,
s – the index of simulation of fuel pump leakage.

Tab. 1. Declines of mean indicated pressure δpi and the maximum combustion pressure δp_{max} due to simulated fuel pump leakage, related to the nominal (reference) values

Ne [kW]	50	100	150	200	250
δpi [%]	22.9	18	19.8	21.2	19.6
δp_{max} [%]	9.9	10.9	12.7	14.3	14.5

If, however, considered the maximum pressure drop as a function of mean indicated pressure (Fig. 2), the result are closely to cylinder load drops, which should be associated with a reduction in the amount of fuel.

In this case direct reference of the mean indicated pressure and the maximum combustion pressure to the nominal state provides more reliable diagnostics inference.

4. Analysis of the impact of fuel pump leakage on the net heat release characteristics

Determination of the heat release dynamics is a complex mathematical and measuring problem [5, 1]. Assuming isentropic transformation the net heat release rated q can be stated in the form [5]:

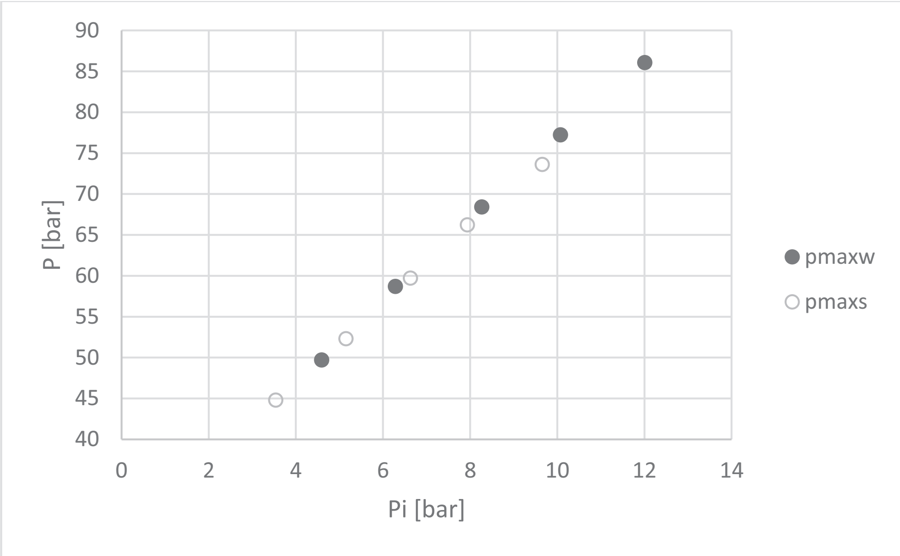

Fig. 2. Comparison of the maximum pressure in the cylinder as a function of mean indicated pressure pi: p_{maxs} – simulation, p_{maxw} – reference state

$$q = \frac{\kappa}{\kappa - 1} pdV + \frac{1}{\kappa - 1} Vdp; \tag{2}$$

where:
κ = cont – isentropic exponent,
p – pressure,
V – cylinder volume.

Net generated heat for a given angle α position of the shaft from the BDC is calculated by the formula:

$$Q = \int_0^\alpha q_n d\alpha. \tag{3}$$

Simulation of clogged injector nozzles resulted in decrease of the total amount of net generated heat, uniformly in the angular range above 170°CA (Fig. 3).

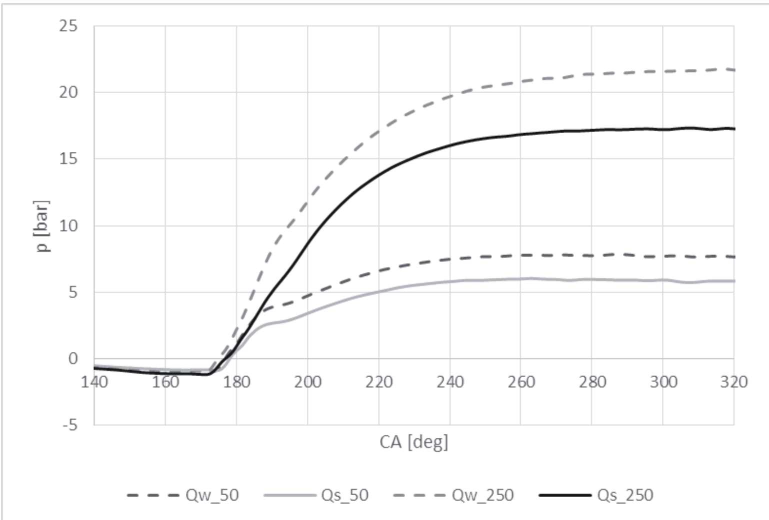

Fig. 3. Comparison of the net generated heat Q for the nominal state (Qw50; Qw250) and the state of fuel pump leakage (Qs50; Qs250) for specific loads 50 and 250 kW

The above Q decreases, however, are the result of a fuel dosage reduction, which discloses a comparison of the values of Q as a function of mean indicated pressure pi (Fig. 7).

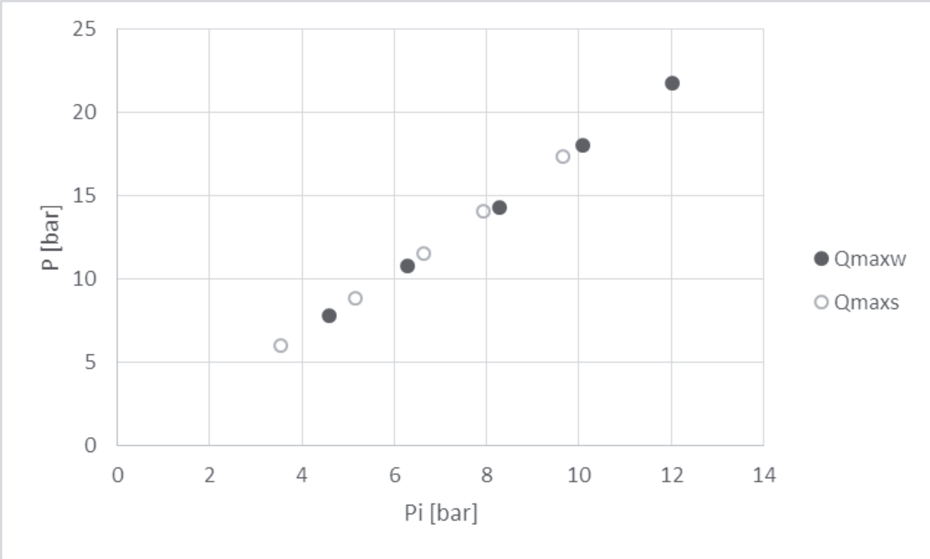

Fig. 3a. Comparison of the net generated heat Q as a function of mean indicated pressure pi: Q_{maxs} – simulation, Q_{maxw} – reference state

The same curves and differences were obtained for the other loads. The observed differences cannot be therefore the basis for reasoning about their reasons.

Better results are obtained by analysis of net heat release rate, which is observed (Fig. 5) a significant reduction in the amplitude of the net heat release rate q for the load of 250 kW.

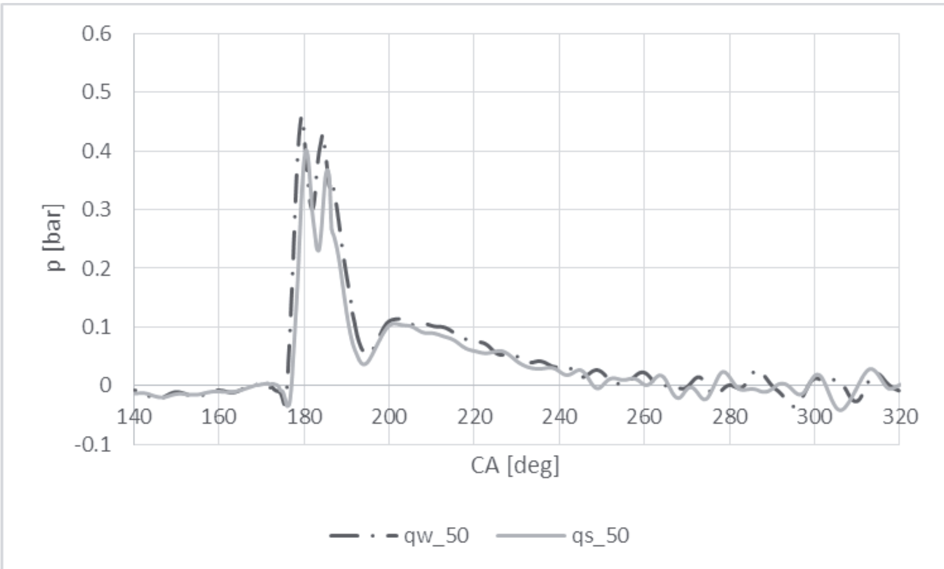

Fig. 4. Comparison of the net heat release rate q for the nominal state (qw50) and the state of clogged injector nozzles (qs50) for specific loads 50 kW

Percent differences of δq_{max} value decreases with decreasing load (Tab. 2).

Tab. 2. The percentage decrease of the maximum net heat release rate δq_{max} caused by fuel pump leakage

Ne [kW]	50	100	150	200	250
δq_{max} [%]	12.5	14.6	22.4	31.8	32.3

Comparison of maximum net heat release rate q in mean indicated pressure domain pi (Fig. 6) indicates a decreases of q_{max} for pi> 5 bar (Fig. 6).

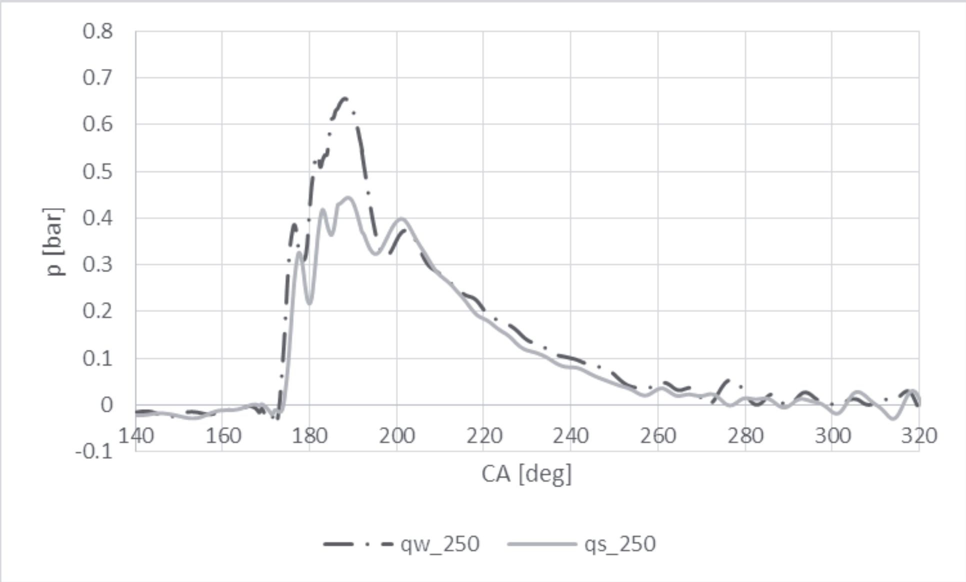

Fig. 5. Comparison of the net heat release rate q for the nominal state (qw250) and the state of clogged injector nozzles (qs250) for specific loads 250 kW

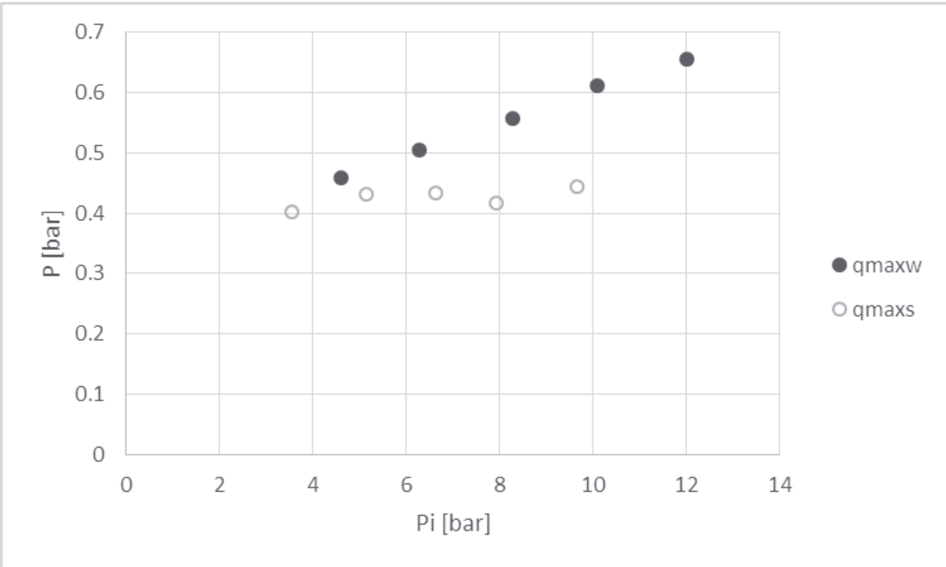

Fig. 6. Comparison of the max of net heat release rate q as a function of mean indicated pressure pi: q_{maxs} – simulation, q_{maxw} – reference state

5. Conclusions

The parameters that can be used in the diagnosis of fuel pump leakage are: maximum combustion pressure p_{max}, mean indicated pressure pi, the maximum net heat released q_{max}.

As a result of fuel pump leakage showed a decrease in fuel delivery per cycle and reduce the mean indicated pressure and maximum combustion pressure.

Significant symptoms of o fuel pump leakage are also decrease of the maximum net heat release rate.

Comparative symptoms analyses of different faults of the fuel injection system are needed for identifying symptomatic method to distinguish these failures.

It is desirable to also record the temperature and composition of exhaust gases to explain the extent to which disability affects the combustion process. It is planned to measure and record these values in subsequent studies, as well as supporting the use of vibration of the fuel injectors.

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