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THE ISSUE OF THE INDICATOR DIAGRAM ANALYSIS FOR THE PURPOSE OF DIAGNOSIS OF MARINE DIESEL ENGINES

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Abstract

The article analyses the possibility of using the electronic type indicators, in the diagnosis of marine engines. The analysis of indicated parameters read from the indicator diagram is now widely use on ships in the diagnosis of marine engines.

To make this possible, measuring indicated systems should meet a number of important requirements to be met to ensure the possibility of their diagnostic use. These include reliable determination of the top dead centre piston (TDC). The above is particularly important in in-depth analysis of indicator diagrams − calculating the heat release characteristics.

The paper presents results of research on the effect of the error on the accuracy of the location of TDC (GMP) on calculated heat release characteristics. In order to demonstrate the impact positional error TDC, simulation study was conducted in which indicated diagrams was used, obtained on a medium-speed four-stroke marine engine type A25/30 and the low-speed two-stroke engine type RTA76, Sulzer Company.

Keywords: *marine diesel engine, indicated parameters, indicator diagram, error TDC, heat release characteristics*

1. Introduction

At older design sea cargo ships, with conventional equipment, marine engines diagnostics are still made on the basis of an analysis of changes in the value of the measured parameters of the engine. Diagnostician is the ship's mechanic, who by analysing changes in the measured parameters relative to their reference values, tries to determine the type of damage. Such action is subjective and usually inefficient, depending on the knowledge and experience of the marine engineer.

Now, many marine engine-rooms are additionally equipped with portable or stationary electronic indicators. Analysed are mainly open (expanded) indicator diagrams – diagrams in a coordinate system $p = f(\alpha)$ (cylinder pressure p variation as a function of crank angle α). Indicated parameters are the essential complement to the standard measurement parameters and diagnostic inference can be more reliable.

Measuring systems destined for indicated should meet a number of important requirements to be met to ensure the possibility of their diagnostic use. These include high precision sensors for the measurement of cylinder pressure, high speed and accuracy of measuring and recording of measured values, a reliable determination of the top dead centre piston (TDC). These and other important issues cylinder pressure measurement highlighted in many publications [1, 2, 4-8]. Compliance with these requirements is of particular importance when for diagnostic purposes will be determined based on the indicator diagram of heat release characteristics.

2. Analysis of the influence of selected factors on the accuracy of the indicator diagram

In many cylinder pressure measurement systems, errors occur, which are related to the "flow" of the reference line (ambient pressure or supercharging pressure). This is related primarily to the construction of sensors. It is observed in electronical indicators in which recourse piezo-quartz sensors and strain gauge type sensors. In order to minimize this error is constructed signal amplifiers, using a high impedance input. "Flow" line reference pressure has an impact primarily on heat release rate calculated [1].

For most of marine engine, cylinder pressure sensor is mounted on the indicator cock (Fig. 1a). Engine combustion chamber with an indicator cock was combined gas channel, the length of which depends on the design of the cylinder head and can be up to several tens of centimetres. The gas channel and indicator cock are cause of the measured signal distortions and their delay. In research of four-stroke, medium-speed, marine diesel engines [4], has been shown that delays may be several degrees of crankshaft rotation. Signal distortion characteristic of medium-speed engines, are negligible small in two-stroke slow-speed marine engines. If the sensor is mounted in special channels of the cylinder head, these types of measurement problems do not occur (Fig. 1b). Then however, it can occur the phenomenon of thermal shock sensor, formed by the action of the flame on the front face of the sensor. It leads to a distortion, inter alia, of measured changes of pressure. In study [1] this is shown, that small increase of temperature in piezo-quartz sensors for only about 100 K causes a decrease in the sensitivity of about 3%. Also decreases the resistance self, for about 10%. In marine diesel engine heavy fuel oil, feeding, additional distortions in measurement circuit may arise as a result of fouling carbon deposit sensor.

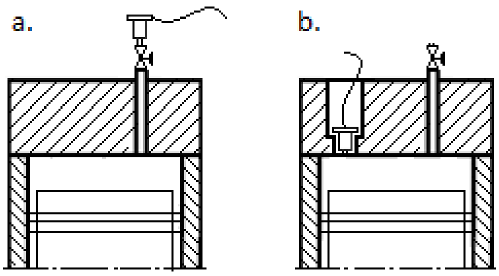

Fig. 1. The sensors for measuring the pressure of the cylinder: a) on the indicator cock, b) in a special channel cylinder head

The important thing for the quality of the indicator diagram is averaging the received multiple charts and their smoothing. In electronic indicators used in operational practice (in ship engine room) is averaged at least 16 charts. In the case of piston, engines used in land transport said about the use of an average of over 30 implementation [1]. By averaging, the appropriate number of execution indicated is possible to eliminate inter alia, random vibration of high frequency electrical noise. After averaging chart should be further smoothing, to eliminate distortion – get smooth and continual graphs [1, 3].

Electronic indicator registers the cylinder pressure variation from the relatively low (the beginning of the compression, the beginning of exhalation) less than 1 MPa, up to the maximum even about 20 MPa. The accuracy of measurement of the pressure instantaneous value affects resolution analogue-to-digital converters and their accuracy. Error of quantification particularly affects the measurement of low pressures.

A very significant impact on the accuracy of the determination of the characteristics of heat release is the correct term for the indicator diagram obtained during the test engine, piston position in the top dead centre (TDC). The main reasons of difficulty with accurately determine TDC are delays caused by crankshaft torsional vibrations, caused by through the channels indicated and cocks indicated, as well as due to non-uniformity of the crankshaft rotational speed [1, 3, 4]. It must be noted that between the kinematic angular position TDC piston and the TDC position shown on the indicator diagram, there is an error that will cause errors calculated heat release characteristics. In [1, 3] stated that the error of determining TDC the amounting to ±2%, will cause distorsion chart calculated heat release rate to about ±12%.

3. Direct and in-depth analysis of indicator diagrams in diagnostics

Increasingly, it is being used for indicated marine engines electronic type indicator, which includes: the combustion pressure sensors in each cylinder, the angular position sensor crankshaft and microprocessors system used for processing and visualization of the results of the measurements. This indicator is easy to use, characterized by high accuracy and fast developing results. This device gives results indicated as the average of dozen or so cycles. All essential values are displayed on the screen, and in addition, an open indicator diagram is presented. Mean indicated pressure is automatically served beside other parameters, based on our numerical integration.

Figure 2 shows an example of an indicator diagram, obtained using the electronic indicator. Marked is on the all-important characteristic values. In addition to those indicated in the figure administered to be the value of the mean indicated pressure and indicated power.

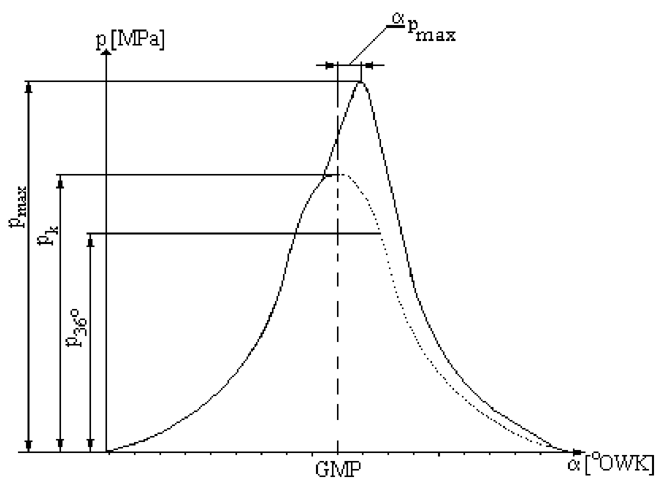

Fig. 2. Indicator diagram obtained from the electronic indicator and its characteristic values: p_{max} – the maximum combustion pressure, p_k – compression pressure, $p_{36°}$ (or p_{exp}) – expansion pressure read 36 degrees of crankshaft rotation after TDC, α_{pmax} – angle after TDC obtain maximum pressure in the cylinder

An important feature of electronic indicators is the ability to save the results in memory and play them after some time. In this way, you can easily compare the graphs indicated performed at different times, which gives a fuller analysis capabilities. This is particularly important when comparing the reference indicator diagram drawn in good technical condition of the engine, with a graph removed after a longer period of operation; then are visible all deviations from the norm.

Figure 3 shows an example of one coordinate system $p = f(\alpha)$ two graphs – curve 1 and curve 2. The pressure value on the expansion curve ($p_{36°}$) graph of measured current (curve 2) is higher than the corresponding value for the standard graph (curve 1). This may prove of chronic working process, after-burning of the fuel during the expansion, e.g. due to incorrect fuel atomization. This state can also affect non-leak fuel injector nozzle or very poor fuel quality.

The graph in Fig. 4 shows is too dynamic gain in pressure. Data from the graph allow calculating the value of $\Delta p_2/\Delta\alpha_2$. Based on a comparison of the measured $\Delta p_2/\Delta\alpha_2$ with exemplary $\Delta p_1/\Delta\alpha_1$; you can quantify the degree of damage. The cause of excessive dynamic rise pressure – $(\Delta p_2/\Delta\alpha_2) >> (\Delta p_1/\Delta\alpha_1)$ – may be premature fuel injection or ignition delay reduction: $\alpha_{zz2} < \alpha_{zz1}$, due to significant thermal overload the elements of the combustion chamber of the engine. A large value of $\Delta p/\Delta\alpha$ causes mechanical engine overload, especially bearings piston-connecting-rod system.

Ongoing monitoring and control of the mean indicated pressure p_i provides a very accurate load current of each cylinder, and also the whole engine, and on this basis to determine whether the load status of each cylinder is the same, if there is too much spread of power between the cylinders. In relation to the average of the instantaneous power of the cylinder, these differences

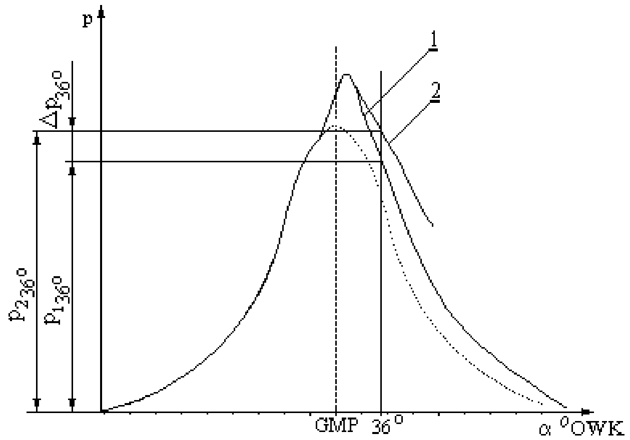

Fig. 3. Exemplary indicator diagram (1) and too high expansion pressure on the diagram (2)

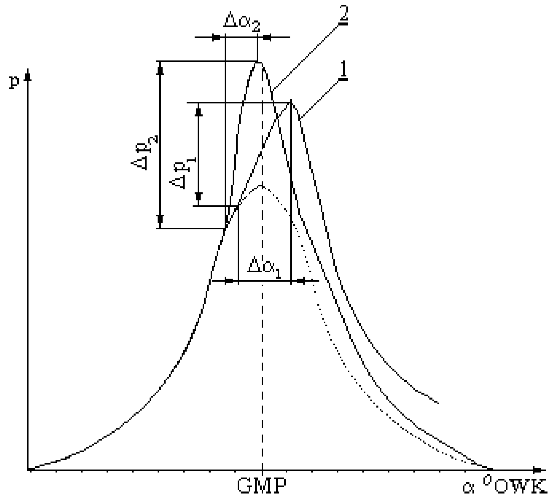

Fig. 4. Exemplary indicator diagram (1) and diagram with high value of $\Delta p/\Delta\alpha$ (2)

should not exceed ± 2.5 %. With irregular engine regulation, mean indicated pressure pi in one or more cylinders will generally be lower than the average value. There are at least several potential reasons for this: may be due to defective regulation of the injection pump – too small dose of fuel on account of the piston-cylinder assembly leakage, as well as because of the poor technical condition of injection equipment and air system supercharger.

The direct analysis of the characteristics feature indicator diagram and changes of indicated parameter values does not always allow on the formulation diagnostic correct conclusions. Even a few different defects can cause similar changes in the values of indicated parameters and shape indicator diagrams. Therefore, this is by recommended in-depth analysis of these graphs based on calculated heat release characteristics. Among other things, this is important in the diagnosis of damage of injection system elements − injection pumps and injectors. Then, however, it is essential to cylinder pressure measurement accuracy – the accuracy of the indicator diagram, which were analysed in Chapter 2. The analysis shows, that on the accuracy of the calculated heat release characteristics has a bug piston TDC location on the indicator diagram.

4. Study the impact of the error of the location of TDC (GMP), on the accuracy calculated heat release characteristics

TDC position errors are a major source errors of determining the mean indicated pressure and thereby greatly influenced by on value of error the maximum value of the net heat release (Q_{max}) and the maximum value heat release rate (q_{max}).

In order to demonstrate the error of the impact positional TDC, simulation study was conducted in which was used indicated diagrams obtained on a medium-speed four-stroke marine engine type A25/30 and the low-speed two-stroke engine type RTA76, Sulzer Company. For the Engine A25/30 it has been adopted TDC location error amounting to ±1° rotation of the crankshaft and the low-speed engine RTA76 ±0.5° rotation of the crankshaft.

In Fig. 5 and 6, it has been shown the effect of errors in the TDC location of the indicator diagram on the characteristics of q and Q for medium-speed diesel engine (Fig. 5) and low-speed diesel engine (Fig. 6).

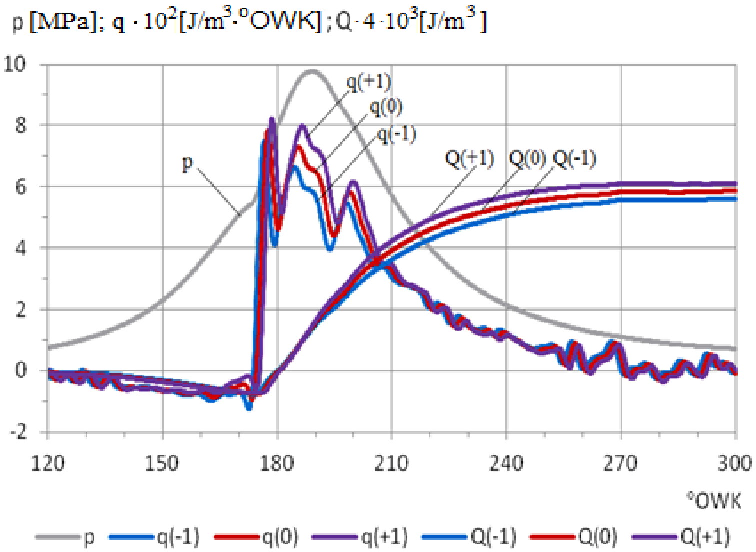

Fig. 5. Effect of TDC position errors on waveforms heat release characteristics q i Q medium-speed marine diesel engine A25/30. The error value TDC (GMP in degrees rotation of the crankshaft) given in brackets

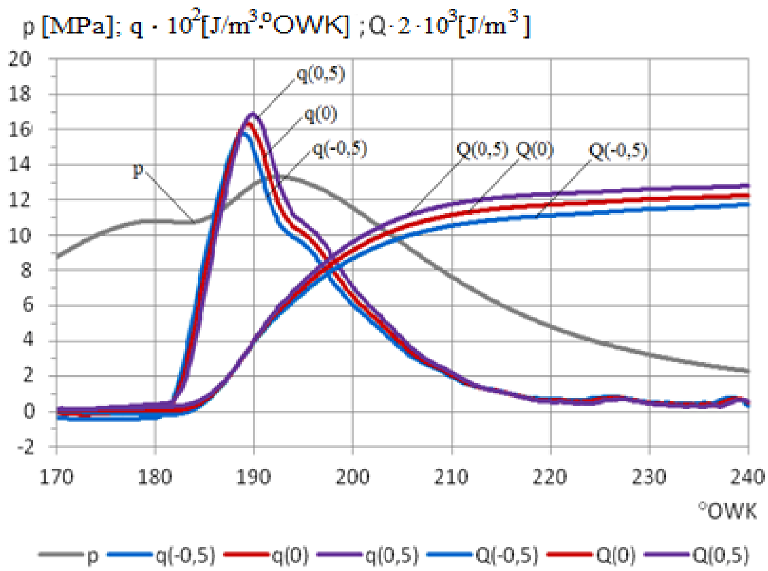

Fig. 6. Effect of TDC position errors on waveforms heat release characteristics q i Q low-speed marine diesel engine RTA76. The error value TDC (GMP) in degrees rotation of the crankshaft) given in brackets

Deviations q_{max} are approximately ±5 % for engine A25 with TDC errors on value ±1° rotation of the crankshaft and ±3.5 % for the engine RTA76 the TDC with errors ranging ±0.5° rotation of the crankshaft. Q_{max} deviations are approximately ±8 % for the A25 engine with TDC errors amounting to ±1° rotation of the crankshaft and ±4.5 % for the engine RTA76 with TDC errors amounting to ±0.5° rotation of the crankshaft.

The values of TDC positional errors are intentionally significant. In practice, using the method of determining the TDC based on thermodynamic models, the error should not exceed ±0.3° rotation of the crankshaft in the case of medium-speed engines and ±0.1° rotation of the crankshaft in the case of low-speed engines.

It should be noted the almost negligible influences of error TDC on the first phase (the growth steeply runs) q (Fig. 5 and 6). This is an important observation in the context of the possibility of using of the symptom for diagnostic purposes.

5. Summary

In the operating conditions for the diagnosis of damage to marine engines are increasingly used indicated diagrams obtained in electronic indicated.

Measuring systems for electronic indication should meet a number of important requirements to guarantee the possibility of their diagnostic use. These include high precision sensors for the measurement of cylinder pressure, high speed and accuracy of measuring and recording of measured values, a reliable determination of the top dead centre piston (TDC).

In many cases, in order to obtain a reliable diagnosis is indicated in-depth analysis of these graphs based on calculated heat release characteristics. Then, however, it is essential to cylinder pressure measurement accuracy – the accuracy of the indicator diagram, including the exact location of TDC in the diagram.

The analysis of the results indicates that the error location TDC to 1% results in a significant deviation of the net heat release maximum value and heat release rate, to a few percent (from 3.5% to 8%).

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